Current Trends in Quality Science

Innovative and sustainable products, materials, and technologies

EDITORS

Katarzyna Michocka

Mariusz Tichoniuk

POZNAŃ 2023

THE POZNAŃ SOCIETY FOR THE ADVANCEMENT OF ARTS AND SCIENCES

Institute of Quality Science

Poznań University of Economics and Business

Current Trends in Quality Science. Innovative and sustainable products, materials, and technologies.

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DOI: 10.56091/CTQS.Inov

Cover design: Izabela Jasiczak

e-ISBN: 978-83-7654-540-0

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Preface

Nowadays, the landscape of consumption and production is shaped by pivotal trends that resonate deeply with environmental concerns. Whether propelled by evolving consumer attitudes or enforced through legislative mandates, the imperative to address environmental sustainability has become increasingly pronounced. Concepts like sustainable development and the circular economy have permeated not only business practices but also everyday life, reflecting a growing societal consciousness toward responsible resource management. Simultaneously, the march of technological progress continues unabated, bringing further innovations. Yet, as novel products and technologies emerge, questions arise not only about their functionality and efficacy but also about their environmental impact and safety implications. Modern technologies should be not only compatible with sustainability goals but also instrumental in driving them forward.

The papers included in the monograph entitled **Current Trends in Quality Science. Innovative and Sustainable Products, Materials, and Technologies** evaluate sustainable technologies (related also to waste recycling), present food and packaging innovations, and discuss consumer attitudes towards food waste and environmental protection activities. The Authors attempt to assess the environmental impact of coated paper packaging, explore ecological and social innovations in the textile industry, and discuss the possibility of recycling platinum group metals and processing plastic waste from the automotive industry. Interesting technologies for the use of composite waste in asphalt and recycled fibers in corrugated board or the modification of composted packaging films and rubber base in rubber compounds are described. The presented innovative products include nanocomposites or packaging materials designed with 3D printing, as well as food products based on active ingredients (e.g., otilonium bromide, aurones – natural flavonoid pigments), natural by-products (pumpkin seed or by-products of chokeberry fruit processing), flavored honey (regarding the preferences of I-generation consumers) and upcycled food products as a sustainable solution for food waste. The idea of implementing a Digital Product Passport (DPP) and the use of modern analytical tools based on Near-infrared (NIR) Spectroscopy in assessing the quality and authenticity of selected products was discussed. Finally, the monograph contains many considerations regarding consumers' approach to the following important issues: the effectiveness of nutrition labels or packaging deposit return systems, the use of disposable packaging or the introduction of nanoproducts in everyday life, the influence of environmentally friendly products and their packaging in shaping sustainable behavior, awareness of food waste and sustainable consumption.

Katarzyna Michocka, Mariusz Tichoniuk

THE EFFECT OF OTILONIUM BROMIDE ON QUALITY OF HUMAN LIFE

Joanna Antos[1,2], Daria Wieczorek[1], Ying-Lien Chen[3], Tang-Long Shen[3]***

[1] *Department of Technology and Instrumental Analysis, Institute of Quality Science,*

Poznań University of Economics and Business, Poznań, Poland

[2] *Faculty of Environmental Engineering and Energy, Poznań University of Technology, Poznań, Poland*

[3] *Department of Plant Pathology and Microbiology, National Taiwan University, Taipei, Taiwan*

**Corresponding Author e-mail:joanna.antos@doctorate.put.poznan.pl*

DOI: 10.56091/CTQS.Innov-1

Abstract

Otilionium bromide (OB) is a quaternary ammonium compound which is commonly known in pharmaceutical industry. It affects the distal gastrointestinal tract as an antispasmodic agent which is used by patients with irritable bowel syndrome (IBS). The drug's action is based on the inhibition of L-type and T-type calcium channels. Around 15% of the Western population struggles with IBS. OB is characterized by weak systematic absorption, which may prevent other negative impact on organism. There have been several successful treatments worldwide using OB and placebo. These medical trials have proven to be safe and successful in patients with irritable bowel syndrome. The medication reduces abdominal pain, boiling sensation and relieves discomfort better than placebo. The effects of using OB are long-lasing, even after dosing is stopped. Studies have shown that treatment with OB bromide improves quality of life. This article describes the mechanism of action, synthesis, pharmacological effects of OB and aspects in which OB improves a person's quality of life.

Keywords: otilonium bromide, irritable bowel syndrome, cationic surfactants, drugs

Introduction

Otilonium bromide (OB, alternate name: Octylonium Bromide) is a quaternary ammonium compound. Its chemical name is diethylmethyl(2-(4-(2-octyloxybenzamido)benzoyloxy)-ethyl) ammonium bromide and molecular formula is $C_{29}H_{43}BrNO_4$. The chemical properties of OB are presented in Table 1. OB was developed over thirty years ago by Menarini Research SpA.

This compound is known in over 40 countries in all Europe, Asia, America and also Africa and Middle East. OB, the generic name for the medication, is the primary name by which it is known in the pharmaceutical industry.

However, it may also be commercially available under different brand names, which can vary depending on the country and the manufacturer (e.g., Doralin, Spasmomen, Spasen, Spasmoctyl, Spasen Somatico, Spasmomen Somatico) (Mannucci et al., 1992).

OB is a drug widely used to help treat gastrointestinal disorders, particularly irritable bowel syndrome (IBS). It is known to affect the symptoms (such as reducing abdominal pain, bloating and relieving discomfort) that people with IBS experience, which in turn can impact their quality of life.

IBS is a chronic functional gastrointestinal disorder characterized by abdominal discomfort or pain accompanied by altered stool frequency or form (Chey et al., 2004). IBS is classified into four subtypes based on the predominant stool pattern: IBS with constipation (IBS-C), IBS with diarrhea (IBS-D), IBS with mixed bowel movements (IBS-M), and IBS unclassified (IBS-U). Diagnosing of this disease can be challenging due to the variability of symptoms over time and the potential overlap with other conditions (Evangelista et al., 1998; Oka et al., 2020).

In 2016, the Rome Criteria IV was published, which are the most recent update to the diagnostic criteria for functional disorders of the gastrointestinal system. These criteria assume that recurrent abdominal pain lasting an average of at least 1 day/week in the past 3 months, related to at a minimum of two of the criteria: associated with a change in the form (appearance) of stools, associated with a change in the frequency of bowel movements, associated with defecation (Lacy and Patel, 2017; Lacy et al., 2016).

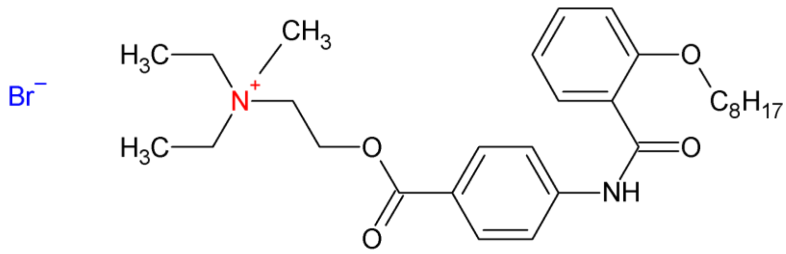
A correct diagnosis according to the Rome IV criteria is the basis for a good diagnostic and treatment strategy in people with IBS. The next step is to determine the form of the disease. Treatment of the disease begins with proper education, helped by a good patient-doctor relationship. With education, one can try to avoid events that cause persistent discomfort. Of course, an important part of the fight against IBS is lifestyle changes and adherence to dietary recommendations. Probiotics, more fiber, avoidance of intolerable foods, and a low FODMAP (Fermentable Oligosaccharides, Disaccharides, Monosaccharides And Polyols) diet are necessary. Lifestyle changes include increasing physical activity, combating excessive stress, learning relaxation techniques (such as yoga) or attending a psychologist.

Once these steps are taken, quality of life should improve. However, if the patient does not experience improvement, pharmacological treatment of symptoms should be implemented. In the case of diarrhea, for example, this is the use of loperamide, eluxadoline.

On the other hand, for constipation, macrogol, lubiprostone, linaclotide are used. Pain and bloating can be treated with congestion-reducing drugs, antidepressants (Adrych, 2019).

Mearin et al., (2021) prepared an article in which they compared population studies. According to them, the highest prevalence rates were in Europe and the United States. They also compared IBS with inflammatory bowel disease (IBD), and according to them, IBS is more common than IBD, about 10 times more common. Quality of life changes at a similar level for both diseases, as does social and health impact (Mearin et al., 2022).

Table. 1. Chemical properties of otilonium bromide

Molecular formula	$C_{29}H_{43}BrNO_4$
CAS Number	26095-59-0
Structural formula	
Molecular weight	563.57g/mol
Solubility	DMF 20 mg/mL DMSO 25 mg/mL Water 0.0000295 mg/mL Ethanol 10 mg/mL BPS (pH 7.2) 10 mg/mL
Partition coefficient	log P= 3.45

Source: own study.

Research methodology

Scopus, The Web of Science, PubMed and Google Scholar were used to find articles related to this study. The following research questions were implemented in this study: ‘What is otilonium bromide?’, ‘What are the quality effects of otilonium bromide for human life?’, ‘How does otilonium bromide help to improve life?’, ‘What is irritable bowel syndrome and how to manage its symptoms?’. The keywords used in the article are: ‘otilonium AND bromide AND quality AND of AND human AND life’, ‘otilonium AND bromide’, ‘otilonium AND bromide AND effects’. The research questions and keywords were developed based on the authors' previous research and focus on the quality of life. The papers were published in English between 1990 and 2023. The wide date range is due to the insufficient number of clinical trials conducted with OB.

Results and discussion

Synthesis of otilonium bromide

Chunxiang et al., (2015) have completed a patent document on OB preparation methods. The patent number is: CN105037193A (Chunxiang et al., 2015). It can be synthesized by several methods. The scheme is presented under Figure 1. One focuses on the formation of 4-(alkyloxy)benzoic acid, followed by reaction with thionyl chloride. Then, with the addition of an amino acid, the N-substituted amide is obtained. Fischer-Speier esterification gives the N-substituted amidoester. The last reaction is closely related to the quaternation of the nitrogen atom to give the final quaternary ammonium compound.

Mechanism of action of OB

OB is designed to be efficiently absorbed through the walls of the large intestine, while having poor systemic absorption. This means that the therapeutic concentration of the compound in the small intestine, large intestine, and smooth muscle of the colon is approximately 10 μmol/L, while its plasma concentration is estimated to be 1000 times lower. According to rat experiments, approximately 97.8% of the ingested OB is excreted in the feces, while less than 1% is excreted in the urine (Rychter et al., 2014; Triantafillidis and Malgarinos, 2014).

OB can inhibit the release of calcium from the sarcoplasmic reticulum or reduce intestinal smooth muscle contraction or counteract visceral hypersensitivity. OB has specific pharmacokinetics and is concentrated in the colon wall and acts locally (Evangelista et al., 2018). OB acts on L-type calcium channels, blocking them. It also acts as a tachykinin NK2 receptor antagonist. It forms associations with NK2 T-type and L-type channels, as evidenced by experiments utilizing the patchclamp technique, wherein its inhibitory effects were demonstrated.

The T-type Ca2þ channel is also inhibited by OB, resulting in reduced small intestinal smooth muscle contractility. The suppression of Ca^{2+} channels can lead to a reduction in spontaneous motility. It is invaluable for IBS diarrhea because, when applied, it has an inhibitory effect on M3 muscarinic receptors. In addition, OB has low systemic absorption, which is the reason for its high efficacy (Gong and Kim, 2023; Shrivastava and Mittal, 2022).

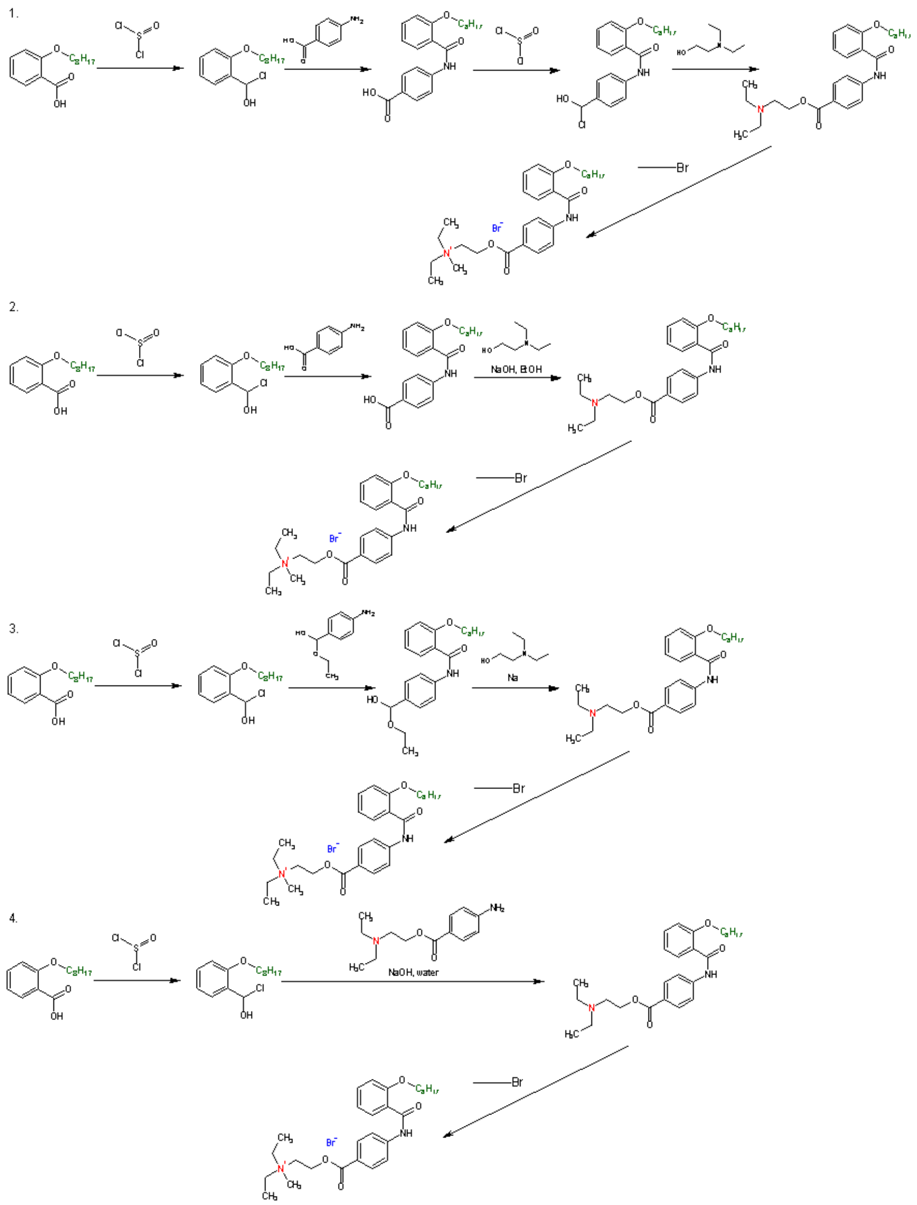


Fig. 1. Scheme for synthesis of OB

Source: own study.

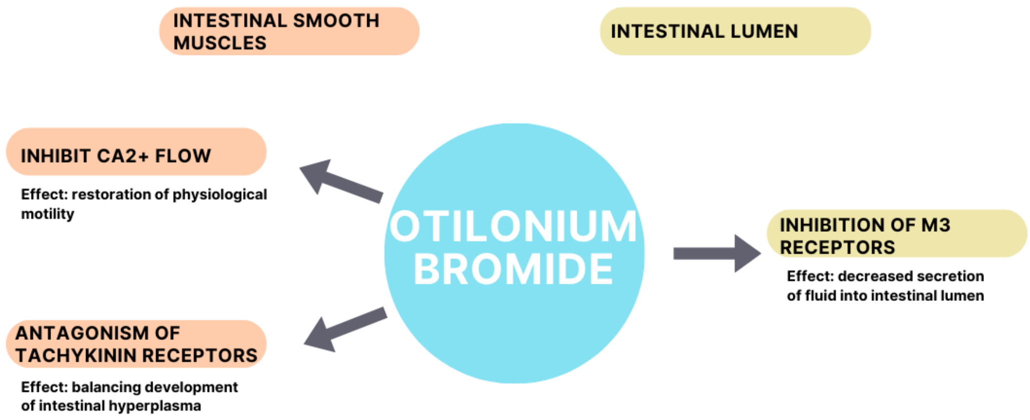


Fig. 2. Mechanism of action of OB

Source: own study.

The effects of OB on quality of human life

Hungin et al., (2003) presented results of an international survey which consists responds from 41,984 people from several countries such as UK, Germany, France, Italy, Spain, Belgium, Netherlands and Switzerland. The prevalence of IBS was oscillated in the level of 11,5%. Among them 9,6% complained about symptoms which occur in last 12 months and the rest have earlier symptoms. Most of cases with IBS connected with female, and when it comes to the age it is 18-34 years old. Above 50% of respondents stated that their health affected their lives (Boeckxstaens et al., 2014; Hungins et al., 2003).

Considering the numerous symptoms that reduce quality of life, it is important to consider the mortality of patients with IBS. Patient mortality can be related to unnecessary surgical treatment, for example, in cases of poor diagnosis. IBS significantly reduces quality of life, which can often lead to depression and suicidal thoughts.

However, according to a U.S. study involving more than 30,000 people, there was no increase in mortality among IBS patients (Card et al., 2014; Chang et al., 2010).

OB has several of effects which impact quality of life. Among them are: symptom relief, pain reduction, improvement of bowel habits, psychological impact as well as treatment compliance.

OB, as it was mentioned before is an antispasmodic agent that works by reducing muscle contractions in the gastrointestinal tract. In this way, it can help relieve symptoms associated with IBS, such as abdominal pain, bloating and changes in bowel habits. Successful treatment of these symptoms can lead to an improved overall quality of life for people with IBS. The effectiveness of OB is confirmed by multiple clinical test all over the world. Most of them are based on a therapeutic dose of 40 mg OB three times a day. Such clinical trials were conducted by Battaglia et al., (1998), Glende et al., (2002), Baldi et al., (1991), Clavé et al., (2011), Chang et al., (2011), Villagrasa et al., (1991). These medical studies have produced results for more than 1,000 people. People during such studies were treated with OB or placebo/different medication/diet. A summary of the research is shown in Table 2 (Baldi et al., 1991; Battaglia et al., 1998; Chang et al., 2011; Clavé et al., 2011; Glende et al., 2002; Villagrasa et al., 1991).

Table. 2. The clinical trials of OB

Study	**Country**	**Patients**	**Treatment**	**Results**
(Baldi et al., 1991)	Italy	72	1) OB: 40 mg 2) Placebo	The reduction of abdominal pain and bloating
(Battaglia et al., 1998)	Italy	378	1) OB: 40 mg 2) Placebo	The reduction in the number of abdominal pain episodes
(Chang et al., 2011)	Taiwan	117	1) OB: 40 mg 2) Mebeverine: 100 mg	OB is as effective as mebverine in soothing IBS symptoms
(Clavé et al., 2011)	Spain	356	1) OB: 40 mg 2) Placebo	The reduction in the incidence of abdominal pain, severity of abdominal bloating and protection against recurrence of IBS symptoms.
(Glende et al., 2002)	Italy	378	1) OB: 40 mg 2) Placebo	The reduction of abdominal pain and discomfort
(Villagrasa et al., 1991)	Spain	114	1) OB: 40 mg 2) high-fiber diet	OB is more effective than high-fiber diet

Source: own study.

Assessment of the effectiveness of the clinical pathway was based on diaries kept by patients. They were to record all symptoms, as well as evaluate pain. In Chang et al., (2011) study, the evaluation criteria for abdominal pain or discomfort were: 0- absent, 1-mild, 2-moderate, 3-severe. In addition, the patients recorded the degree of bloating, abdominal flatulence and satisfactory stool frequency on a visual analog scale. At the end of the clinical trial the final grade was presented by patients and researchers with score criteria (0 – worsened, 1 – no change, 2 – slightly improved, 3 – improved, 4 – significantly improved (Chang et al., 2011). Studies have been similarly conducted by other researchers but with some different criteria. Glende et al., (2002) compared the results presented in special diaries. They presented more criteria for the study, and these were: the intensity of abdominal pain, the frequency of abdominal pain episodes, intestinal habits, the average daily number of evacuations, the days without evacuation during the week, mucus in the stool, difficulty of evacuation, the consistency of stools. As in the previous study, outcomes were controlled throughout the clinical trial (Glende et al., 2002).

Abdominal pain is a prevalent and frequently incapacitating symptom experienced by individuals with IBS. OB has demonstrated its efficacy in effectively reducing pain and discomfort in patients with IBS. By alleviating or even eliminating pain, it can positively impact an individual's capacity to participate in daily activities and enhance their overall well-being. In Clavé et al., (2011) clinical trial, abdominal pain was one of the most important factor. The influence of OB was greater than placebo in terms of reduction in the frequency of weekly abdominal pain episodes at the end of the treatment period. In the clinical trail 179 people were treated with OB and 177 with placebo. Patients were selected according to Rome II definition. Due to the fact that IBS is more popular in female the investigated group was 70% female (Clavé et al., 2011).

What's more, study data show that the positive effect of OB use can persist even after treatment ends, so the effect of reducing pain or changing bowel habits can be long-lasting. Results proving this statement were obtained in a study by Forte et al (2012). Patients took part in a 10-week follow-up period after a 15-week clinical trial in which they were no longer taking placebo/OB. This knowledge can be helpful when patients want to treat themselves with an intermittent medication regimen (Forte et al., 2012).

IBS often leads to unpredictable bowel movements, ranging from diarrhea to constipation. OB plays a role in regulating bowel function by reducing the frequency and intensity of spasms in the intestinal muscles. As a result, individuals may experience more consistent and regular bowel habits, giving them a sense of control and minimizing the disruptions caused by erratic bowel movements (Boeckxstaens et al., 2014; Costa and Ovalle Hernández, 2019).

IBS can have a significant psychological impact, often causing stress, anxiety, and depression, which is the reason for recommending patients to practice sports, meditation, antidepressants or visits to a psychologist. The unpredictable nature of IBS and its associated symptoms can lead to decreased social activities, avoidance of certain situations, and impaired quality of life. By effectively managing the physical symptoms of IBS, OB may also contribute to a reduction in psychological distress and an overall improvement in mental well-being.

As mentioned earlier, OB is generally well tolerated and has a good safety profile. Its easy use and minimal side effects may contribute to better treatment compliance. Consistent use of the drug as prescribed can help maintain symptom control and optimize overall quality of life for people with IBS.

Conclusions

OB is an antispasmodic medication that has been approved by the FDA (Food and Drug Administration). The most effective dose of the drug is 40 mg. OB improves the quality of life of IBS patients on several levels by improving IBS symptoms such as abdominal pain, bloating, satisfactory stool frequency and flatulence. With positive management of pain or bowel cycle, patients can lead a normal life – without the pain and stress associated with it. Patients with active symptoms may feel betrayed by their bodies because they cannot lead an active life. This feeling can lead to depression, and it's important to try to counteract this condition by accepting the disease, as well as following a proper diet, learning to manage stress, educating themselves about the disease and taking medication as needed. However, the number of clinical trials with OB is small, and the target group is insufficient. It is important to conduct a study involving a large number of people to get better results.

Acknowledgements

Authors contribution: Joanna Antos and Daria Wieczorek acquired, analysed and interpreted the data about the effect of otilonium bromide on quality of human life and wrote the manuscript. Ying-Lien Chen and Tang-Long Shen were responsible for revising the manuscript.

The work was financially supported by The National Centre for Research and Development grant PL-TW/VIII/4/2021.

References

Adrych, K., 2019. Irritable bowel syndrome in the light of the latest guidelines. *Varia Medica 3*, 89-95.

Baldi, F., Longanesi, A., Blasi, A., Monello, S., Cestari, R., Missale, G., Corazziari, E., Badiali, G., Pescatori, M., & Anastasio, G. (1991). Clinical and functional evaluation of the efficacy of otilonium bromide: A multicenter study in Italy. *The Italian Journal of Gastroenterology*, *23*(8 Suppl 1), 60-63.

Battaglia, G., Morselli-Labate A.M., Camarri, E., Francavilla, A., De Marco, F., Mastropaolo, G., Naccarato, R. Otilonium bromide in irritable bowel syndrome: a double-blind, placebo-controlled, 15-week study. Aliment Pharmacol Ther. 1998 Oct;12(10):1003-10. doi: 10.1046/j.1365-2036.1998.00397.x. PMID: 9798806.

Boeckxstaens, G., Clavé, P., Corazziari, E. S., & Tack, J. (2014). Irritable bowel syndrome: Focus on otilonium bromide. *Expert Review of Gastroenterology & Hepatology*, *8*(2), 131-137. https://doi.org/10.1586/17474124.-2014.869477

Card, T., Canavan, C., & West, J. (2014). The epidemiology of irritable bowel syndrome. *Clinical Epidemiology*, 71. https://doi.org/10.2147/CLEP.S40245

Chang, F.-Y., Lu, C.-L., Luo, J.-C., Chen, T.-S., Chen, M.-J., & Chang, H.-J. (2011). The evaluation of otilonium bromide treatment in asian patients with irritable bowel syndrome. *Journal of Neurogastroenterology and Motility*, *17*(4), 402-410. https://doi.org/10.5056/jnm.2011.17.4.402

Chang, J. Y., Locke, R. G., McNally, M. A., Halder, S. L., Schleck, C. D., Zinsmeister, A. R., & Talley, N. J. (2010). Impact of functional gastrointestinal disorders on survival in the community. *American Journal of Gastroenterology*, *105*(4), 822-832. https://doi.org/10.1038/ajg.2010.40

Chey, W. D., Chey, W. Y., Heath, A. T., Dukes, G. E., Carter, E. G., Northcutt, A., & Ameen, V. Z. (2004). Long-term safety and efficacy of alosetron in women with severe diarrhea-predominant irritable bowel syndrome. *The American Journal of Gastroenterology*, *99*(11), 2195-2203. https://doi.org/10.1111/j.15720241.2004.-30509.x

Chunxiang, J., Tao, W., Huang, F., Wenbin, C., Jingxin, S., Xiaofei, 2015. Preparation method of otilonium bromide. *CN105037193A.*

Clavé, P., Acalovschi, M., Triantafillidis, J. K., Uspensky, Y. P., Kalayci, C., Shee, V., Tack, J., & on behalf of the OBIS Study Investigators. (2011). Randomised clinical trial: Otilonium bromide improves frequency of abdominal pain, severity of distention and time to relapse in patients with irritable bowel syndrome: Randomised clinical trial: otilonium bromide in IBS. *Alimentary Pharmacology & Therapeutics*, *34*(4), 432-442. https://doi.org/10.1111/-j.1365-2036.2011.04730.x

Costa, V. A., & Ovalle Hernández, A. F. (2019). Rol de los antiespasmódicos en el manejo del síndrome de intestino irritable. *Revista Colombiana de Gastroenterología*, *34*(3), 269-276. https://doi.org/10.22516/25007440.309

Evangelista, S., Giachetti, A., Chapelain, B., Neliat, G., & Maggi, C. A. (1998). Receptor binding profile of otilinium bromide. *Pharmacological Research*, *38*(2), 111-117. https://doi.org/10.1006/phrs.1998.0340

Evangelista, S., Traini, C., & Vannucchi, M. G. (2018). Otilonium bromide: A drug with a complex mechanism of action. *Current Pharmaceutical Design*, *24*(16), 1772-1779. https://doi.org/10.2174/13816128246661805071-22935

Forte, E., Pizzoferrato, M., Lopetuso, L., & Scaldaferri, F. (2012). The use of anti-spasmodics in the treatment of irritable bowel syndrome: Focus on otilonium bromide. *European Review for Medical and Pharmacological Sciences*, *16*(1), 25-37.

Glende, M., Morselli-Labate, A. M., Battaglia, G., & Evangelista, S. (2002). Extended analysis of a double-blind, placebo-controlled, 15-week study with otilonium bromide in irritable bowel syndrome: *European Journal of Gastroenterology & Hepatology*, *14*(12), 1331-1338. https://doi.org/10.1097/00042737-200212000-00008

Gong, Y., & Kim, Y. R. (2023). Therapeutic potential of otilonium bromide against Vibrio vulnificus. *Research in Microbiology*, *174*(1-2), 103992. https://doi.org/10.1016/j.resmic.2022.103992

Hungin, A. P. S., Whorwell, P. J., Tack, J., & Mearin, F. (2003). The prevalence, patterns and impact of irritable bowel syndrome: An international survey of 40 000 subjects. *Alimentary Pharmacology & Therapeutics*, *17*(5), 643-650. https://doi.org/10.1046/j.1365-2036.2003.01456.x

Lacy, B., & Patel, N. (2017). Rome criteria and a diagnostic approach to irritable bowel syndrome. *Journal of Clinical Medicine*, *6*(11), 99. https://doi.org/10.3390/jcm6110099

Lacy, B., & Patel, N. (2017). Rome criteria and a diagnostic approach to irritable bowel syndrome. *Journal of Clinical Medicine*, *6*(11), 99. https://doi.org/10.3390/jcm6110099

Mannucci, C., Bertini, J., Cocchini, A., Perico, A., Salvagnini, F., & Triolo, A. (1992). Simultaneous determination of otilonium bromide and diazepam by first-derivative spectroscopy. *Journal of Pharmaceutical Sciences*, *81*(12), 1175-1177. https://doi.org/10.1002/jps.2600811209

Mearin, F., Sans, M., & Balboa, A. (2022). Relevance and needs of irritable bowel syndrome (Ibs): Comparison with inflammatory bowel disease (Ibd). (Please, if you are not interested in IBS, read it.). *Gastroenterología y Hepatología (English Edition)*, *45*(10), 789-798. https://doi.org/10.1016/j.gastre.2021.12.008

Oka, P., Parr, H., Barberio, B., Black, C. J., Savarino, E. V., & Ford, A. C. (2020). Global prevalence of irritable bowel syndrome according to Rome III or IV criteria: A systematic review and meta-analysis. *The Lancet Gastroenterology & Hepatology*, *5*(10), 908-917. https://doi.org/10.1016/S2468-1253(20)30217-X

Rychter, J., Espín, F., Gallego, D., Vergara, P., Jiménez, M., & Clavé, P. (2014). Colonic smooth muscle cells and colonic motility patterns as a target for irritable bowel syndrome therapy: Mechanisms of action of otilonium bromide. *Therapeutic Advances in Gastroenterology*, *7*(4), 156-166. https://doi.org/10.1177/1756283X145-25250

Shrivastava, A., & Mittal, A. (2022). A mini review on characteristics and analytical methods of otilonium bromide. *Critical Reviews in Analytical Chemistry*, *52*(7), 1717-1725. https://doi.org/10.1080/10408347.2021.1913983

Triantafillidis, J., & Malgarinos, G. (2014). Long-term efficacy and safety of otilonium bromide in the management of irritable bowel syndrome: A literature review. *Clinical and Experimental Gastroenterology*, 75. https://doi.org/-10.2147/CEG.S46291

Villagrasa, M., Boix, J., Humbert, P., & Quer, J. C. (1991). Aleatory clinical study comparing otilonium bromide with a fiber-rich diet in the treatment of irritable bowel syndrome. *The Italian Journal of Gastroenterology*, *23*(8 Suppl 1), 67-70.

TOWARDS A SUSTAINABLE FUTURE: EXPLORING ECOLOGICAL AND SOCIAL INNOVATIONS IN THE CLOTHING INDUSTRY

Katarína Chomova*[1], Malgorzata A. Jarossová, Renáta Ševčíkov[2]

Department of Marketing, University of Economics in Bratislava, Slovakia
**Corresponding Author e-mail:* katarina.chomova@euba.sk

DOI: 10.56091/CTQS.Innov-2

Abstract

The clothing industry is one of the largest and oldest in the world and is undergoing a significant transformation as sustainability becomes a critical focus. With growing concerns about the impact of the industry on the planet and society, there is a pressing need for change. The article explores the ecological and social innovations that are driving this change and propelling the industry towards a more sustainable future. By examining the adoption of sustainable practices, such as rental, resale and Second-hand model, materials with lower carbon footprint, modular and upcycled fashion, highly durable and circular clothes, virtual fashion and gamification, blockchain etc., the article highlights the industry's commitment to mitigate its ecological footprint. The article examines the impact of these innovations on both the environment and stakeholders within the industry and also highlights the role of consumer awareness and changing preferences in driving sustainability efforts. Through this exploration, the article provides valuable information on the ongoing journey toward sustainability in the textile industry and the opportunities and challenges that lie ahead.

Keywords: ecological and social innovations, clothing industry, transparency, certifications, virtual fashion, rental model

Introduction

Clothing industry is a fundamental part of everyday life and an essential sector in the global economy. It is hard to imagine a world without clothing. Clothes are worn by almost everyone, nearly all the time, and for many are an essential expression of individuality (Ellen Macarthur Foundation, 2017). The textile industry is also a significant sector in the global economy, providing employment for hundreds of millions around the world.

The development of the textile industry towards more sustainable and circular operation models supports the Sustainable Development Goals of the United Nations: Goal 12: Responsible Consumption and Production, and goal 9: Industry, innovation, and Infrastructure. In the search for solutions to the environmental impacts of textile production, the bioeconomy plays a crucial role.

It provides new, sustainably produced biobased and recyclable raw materials, recycling of materials and closed-loop operations, as well as technologies, innovations, and skills needed for all this.

The textile system operates in an almost completely linear way: large amounts of non-renewable resources are extracted to produce clothes that are often used for only a short time, after which the materials are mostly sent to landfill or incinerated. Furthermore, this take-make-dispose model has numerous negative environmental and societal impacts. This paper outlines the importance of innovation and new opportunities towards a different system. A new textile economy presents an opportunity to deliver substantially better economic, societal, and environmental outcomes (Ellen Macarthur Foundation, 2017).

There are many basic and technical differences between textiles, apparel and fashion. Apparel (clothing) industry encompasses every kind of clothing, from sportswear to business wear, from value clothing to statement luxury pieces (Statista, 2023b). Textile industry is a very broad term that includes fiber, yarn, sewing thread, and fabric (Shubham, 2022). Textile means the whole thing from fiber to fashion, apparel limited to cloth only. The industry of fashion designing includes various works related to the world of fashion such as designing, manufacturing, marketing, retailing, advertising, and promoting all sorts of clothing everywhere (Shubham, 2022).

Materials and methods

This article initially conducted a systematic literature review to explore the key enablers based on innovation, which supports sustainability adoption in the clothing industry. This study is structured as follows: The following section explains the basic facts regarding global clothing. Within this review, we argue and highlight that the sustainable segment of the clothing market increases continuously. The second part shows ecological and social innovations and opportunities in the clothing industry. The final section encompasses the key conclusions, and provides recommendations for future research in this field. The outcomes of the present study will be beneficial for researchers, practitioners, and policymakers.

Basic facts regarding global clothing industry

Although the international market has been hit by the COVID-19 pandemic, with revenue falling back to 2014 levels in 2020, the industry is predicted to recover quickly. Revenue is expected to reach a new high as early as 2022, rising to a value of US$2,247 billion by 2025 (Fig. 1.) (Gözet & Wilts, 2022).

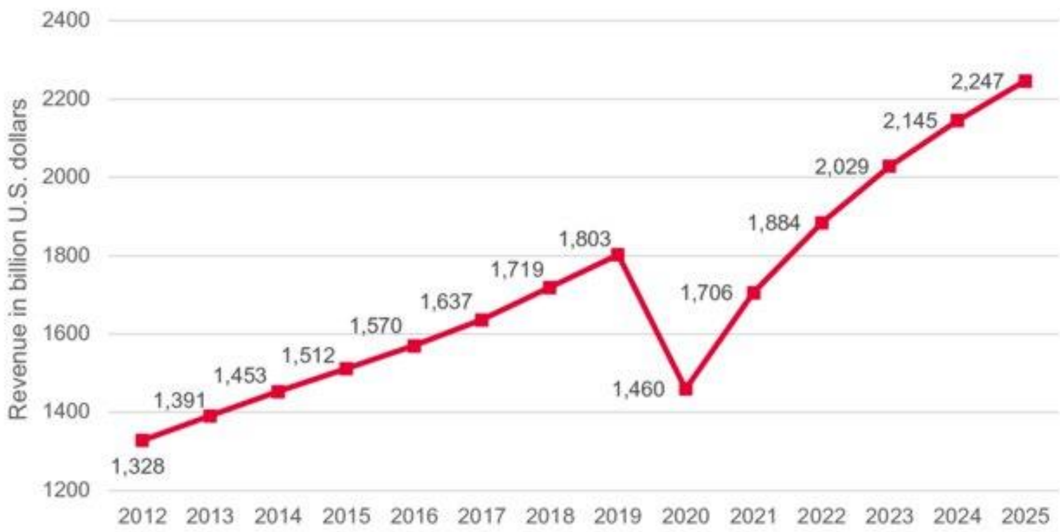


Fig. 1. Revenue of the global clothing market

Source: Gözet & Wilts, 2022.

The countries that account for the majority of this clothing demand are the United States and China, both generating substantially higher revenues than any other country. It is perhaps no surprise that the same two countries play a significant role in international trade. In 2021, China led the rankings for the highest value of clothing exports. The U.S. was second only to the EU in the value of clothing imports (Statista, 2023a).

The clothing market is dominated by the biggest companies (Table. 1). Nike is a standout performer, generally placing in the top spots for selected financial metrics. For example, Nike had the highest brand value of any mass clothing brand in 2022, at roughly 110 billion dollars. Moët Hennessy Louis Vuitton is another company that consistently placed highly. LVMH had a market capitalization of 317 billion dollars in September 2022 (Statista, 2023a).

The European Union is the region which imports the most clothing worldwide by quite some distance, with roughly a third of world imports. Many companies in Europe, as well as other countries of the world, choosing to outsource production to China and other cheaper locations across the world (Table 2).

Table 1. Examples of some major players in the global clothing industry based on their market caps

VF Corporation	American global clothing and footwear company with 13 brands (Napapijri, Supreme, Timberland, Vans, etc.). The company controls 55% of the U.S. backpack market with the JanSport, Eastpak, Timberland, and The North Face brands.
PVH	American clothing company which owns brands such as Tommy Hilfiger, Calvin Klein, Warner's, Olga and True & Co. The company also licenses brands such as Kenneth Cole New York and Michael Kors.
Hanes	American multinational clothing company. Hanesbrands owns several clothing brands, including Hanes, Champion, Playtex, Bali, L'eggs, Just My Size, Barely There, Wonderbra, Maidenform, Berlei, and Bonds.
Tapestry	American multinational luxury fashion holding company. It is based in New York City and is the parent company of three major brands: Coach New York, Kate Spade New York and Stuart Weitzman. Originally named Coach, Inc.
Inditex	Spanish multinational clothing company. The company's flagship store is Zara, but it also owns a number of other brands such as Zara Home, Bershka, Massimo Dutti, Oysho, Pull&Bear, Stradivarius, Uterqüe and Lefties.
Hennes & Mauritz (H&M)	H&M Group is a multinational clothing company based in Sweden that focuses on fast-fashion clothing for anyone, any gender.
Adidas	German athletic clothing and footwear corporation.
Nike	American athletic footwear and clothing corporation. Nike markets its products under its own brand, as well as Converse.
Kering	French-based multinational corporation specializing in luxury goods. It owns the brands Balenciaga, Bottega Veneta, Gucci, Alexander McQueen and Yves Saint Laurent.
Fast retailing	Japanese multinational retail holding company with brand Uniqlo etc.
LVMH Moët Hennessy Louis Vuitton	French multinational holding and conglomerate specializing in luxury goods. LVMH controls around 60 subsidiaries that manage 75 prestigious brands. These include Tiffany & Co., Christian Dior, Fendi, Givenchy, Marc Jacobs, Stella McCartney, Loewe, Loro Piana, Kenzo, Celine, Sephora, Princess Yachts, TAG Heuer, and Bulgari.
Gap Inc.	American worldwide clothing and accessories retailer. The company operates four primary divisions: Gap (the namesake banner), Banana Republic, Old Navy, and Athleta.

Source: own study.

Table 2. Top 10 textile exporting countries in 2020

Country	**Percentage of global textile exports in 2020**
China	35.60
Vietnam	5.03
Bangladesh	4.82
India	3.84
Turkey	3.69
Pakistan	1.93
Cambodia	1.69
Indonesia	1.54
South Korea	1.40
Chinese Taipei	1.06

Source: Filho et al., 2022.

Many of Europe's most popular fashion brands are among the leading clothing companies worldwide in terms of brand value (Table 2). Based on clothing companies' turnover in Europe alone, Inditex of Spain comes out on top, with a turnover of around 17.5 billion euros in 2021, followed by H&M of Sweden. Inditex is responsible for several well-known clothing brands, including Zara, Bershka, Massimo Dutti, and Pull & Bear (Statista, 2023b).

Consumers, as well as companies in the clothing industry, are conscious of the importance of sustainability. Therefore, it is not a surprise that the global revenue share in the sustainable segment of the clothing market was forecast to continuously increase between 2023 and 2026 by in total 1.4 percentage points. Revenue share of the sustainable clothing market worldwide from 2013 to 2026 is depicted in Figure 2. According to this forecast in 2026, the share will have increased for the third consecutive year to 6.14 percent. Notably, the revenue share of the sustainable segment of the clothing market was continuously increasing over the past years (Statista, 2023b).

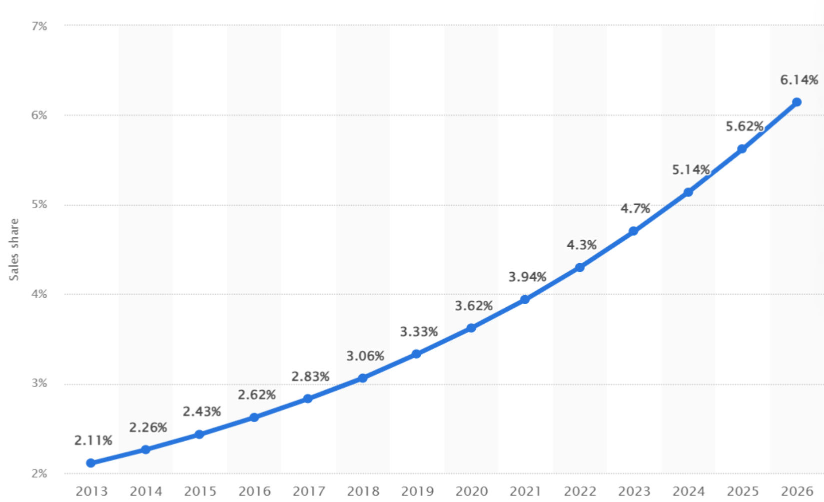


Fig. 2. Sustainable clothing market

Source: Statista, 2023b.

To stay on the 1.5-degree pathway, also the clothing industry needs to go beyond this vision of accelerated abatement to fundamentally redefine business models and current imperatives of economic growth and rising consumerism (McKinsey, 2022). For a prosperous future and habitable earth, the industry's ingenuity and creative spirit will be required to decouple value creation from volume growth and to move from commitments to actions (McKinsey, 2022). And beyond 2030, the challenge becomes even greater: overconsumption and overproduction, linear model of fashion industry, carbon footprint of textile and clothing industry, plastic in textile, clothing waste, water and soil pollution, unfair wages and unhealthy work environment, modern slavery, animal welfare, non-transparency supply chain and greenwashing.

Ecological and social innovations and opportunities in the clothing industry

As we stated in the first part of the paper, the fashion industry is responsible for substantial contribution to global GHG emissions. But it also creates an opportunity to institute real change. In a post-covid-19 world, there is a chance for brands to take responsibility, understand their own emissions and abatement levers, collaborate with partners to decarbonize the value chain and work with stakeholders to build a less emissions-intensive product lifecycle. This will become critical beyond 2030 when the industry needs to find new ways to decouple volume growth from value growth to stay on the 1.5-degree pathway. In an historic year, the economic and ethical drivers have never been stronger. which is why now is the time for decision-makers to deepen their understanding of GHG emissions and to accelerate their response (McKinsey, 2022). In the following section, we present a few ecological and social innovations and opportunities in the fashion and clothing industry.

Rental model

The future of fashion may be a service that replaces ownership with fast on-demand rental of fashion from a limitless global pool of outfits (Commonobjective, 2023). Two models of a rental are proposed:

Rental subscription offers customers the possibility to simply pay a small fee up front, and then a regular fee for each month that they wanted to lease the clothes. When they grow tired of their rental clothes, they can just send them back and stop paying (Design4circle, 2021). Ganni is exclusively designing items for its rental platform, 'Ganni Repeat', through its latest collaborations (Ganni, 2023). Examples of this include, Ganni x Nanna Bernholm – made by reworking existing fabrics from previous Ganni collections – and the second Ganni x Levi's collection, launched in 2021, consisting of a 14-piece ready-to-wear collection of garments made of cottonised hemp. Therefore, if customers want to access such innovative designs, they are directly incentivized to try rental, instead of buying. Other examples of this offered service are brands such as YCloset, Kleiderei, Gwynnie Bee.

Short term rental offers customers the possibility to rent garments for one of occasions and needs – baby and children's clothes, maternity wear, formalwear, sportswear, luxury items (Ellen Macarthur Foundation, 2017). An example of this offered service are brands such Occasion wear hire, Vigga, Rent the Runway.

"*The rental model is clearly a winner for the higher end of the market where consumers may have no intention of wearing an occasion dress more than once… but at the lower end, it's all too easy to go online and be able to buy outright any trend or item. For rental to be a success at this market level, companies need to offer a sufficient choice of brands and styles that would engage consumers and tempt them away from outright purchase, and the rental service needs to be smooth and faultless*". says Patsy Perry, senior lecturer in fashion marketing at the University of Manchester (UN Environment Programme, 2023b).

Resale / second-hand model

The internet is a huge facilitator, providing previously unseen possibilities for giving away, swapping and selling/buying Second-hand (Close the loop, 2023). Various sites and apps bring suppliers and demands together (sometimes for a fee). When products are shared or sold on, we don't have to make as much new stuff, meaning fewer resources are used. In addition, borrowing and sharing saves money. It costs the recipient a lot less than buying something new (Design4circle, 2021). The online marketplace for peer-to-peer resale – "Vinted", enables users to swap used products as well as to purchase them.

This encourages more use of products without the need for users to have access to disposable income. Vinted also incentivizes users to buy Second-hand by setting time-bound shipping deadlines for sellers and enabling ‘bundle discounts’ on multiple purchases from the same seller. Examples of this offered service are brands such as ThredUp, Remixshop etc.

Materials with lower carbon footprint

Common Objective showed that switching from conventional to organic cotton can cut global warming potential by 46 percent. Current supplies aren’t nearly enough to meet fabric demand – less than one percent of all cotton production is organic – but the use of more sustainable fabrics will undoubtedly play an important role in reducing fashion's carbon footprint going forward (Commonobjective, 2023).

According to Common Objective, mechanically recycled polyester generates 70 percent less emissions than virgin polyester. Outdoor clothing brand Patagonia have long been known for their use of recycled polyester, but other big players are getting in on the act – Nike, H&M and Target are all among the top ten users of sustainable synthetics (Commonobjective, 2023). Another material with a lower carbon footprint can be mycelium mushrooms. Mycelium mushrooms are already a key ingredient in beauty products, now mycelium – the vegetative part of a fungus consisting of a mass of branching, thread-like hyphae – is being transformed into leather alternatives in fashion, too.

Modular fashion

Some might use the term multi-functional, others prefer convertible or adaptable. The semantics may vary but, conceptually speaking, modular fashion translates into a garment, shoe or accessory that changes shape or form for different purposes. Trend forecasting company WGSN described modular design thinking as the clip on, clip off trend in its report, entitled “Five Key trends for 2021 and beyond: Fashion” (Ecotextile, 2021). Examples of modular fashion can be a winter clothing brand, Canada Goose, in collaboration with designer Angel Chen, launched a capsule collection featuring parkas that can be worn upside down or cropped. Already active in this arena with products like a cape that converts into a cross-body bag, H&M brand COS launched a multi-functional capsule collection in early 2020. It included a jacket with adjustable length, trouser pockets that converted into a clutch and a three-in-one garment that could function as a shirt, skirt, or dress (Ecotextile, 2021).

Upcycled fashion

The strategy focuses on reusing discarded pieces of fabric to create new products with additional value. Discarded textile is creatively reused and can re-enter the market as a new, upcycled product. The process comes down to making new clothes from old pieces or fabrics.

This closed-loop system often requires intermediaries such as thrift shops or other organizations that collect clothes (Design4circle, 2021).

Highly durable clothes

Customers specifically select high-quality, durable garments that come with a warranty, an increased personalization, and that can be easily repaired. Repairability means the operation by which a faulty or broken product or component is returned back to a usable state. Examples of this offered service are brands such Patagonia, Houdini, MUD Jeans, etc.

Circular products

Innovations in recycling and end of life processes include automation of sorting, safe chemical fiber separation and novel end uses for textile waste (Filho et. al., 2022). Several brands have in-store collection points for garments at the end of their life, which can be recycled, or resold. Take-Back program Patagonia, which launched in 2021, allows us to recycle our old cotton products while supporting recycling chains for clothing waste. There are companies specializing in textile processing. Resyntex, a project using chemical recycling, which could provide a circular economy business model for the textile industry. Cambodia-based Tonlé uses surplus fabric from mass clothing manufacturers to create zero-waste fashion collections. It uses more than 97 percent of the material it receives and turns the rest into paper (UN Environment Programme, 2023b). Under the waste directive approved by the Parliament in 2018, EU countries are obliged to collect textiles separately by 2025. The new Commission strategy also includes measures to tackle the presence of hazardous chemicals, calls producers to take responsibility for their products along the value chain, including when they become waste and help consumers to choose sustainable textiles (European Commission, 2023b). In the future, automated processes such as optical fiber sorting may make recycling our clothes easier – we can't go on throwing millions of tons of clothing into landfill every year.

Transparency through technology, certifications and price

Blockchain technology with for example QR code can inform about transparency on a product's content, production history, and properties for use and after use, for example information on substances of concern and resource use, durability and care information, or details on material content and recycling options is crucial to inform actions. As one of the most promising applications, blockchain solutions address fashion's supply chain deficiencies by giving fashion brands the ability to track their products from the raw materials to the end product: assuming trustworthy information is inputted at the source, that same information will reach the in-house or retail end user without any possibility of interpretation (Kapfunde, 2022).

Another solution can be to use a digital product passport, which can (European Commission, 2023a):

- to enable sharing of key product related information that are essential for products' sustainability and circularity. Consequently, to accelerate the transition to circular economy, boosting material and energy efficiency, extending product lifetimes, and optimizing product design, manufacturing, use and end of life handling;
- to provide new business opportunities to economic actors through circular value retention and optimization (for example product-as-a-service activities, improved repair, servicing, remanufacturing, and recycling) based on improved access to data;
- to help consumers in making sustainable choices; and to allow authorities to verify compliance with legal obligations.

Certification verified by third parties is a good tool to ensure transparency. The EU has an EU Ecolabel that producers respecting ecological criteria can apply to items, ensuring a limited use of harmful substances and reduced water and air pollution (EP, 2023). Other certifications are shown in Table 3 (Ethicalmadeeasy, 2023).

Table 3. Examples of some certifications in textile and clothing industry

Australian Certified Organic (ACO)	Australian production standard an organic product is produced without the use of any harmful chemicals.
The Better Cotton Initiative (BCI)	It works towards making cotton a sustainable mainstream commodity and improving the environmental and social impacts brought about by cotton production.
Fairtrade	The Fairtrade certification advocates for the protection of the rights of farming and worker communities all around the world.
The Global Organic Textile Standard (GOTS)	It sets the standard for textiles made from organic fibers. GOTS certified products adhere to strict environmental and social criteria and must contain a minimum of 70% organic fibers.
The STANDARD 100 by OEKO-TEX	It is a third-party textile certification that tests textile components for harmful substances, and ultimately ensures that these textiles and components are completely safe for human use.

Source: own study.

The price of clothing should reflect the full costs of its production. Such costs are first analyzed and presented in company reporting, and ultimately reflected in product prices (Ellen Macarthur Foundation, 2023). As the first used price transparency brand *Everline.*

New technologies to support sustainable fashion

Digital product development systems featuring advanced 3D design and visualization technologies would reduce transport costs and the need for physical production altogether in certain cases, such as garment sampling (Filho et al., 2022). An Ellen MacArthur Foundation study notes that some companies are already offering digital clothes, providing users with a picture of themselves for social media use, removing the need to produce physical products. Virtual fashion rises due to ethical awareness and uses of digital fashion technology such as artificial intelligence to create products with complex social and technical software (Ellen MacArthur Foundation, 2021). Virtual fashion contributes to waste reduction by minimizing the production of unsold or unwanted physical garments. Gamification is a marketing technique taking inspiration from the methods of classic video gaming. The connection between fashion and gamification revolves around making the fashion experience more interactive, enjoyable, and engaging for consumers by incorporating elements inspired by gaming principles. It's aim is to use these elements like point scoring and competition to encourage user engagement of a product or service. Games and apps are now embracing principles of sustainability. The best learning is often achieved by having fun because it comes with positive emotions.

Sustainable fashion brand *Maakola* has partnered with blockchain technology company Genuine Way to create WearMe30Times, a new tool that helps consumers reduce their fashion footprint by encouraging them to get more wear out of their clothing. WearMe30Times harnesses technology to help consumers reduce their impact on the environment by extending the lifespan of their clothes (Genuineway, 2023). Every piece of clothing from a participating brand includes a garment label with a dedicated QR code. By scanning that QR code consumers can keep track of how often they wear the garment, building up to a goal of wearing everything at least 30 times – a goal inspired by eco-activist Livia Firth's #30Wears campaign. Gamification and social media challenges create an engaging experience to help them to reach that goal (Genuineway, 2023).

Customer education campaign and programs

Consumers must play their part in driving industry decarbonization efforts through their purchasing decisions. Educational programs are key to supporting companies on their transformation to a circular economy.

New skills, competences and capabilities are needed in order to implement circular economy principles and circular business models in the textile industry Design4circle (2021). When provided with information, consumers may prefer products with lower emissions footprints, such as those made with low-carbon materials. During the use-phase, consumers can take better care of products by reducing washing and drying. This improvement in behaviour can deliver as much as an 11% abatement in emissions under the accelerated abatement scenario. Consumers also have a role to play in recycling products, which can reduce incineration and landfill (McKinsey, 2022).

Marketing messages which encourage consumption also need to change. Sustainable consumer behaviors could be supported through promoting a preference for sustainable materials, environmentally friendly garment washing and drying methods, garment recycling, rental and repair practices, reuse and sharing options (Niinimäki, 2020).

Cooperation between brands

Brands and value chain stakeholders have an opportunity to work closely and develop equal partnerships, particularly by assessing purchasing practices and incentivizing value chain players on decarbonization activities (McKinsey, 2022). *Samsung* in cooperation with *Patagonia* is releasing a wash cycle and a new filter, which will dramatically shrink microfiber pollution. A new filter that can be added to existing washers and used along with a "Less Microfiber" cycle that Samsung also designed. The combination makes it possible to shrink microfiber pollution by as much as 98% (Fast Company, 2023).

Sustainable fashion index

Sustainable fashion index can help the customer decide on clothing with a lower impact on the environment (Table 4).

Table 4. Sustainable fashion index

Cradle to Cradle Certified	It is a global system of scoring brands for their commitment to the circular economy.
Higg Index	The Higg Index is a suite of tools for the standardized measurement of value chain sustainability, and it is central to the SAC's mission to transform businesses for exponential impact. It is part of the sustainable apparel coalition.
The Fashion Transparency Index	It is an annual review of 250 of the world's largest fashion brands and retailers ranked according to their level of public disclosure on human rights and environmental policies, practices and impacts in their own operations and in their supply chains.
Good on You	It is the world's most comprehensive brand rating system and online discovery platform for fashion. It connects conscious shoppers to fashion retailers globally.
The KnowTheChain	Benchmarks help identify and share leading practices, enabling companies to improve their standards and procedures. The KnowTheChain benchmarks aim to help companies protect the wellbeing of workers by incentivizing companies and identifying gaps in each sector evaluated.

Source: own study.

The new strategies to tackle this issue include developing new business models for clothing rental, designing products in a way that would make reuse and recycling easier (circular fashion), convincing consumers to buy clothes of better quality that last longer (slow fashion) and generally steering consumer behavior towards more sustainable options (EU Parlament, 2019).

A more sustainable model of textile production also has the potential to boost the economy. *"Europe finds itself in an unprecedented health and economic crisis, revealing the fragility of our global supply chains*," said lead MEP Jan Huitemafrom (Renew, the Netherlands. *"Stimulating new innovative business models will in turn create new economic growth and the job opportunities Europe will need to* recover" (Šajn et. al, 2022).

Conclusion

The aim of the article was to highlight ecological and social innovations in the clothing industry. We focused on the new opportunities and challenges that the clothing sector faces with the goal of keeping the global temperature below 1.5 degrees. There are many options for the clothing industry that are more ecological compared to the old approach.

As an example, we state the following in the article: rental, resale and Second-hand model, materials with lower carbon footprint, modular and upcycled fashion, highly durable and circular clothes, new technologies to support sustainable fashion like virtual fashion and gamification. To avoid greenwashing it's important to focus on transparency through technology like blockchain, certifications and ecolabels or sustainable fashion index and educate customers through the campaign and different educational programs. All listed opportunities enabling the clothing industry to transform into a more sustainable model.

Acknowledgement

The paper is a partial output of the VEGA research task no. 1/0398/22 "The current status and perspectives of the development of the market of healthy, environmentally friendly and carbon-neutral products in Slovakia and the European Union" conducted at the University of Economics in Bratislava.

DUT – Driving Urban Transitions. HORIZON – CL5-2021-D2-01-16

KEGA no. 030EU-4/2022 – Integrated environmental quality management in the network of automotive suppliers.

References

Adamkiewicz, J. , Kochańska, E., Adamkiewicz, I., Łukasik, R. M. (2022). Greenwashing and sustainable fashion industry, *Current Opinion in Green and Sustainable Chemistry*, 38, 100710, https://doi.org/10.1016/j.cogsc.-2022.100710

Beton, A., Dias, D., Farrant, L., Gibon, T., Le Guern, Y., Desaxce, M., et al., (2014). *Environmental improvement potential of textiles (IMPRO-Textiles)*. Publications Office of the European Union.

Close the loop. (2023). Guide towards a circular fashion industry – introduction. -https://www.close-the-loop.be-/en/phase/8/retail#tab-19

Commonobjective. (2023). *4 Ways Brands Can Reduce Climate Impact*. https://www.commonobjective.co/ article/can-fashion-stop-climate-change

Design4circle. (2021). *Circular economy in the textile and footwear industry skills and competences for a sector renewal*, https://design4circle.eu/wpcontent/uploads/2021/04/circular%20economy_in_the_textile_and _footwear_industry_skills_competencies_for_sectoral_renewal.,pdf

Ecotextile. (2021). *Modular fashion the next big thing*. https://www.ecotextile.com/2021063028006/features/ modular-fashion-the-next-big-thing-2.htmlň

Ellen MacArthur Foundation. (2017). *Fashion and the circular economy. https://ellenmacarthurfoundation.org/ topics/fashion/overview*

Ellen MacArthur Foundation. (2021a). *Rethinking business models for a thriving fashion industry*, https://ellenmacarthurfoundation.org/fashion-business-models/overview

Ellen Macarthur Foundation. (2017*). A new textile economy: Redesigning fashion´s future*. http://www.ellenmacarthurfoundation.org/publications

Ellen Macarthur Foundation. (2023). *Fashion and the circular economy – deep dive.* https://www.ellenmacarthurfoundation.org/fashion-and-the-circular-economy-deep-dive

Ethicalmadeeasy. (2023). Understanding fashion labels: 10 ethical fashion certifications you need to know. https://ethicalmadeeasy.com/10-ethical-fashion-certifications/

European Parliament. (2021). *The impact of textile production and waste on the environment (infographic)*. https://www.europarl.europa.eu/news/en/headlines/society/20201208STO93327/the-impact-of-textile-production-and-waste-on-the-environment-infographics

European Parliament News. (2021). *The impact of textile production and waste on the environment infographics*. https://www.europarl.europa.eu/news/en/headlines/society/20201208STO93327/the-impact-of-textile-production-and-waste-on-the-environment-infographics

European Commission. (2023a). *Digital Product Passport*. https://hadea.ec.europa.eu/calls-proposals/digital-product-passport_en#description

European Commission. (2023b). *EU strategy for sustainable and circular textiles*

EU Parlament (2019). *Environmental impact of the textile and clothing industry: What consumers need to know. https://www.europarl.europa.eu/thinktank/pl/document/EPRS_BRI(2019)633143*

Fahad. (2019). The Influence of Consumption Values on Green Purchase Intention: A Moderated Mediation of

Fashion Revolution. (2023). *Fashion Transparency Index 2023.* https://www.fashionrevolution.org/

Fast Company. (2023). *Why Patagonia helped Samsung redesign the washing machine.* https://www.fastcompany.com/90904159/why-patagonia-helped-samsung-redesign-the-washing-machine

Filho, L. Perry, Heim, Dinis, Moda, Ebhuoma & Paço. (2022). An overview of the contribution of the textiles sector to climate change. Front. Environ. Sci., *Sec. Toxicology, Pollution and the Environment*, 10. https://doi.org/ 10.3389/fenvs.2022.973102

Ganni. (2023). Ganni repeat. https://www.ganni.com/en-gb/ganni-repeat.html

Genuineway. (2023). *Wear Me 30 Times, let's be sustainable together!* https://genuineway.io/wear-me-30-times-lets-be-sustainable-together/

Gözet, B., Wilts, H., Manshoven, S., & Bakas, I. (2021). Progressing towards waste prevention in Europe – the case of textile waste prevention. Publication Office of the European Union. https://doi.org/10.2800/494502

Gözet, B., & Wilts, H. (2022). *The circular economy as a new narrative for the textile industry: An analysis of the textile value chain with a focus on Germany's transformation to a circular economy* (Zukunftsimpuls no. 23). Wuppertal Institute.

Greenwash Perceptions and Green Trust. *Pakistan Journal of Commerce and Social Sciences*, 13(4), 826-848, https://ssrn.com/abstract=3522451

https://environment.ec.europa.eu/strategy/textiles-strategy_en?fbclid=IwAR21m1VWUV8zyJBve0Xf5NM8uh-d52b_W3M3yYi685OSn2w5b7Hu_Fd5cu70

https://www.mckinsey.com/~/media/mckinsey/industries/retail/our%20insights/fashion%20on%20climate/fashion-on-climate-full-report.pdf

Kant, R., (2012). Textile dyeing industry: An environmental hazard. *Natural Science 4,* Vol. 4, No. 1, 22-26. http://dx.doi.org/10.4236/ns.2012.41004

Kapfunde, M. (2022). Blockchain In Fashion: Is It Ready? https://www.theinterline.com/2022/03/10/blockchain-in-fashion-is-it-ready/

McKinsey. (2022). *Fashion on Climate*.

Niinimäki, K., Peters, G., Dahlbo, H., Perry, P., Rissanen, T., & Gwilt, A. (2020). The environmental price of fast fashion. *Nat. Rev. Earth Environ*, 1(4), 189-200. doi:10.1038/s43017-020-0039-9.

Parker., S. (2022). *The World's Top Cotton Producers.* https://www.visualcapitalist.com/ranked-the-worlds-top-cotton-producers/

RFR. (2023). *How to contribute to Circular Economy.* www.rfittingroom.com/circular-vs-linear-economy

Šajn, N. (2022). Textiles and the environment. European Parliamentary Research Service. BRIEFING. https://www.europarl.europa.eu/RegData/etudes/BRIE/2022/729405/EPRS_BRI(2022)729405_EN.pdf

Shubham A. J. (2022). *Fashion Industry and Its Key Sectors.* https://textilelearner.net/key-sectors-of-fashion-industry/

Statista. (2023). *Global apparel market – statistics & facts.* https://www.statista.com/topics/5091/apparel-market-worldwide/#statisticChapter

Statista. (2023a). *Revenue share of the sustainable apparel market worldwide from 2013 to 2026* https://-www.statista.com/forecasts/1307848/worldwide-sales-of-sustainable-clothing -items

Statista. (2023b). *Apparel and clothing market Europe – statistics and facts* https://www.statista.com/topics/3423/clothing-and-apparel-market-in-europe/#topicOverview

Textileindustry. (2023). *Difference between Textile and Apparel*. https://www.textileindustry.net/difference-between-textile-and-apparel/

Textile Exchange. (2021). *2025 Recycled Polyester Challenge was designed to accelerate change.* http://textile-exchange.org/2025-recycled-polyester-challenge/

UN Environment Programme. (2023b). *Putting the brakes on fast fashion.* https://www.unep.org/news-and-stories/story/putting-brakes-fast-fashion

WGSN. (2021). *10 key trends 2021 and beyond.* https://www.wgsn.com/en/wgsn/press/press-releases/wgsn-reveals-10-key-trends-2021 and-beyond

World resources institute. (2019). *Numbers economic social and environmental impact fast fashion*. https://-www.wri.org/insights/numbers-economic-social-and-environmental-impacts-fast-fashion

METAL NANOPARTICLES AS A COMPONENT OF NANOCOMPOSITES USED FOR PACKAGING MATERIALS

Ryszard Cierpiszewski, Wojciech Kozak

Department of Industrial Products and Packaging Quality, Institute of Quality Science,
Poznań University of Economics and Business, Poznań, Poland
**Corresponding Author e-mail: r.cierpiszewski@ue.poznan.pl; w.kozak@ue.poznan.pl*

DOI: 10.56091/CTQS.Innov-3

Abstract

The paper presents the possibilities and current trends of using various metal nanoparticles and their oxides to produce packaging materials intended for food. The information presented was collected based on a review of the latest literature on the use of nanoparticles in packaging materials. Introducing a nanofiller into a polymer changes its mechanical, barrier, and optical properties. Both synthetic and natural polymers are used to obtain nanocomposites. In many cases, the resulting packaging material also has antimicrobial and antioxidative properties. They depend not only on the type of metal but also on the degree of its fragmentation and the shape of the particles. Fascinating is using such nanocomposites as elements of active packaging to meet consumer preferences and economic changes. The subsections present the application possibilities of materials containing particular types of metal nanoparticles and their derivatives. As with all novel solutions, nano-composites are promising packaging materials with many advantages, but they also have some disadvantages, as mentioned in the conclusions.

Keywords: nanocomposites, metal nanoparticles, metal oxide nanoparticles, active packaging

Introduction

The International Organisation for Standardisation defines a nanomaterial as a material with any external dimensions or having an internal or surface structure in the nanoscale. "Nanoscale" refers to the size range from approximately 1 nm to 100 nm (COMMISSION RECOMMENDATION, 2011). Nanotechnology enables the production of materials with properties changed compared to their traditional counterparts. It causes great interest in such materials and numerous studies in this direction (Arshad et al., 2023).

Chadha et al., (2023) proposed using nanoparticles in packaging in two parts:

1. Improving the packaging's mechanical, thermal, and barrier properties.
2. Influencing the conditions inside packaging by adsorbing or emitting selected chemical compounds. This action helps maintain the quality of products.

Some authors add additional functions: to inform consumers about changes in the condition of the packaging (Baysal et al., 2023).

An interesting direction in packaging development is using nanocomposites to produce materials with antimicrobial properties as elements of active packaging (Cierpiszewski, 2016). To produce active packaging with antimicrobial properties, materials containing organically modified nano kaolins, natural biopolymers (e.g., chitosan), natural antimicrobial substances (e.g., nisin, thymol), enzymes (e.g., peroxidase), nanotubes and synthetic antimicrobial substances (EDTA, benzoic acid) and various combinations of the mentioned substances are used (Rim et al., 2013; Dobrucka & Przekop, 2019; Barage et al., 2023; Adeyeye & Ashaolu, 2021). Composites containing metal nanoparticles or their oxides are also important (Bikiaris & Triantafyllidis, 2013; Priyadarshi et al., 2022, Anjum et al., 2023, Dash et al., 2022).

In addition to the physicochemical properties and possibilities of using the obtained materials to produce packaging, their possible impact on human health is also essential (Onyeaka et al., 2022; Stuparu-Cretu et al., 2023; Jaswal & Gupta, in press). Therefore, the possibilities of nanoparticle migration from packaging material are being investigated (Souza & Fernando, 2016; Paidariet et al., 2021, Ćwiek-Ludwicka & Ludwicki, 2017). Legal regulations and consumer perception of nanomaterials are essential in this respect (Jurewicz, 2017; Suwała & Pietruszka, 2017; Przybyłowski, Chomaniuk & Reszka; 2016).

The aim of the work was to discuss the proposal of using nanoparticles of selected metals for the production of food packaging materials. The metals most frequently used and proposed for the production of nanocomposites were selected and described.

Silver nanoparticles

Among the metals in the form of nanoparticles, silver nanoparticles are one of the most beneficial forms of heavy metals in nanotechnology applications (Islam, Jacob & Antunes, 2021), whose antimicrobial properties have been known since ancient times. Silver has many advantages over other antimicrobials; primarily, it has a wide range of action and can be stored for an extended period. An additional advantage of this element is the ease of its introduction into many materials (Echegoyen, 2015; Brandelli et al., 2017; Duncan, 2011).

However, no information exists on the development of resistance of microorganisms exposed to silver nanoparticles (Kędziora & Sobik, 2013). Appropriate regulations regulate the use of silver in the EU (EFSA, 2011) and USA (USFDA, 2014), but caution is still advised due to the lack of conclusive research on the toxicity of such materials (Carbone et al., 2016). The use of silver nanoparticles in consumer products is increasing daily due to their antibacterial properties. Many scientific papers and review articles have been published on the applications and synthesis of silver nanoparticles, but there are few publications on the toxicity of silver nanoparticles. Many questions need to be answered, e.g., which form of silver causes more significant toxicity: silver nanoparticles or ionic silver? (Jaswal & Gupta, in press).

In connection with the proposals to use nanocomposites containing nanosilver for food packaging, the migration of this metal into the packaged product was also tested; the migration of silver onto the surface of chicken meat packed in packaging made of plasticized poly(vinyl chloride) reached the level of 0.03-8.4 mg/kg. It depended on storage time and temperature (Cushen et al., 2014). In another work, the migration of silver from polyethylene bags containing nanosilver to water, acid, alcohol, and fat was investigated. It turned out that silver migrates to all the tested simulants, and the amount of migration also depends on the temperature and storage time. It was observed that the size of the migrating nanosilver is less than 300 nm, a dimension that is dangerous to organisms' safety. (Huang, 2011). Conversely, Rodewald's disertation (2013) shows that the specific migration of silver is much lower (<0,1 μg/cm^3) than the permissible values specified in the relevant regulations. Similar to Marrez et al.,(2020) and Mohammadalinejhad et al., (2021), papers concluded that the migration of silver is less than normative limits. The EFSA Panel on Food Contact Materials, Enzymes, and Processing Aids (CEP) assessed the safety of adding silver nanoparticles to plastics. The work shows that silver nanoparticles remain embedded in the polymer under the tested conditions of use and do not migrate. The migration of silver in soluble ionic form reaches up to 6 μg/kg. It is lower than the group limit of 50 μg silver/kg food proposed by the AFC Panel 2004. However, the Panel noted that exposure to silver from other dietary sources may exceed recommended levels (EFSA, 2021).

Generally, the synthesis of silver nanoparticles (AgNPs) is classified into three main categories: chemical, physical, and biological methods, with each category determined by the nature of the preparation method (Ali et al., 2021).

The antimicrobial effectiveness of silver nanoparticles is influenced not only by their size but also by their shape. In the study of the antibacterial properties of hydroxypropyl methylcellulose films containing silver nanoparticles with diameters of 41 and 100 nm against *Escherichia coli* and *Staphylococcus aureus*, the results indicate that silver nanoparticles with a diameter of 41 nm have better antimicrobial properties (Moura et al., 2012). Sadeghi et al., (2012) demonstrated better anti-microbial properties of plate-shaped silver particles than other shapes.

The distribution of nanoparticles in the polymer matrix also influences the antimicrobial properties of the obtained materials. It has been shown that evenly distributed smaller-sized silver particles have better antimicrobial effectiveness than large-sized silver particles, even at higher contents (Rodewald, 2013).

In the paper of Jo et al., (2018), the bactericidal effect of silver nanoparticles introduced into polyethylene (LDPE) and polypropylene (PP) foil was assessed. The LDPE-based nanocomposite film had strength comparable to commercial LDPE, but its stiffness was higher at high Ag concentrations. The Ag/PP nanocomposite film showed better mechanical properties than commercial PP. Both tested films were effective against *Escherichia coli* and *Staphylococcus aureus*, causing a 99.9% reduction in viable bacteria. The results indicate that the materials obtained may be used to develop antibacterial food packaging.

The addition of nanosilver to other polymers, e.g., cellulose acetate, polylactic acid (PLA), or polyvinyl alcohol (PVA), has also been studied. It was found that films based on cellulose acetate and nanosilver exhibited strong antibacterial activity (Marrez et al., 2020). Other tested composites were obtained by introducing natural polymer fibers of cellulose, chitosan, and lignocellulose containing silver nanoparticles into a poly(lactic acid) matrix. It was noticed that all obtained films with the addition of nanosilver-containing fibers showed antimicrobial activity against food-borne pathogens (Mohammadalinejhad et al., 2021).

AgNPs have recently been integrated into various biopolymers (such as starch, chitosan, and cellulose) to create antimicrobial food packaging materials. In this paper, a novel antioxidant, antibacterial, and biodegradable food packaging film was elaborated by incorporating natural kaolin clay (KC) and *Ficus carica*-mediated silver nanoparticles (AgNPs) into Chitosan (Cht). All the films were tested for their ability to keep the freshness of apple slices as wrapping material for the packaging properties. The films exhibited good results, and the Cht/KC/AgNPs showed promising performance regarding the apple slices' moisture loss, browning index, total phenolic compound, and antioxidant activity. Moreover, the Cht/KC/AgNPs film exhibited a migration of silver, meeting the standards set by EFSA and ECHA, which makes this film safe for food packaging (Mouzahim, 2023).

Nanosilver and lauryl oil were distributed in chitosan. The obtained material was spread on polyethylene foil. The films produced were characterized by good antimicrobial activity, and their use for packaging pork allowed them to maintain their quality at an appropriate level for 15 days (Wu et al., 2019).

Sahu et al., (2021) used an ionic liquid to produce composite films based on poly(vinyl alcohol) (PVA), graphene oxide (GO), and silver nanoparticles. It was found that the presence of the ionic liquid increases the dispersion of nanofillers in the poly(vinyl alcohol) matrix and improves its mechanical and thermal properties. Tests of the antibacterial activity of these films against *E. coli* and *S. aureus* showed better performance of PVA/Ag/GO-IL films compared to PVA/Ag/GO and PVA/Ag films.

In Yaqoo's paper, biocomposite films with remarkable antioxidant and antimicrobial properties were synthesized by incorporating biosynthesized silver nanoparticles and grapefruit skin extract into a polyvinyl alcohol matrix. The composite films exhibited antioxidant potential and antimicrobial activity in response to foodborne pathogens. The results showed that the synthesized composite films have great potential as a low-cost, greener substitute for conventional materials for food packaging, confirming packaged foods' safety and economic viability (Yaqoob et al., 2023).

Recently, silver nanoparticles obtained using phytochemical methods for food have gained enormous popularity in packaging materials. Their popularity is due not only to their active functions but also to their profitability and environmental friendliness (Ali et al., 2023).

Other materials containing silver nanoparticles that were synthesized and characterized were nanocomposites based on poly(3-hydroxybutyrate-co-3-hydroxyvalerate). The antimicrobial activity of this nanocomposite against *Salmonella enterica* and *Listeria monocytogenes* was intense, and the antimicrobial activity was maintained even after seven months (Castro-Mayorga, 2016).

Titanium dioxide

Titanium(IV) dioxide is one of the most frequently produced nanomaterials in the world. This compound is generally considered harmless and indifferent to human health, but studies indicate the potentially harmful effects of TiO_2 in the form of nanoparticles (Gruszka et al., 2019). However, its toxicity is much lower than that of other metals, which have antimicrobial properties and occur in nanoparticles (Kahru & Dubourguier, 2010). On the other hand, according to EU legislation, nanoparticles TiO_2 are not authorized for use in plastic food-contact materials (Ćwiek-Ludwicka & Ludwicki, 2017).

Since TiO_2 is a photocatalyst, antimicrobial materials based on this compound are active only in the presence of UV radiation. In this case, TiO_2 nanoparticles are an effective agent against many food pathogens, e.g., *Salmonella choleraesuis subsp*., *Vibrio parahaemolyticus* and *Listeria monocytogenes bacteria* (Kim et al., 2003). TiO_2 nanoparticles are used in preparations for disinfecting various surfaces, surgical tools, catheters, etc. (Kosmala & Szymańska, 2016).

From the packaging point of view, TiO_2 nanoparticles, after being incorporated into the polymer matrix, give the resulting material several interesting properties, e.g., photocatalytic activity, better mechanical, thermal, and physical strength, and high antimicrobial activity (Duncan, 2011).

Both natural polymers (e.g., chitosan, starch, and poly(lactic acid) (PLA)) and synthetic polymers (e.g., HDPE) are used as materials for the production of TiO_2 nanocomposites (Ivask et al., 2012).

An example of a nanocomposite of natural origin is a foil made of whey protein and cellulose nanofiber containing titanium dioxide particles and rosemary oil. It was found that the proposed material significantly reduced the growth of microorganisms, lipid oxidation, and lipolysis of lamb meat during storage and allowed the shelf life to be extended from approximately 6 to 15 days (Alizadeh-Sani et al., 2017). Another example of a nanocomposite based on materials of natural origin is a carboxy-methylcellulose film modified with gelatin and TiO_2-Ag nanoparticles. The research results showed that TiO_2-Ag nanoparticles at low concentrations increased the film's tensile strength and reduced its elongation at break (Farshchia et al., 2019). In the work of Peter et al., (2021), poly(lactic acid) films containing Ag and TiO_2 nanoparticles were obtained by extrusion. It turned out that after adding nanoparticles, the mechanical strength of the film increased by 30%, and the water vapor permeability decreased by 11-27%, depending on the weight content of the nanofiller. Oxygen permeability decreased by 24.6% for the foil containing 3% nanoparticles compared to pure PLA. Nanocomposites containing 0.5% and 3% of nanoparticles exhibited the highest antibacterial activity. Another material of natural origin used to obtain nanocomposites is chitosan.

Menezes et al., (2023) develop and characterize biopolymeric films of chitosan and cassava starch with the addition of titanium dioxide (TiO_2) nanoparticles for use as food packaging. The results indicate that the properties of films related to water (permeability, solubility, and water sorption) and mechanical (tension, elongation, and Young's modulus) are strongly influenced by the characteristics of the biopolymers used and can be improved with the introduction of TiO_2. The water sorption was reduced by adding TiO_2, making the film more hydrophobic and exhibiting higher tensile strength and elongation.

In the paper of Lan et al., (2021), a film made of this material containing TiO_2 nanoparticles and red apple pomace extract was tested. The addition of TiO_2 in nano form significantly improved the barrier properties of the foil against water vapor and UV-Vis radiation. Also, it improved the mechanical strength and thermal stability of the foil. The obtained material had excellent antioxidant and antibacterial properties and was sensitive to pH changes. Another example of using chitosan is a foil made of chitosan and poly(ethylene oxide) with Ag/TiO_2 nanoparticles. The obtained results show that increasing the content of Ag and TiO_2 nanoparticles increases dielectric properties, electrical conductivity, and antimicrobial activity (Abutalib & Rajeh, 2021).

Nanocomposites based on poly(vinyl alcohol) were also tested. A film based on poly(vinyl alcohol) and gelatin containing ZnO and TiO_2 nanoparticles and their mixture deposited on zeolite was tested. It has been noted that such material can release antimicrobial compounds in a controlled manner (Azizi-Lalabadia et al., 2019).

Synthetic polymers used to obtain nanocomposites with nano TiO_2 include polyethylene and polyurethane. Two titanium dioxide minerals (anatase and rutile) were introduced into low-density polyethylene, and then their ability to deactivate *Pseudomonas spp. and Rhodotorula mucilaginosa* was tested. In contact with these materials, the number of colonies of cultured bacteria decreased significantly. In an in vivo test conducted on pears packed in the tested foils and stored at 5°C for 17 days, the number of mesophilic bacteria and yeasts decreased significantly compared to samples stored in LDPE foil. The best effect was obtained when the LDPE nanocomposite film was irradiated with UVA radiation (Bodaghi et al., 2013). Nanocomposites obtained by introducing TiO_2 nanoparticles into polyurethane (Athir et al., 2020) and introducing a nano TiO_2/Ag^+ mixture into poly(vinyl chloride) were also tested. Effective antibacterial activity also characterized such materials (Cheng et al., 2006).

The application of TiO_2 can also impart ethylene scavenging activity to the active film, which is essential to extend the shelf life of fruits after harvest. The negligible migration of TiO2 from the composite film to food makes it safe for use in food packaging applications (Zhang & Rhim, 2022).

Phothisarattana et al., (2021) also showed that incorporating TiO_2 into biodegradable films extends banana shelf life because of ethylene scavenging activity.

When introducing nanoparticles into the packaging material, attention should be paid to the possibility of their migration, which may cause sensory changes in the packaged food, e.g., TiO_2 facilitating the oxidation of lipids in the cell membrane may cause rancidity of fats contained in food.

However, the tests did not confirm these concerns in the case of cheese packed in polyethylene bags with the addition of TiO_2. However, unacceptable sensory properties were recorded much earlier in samples of cheese packed in bags made of pure polyethylene (Nicula et al., 2012).

Close et al., (2015) studied oxygen scavenging at room temperature using a titanium oxide nanotube. The obtained titanium oxide nanotube exhibited oxygen uptake rates up to three orders higher than commercially available iron-based scavengers. The results show that the studied scavengers work at their best in dry conditions, making them particularly suitable for applications that require a dry environment (e.g., pharmaceuticals and nutraceuticals). Increasing the RH in the headspace gradually reduced its capacity and oxygen uptake rate (Tulsyan et al., 2017).

Gold nanoparticles

Like other metal nanoparticles, gold also has properties that can be practically used in packaging. Of particular importance are solutions involving the incorporation of gold nanoparticles (AuNPs) into the structure of polymers, creating active composites that fulfill various functions. Due to their properties, such materials may be useful primarily for food packaging.

Firstly, gold nanoparticles, like silver, shows antimicrobial and antioxidant properties. An example of it can be a composite film of AuNPs and graphene oxide built into PVA (poly(vinyl alcohol)). This material shows antimicrobial activity against *Escherichia coli* for extending shelf life of banana. The addition of glyoxal as a binding agent to this composite increases its antimicrobial effect. (Paidari & Ibrahim, 2021; Hayat, 2012). In turn, composite based on AuNPs conjugated with gallic acid (GA-AuNPs) can effectively help in reduction of oxidative and physiological degradation of food products (Chowdhury et al., 2020).

Another study 3-aminopropyltrimethoxysilane in the chitosan/gold nanoparticles combination was investigated. It showed enhanced activity against *Salmonella* as an effect of synergistic antimicrobial impact of its components (Virgili et al., 2021). Whereas active biofilms based on quinoa starch-containing AuNPs showed antimicrobial effect against *Escherichia coli* and *Staphylococcus aureus* (Pagno et al., 2015). It also showed increased UV radiation absorption and a decreased water solubility which is important for packaging materials. Additional effect observed are better barrier properties, especially to oxygen.

An interesting application of gold nanoparticles seems to be biosensors, which are promising in food contamination monitoring (e.g., heavy metals) (Chen et al., 2018; Dobrucka, Długaszewska & Kaczmarek, 2019).

Zinc oxide

Zinc oxide is a widely used chemical compound with antibacterial, antifungal, anticorrosive, and UV-blocking properties at the nanoscale (Ivask et al., 2012). It is listed as generally recognized as safe by the United States Food and Drug Administration (FDA) (Lee, Kwon & Cho, 2023). According to EU regulation (EU No 2016/1416) nano zinc oxide can be use in unplasticized polymers (Ćwiek-Ludwicka & Ludwicki, 2017).

Zinc oxide has been introduced into various materials, e.g., paper, chitosan, low-density polyethylene (LDPE), polypropylene (PP), and polyurethane (PU) (Espitia et al., 2012). Applying ZnO nanoparticles to paper causes the obtained material to have antimicrobial activity against *E. coli*, and UV radiation contributes to the increase in the antibacterial activity of ZnO nanoparticles. Other parameters affecting its activity are the exposure time to UV and the interaction time of bacteria with ZnO nanoparticles (Ghule et al., 2006).

Poly(lactic acid) enriched with cellulose acetate nanocrystals was also used as a matrix for nano-composites with zinc oxide nanoparticles. It turned out that the obtained foils, compared to pure PLA, provided better protection against UV radiation, had higher mechanical strength, and constituted a better barrier against oxygen and water vapor. The obtained composite also had excellent antibacterial activity against *Escherichia coli* and *Staphylococcus aureus* (Yu et al., 2021). Similar tests were carried out using polyurethane foil. Also, in this case, it turned out that after the introduction of zinc oxide nanoparticles, the mechanical properties of the foil were significantly improved (Espita et al., 2012). Foils made of polyurethane, chitosan, and zinc oxide nanoparticles have also been proposed for food packaging. The introduction of zinc oxide nanoparticles improved the foil's antibacterial, barrier, and hydrophobic properties. The obtained foil was used to pack carrot pieces, extending the vegetable's storage period to 9 days. When stored in air and PE foil packaging, carrots were of acceptable quality for 3 days (Saral Sarojini et al., 2019).

The results obtained by Berrabah et al., (2023) showed that the incorporation of ZnO-NPs to poly(3-hydroxybutyrate-co-3-hydroxyhexanoate) at 3 wt% leads to higher crystallinity, improved mechanical properties and antimicrobial activity, compared with neat polymer and other bionanocomposites.

A novel composite film was prepared using a solution casting method using hydroxyethyl cellulose, carboxymethyl chitosan (CMCS), and zinc oxide nanoparticles as raw materials. The addition of CMCS and ZnO enhanced the composite film's solvent resistance and UV shielding ability. In addition, the synergistic effect of CMCS and ZnO helped the composite film efficiently inhibit the pathogenic bacteria Listeria monocytogenes and Pseudomonas in food (Cen et al., 2023).

Copper and copper oxide

Copper and copper oxide nanoparticles are two other types of nanoparticles proposed in the scientific literature for use in packaging. However, EU legislation does not authorize these substances in food packaging. The interest in copper or copper oxide use results from their antimicrobial activity, limiting the growth of bacteria, viruses, and fungi (Kuswandi & Moradi, 2019). Various polymers, both synthetic and natural, were used as matrices for the production of nanocomposites. In the work of Longano et al., (2012), copper nanoparticles were introduced into poly(lactic acid), which allowed combining the antibacterial properties against *Pseudomonas spp*. of Cu nanoparticles with the biodegradability of the polymer matrix. Conte et al., (2013) investigated the possibility of using PLA foil with copper nanoparticles for cheese packaging. The in vivo and in vitro tests confirmed this material's excellent properties as food packaging. However, due to copper's susceptibility to oxidation under atmospheric conditions, the use of copper nanoparticles is limited (Gawande et al., 2016). This problem does not occur with nano copper oxide.

Moreover, copper oxide (CuO) is cheaper, readily miscible with polymers, chemically and physically stable, and highly ionic (Gawande et al., 2016; Ren et al., 2009). Barabaszová et al., (2020) studied the influence of copper oxide nanoparticles and vermiculite(V) nanoparticles introduced into poly(vinyl acetate) on the properties of the resulting nanocomposite. The effect of the obtained material against *Staphylococcus aureus* and *Enterococcus faecalis* was checked. The results showed that the content of 0.1% by weight nano CuO (and CuO/V) in the PVA matrix produces an antibacterial surface against *Staphylococcus aureus* (Barabaszová et al., 2020). Bikiaris and Triantafyllidis (2013) proved that nanocomposites composed of high-density polyethylene and copper nanofibers have improved mechanical properties, better oxygen barrier, and stronger antimicrobial properties than the starting polymer. The degree of improvement in these properties depended on the content of copper nanofibers, and the best parameters were achieved with their content at 2.5 and 5.0%. This material has been proposed for use in food packaging.

Blending poly(butylene adipate-co-terephthalate) (PBAT) with thermoplastic starch (TPS) was investigated for cost reduction and better biodegradability. However, the film blend showed poor thermal, mechanical, and barrier properties. The hydrophilicity of TPS significantly reduced the oxygen permeability of pristine PBAT, while low CuONP concentrations promoted the gas diffusion rate. The bionanocomposite film showed effective antibacterial activity against *Escherichia coli* (Bumbudsanpharoke et al., 2023).

Iron nanoparticles

Iron as a metal has been used in packaging for years. It is the basis for the production of metal cans for canned food and glass packaging closures (e.g., crown closures).

The use of iron nanoparticles opens up completely new possibilities for modern packaging Iron (FeNPs) and iron oxide nanoparticles (FeONPs) shows various interesting properties. Foltynowicz (2018) discussed the safety of using composite oxygen scavengers based on nanoiron. In the study of the specific migration from composite oxygen scavengers based on nanoiron performed by Hamilton Co., the nanoiron contained in the cross-linked silicone matrix did not migrate to the test fluid. The study of the specific migration from composites oxygen scavengers based on nanoiron performed by Hamilton Co. did not reveal any migration of the nanoiron contained in the cross-linked silicone matrix to the test fluid that imitated the food products, including fats. According to EU legislation EFSA, iron nanoparticles modified bentonite and kaolinite are authorized as oxygen absorber, for use in active food contact materials (EFSA, 2013a; EFSA, 2013b).

Firstly it can be used as an efficient antimicrobial agent to minimize the influence of microorganisms on food during processing or storage (Mary & Jayavel, 2022). In this case iron nanoparticles can be used as antimicrobial coatings on the inner surface of the packaging (Ligaj et al., 2020). An example of such material can be composite of polydopamine with iron oxide nanoparticles conjugated with nisin. This material can reduce the presence of *Alicyclobacillus acidoterrestris* bacteria, which causes problems in the food processing (Song et al., 2019).

Nano iron particles can also be used to improve barrier properties of polymer based packaging materials. This is very important for shelf life of packed food. The nanoparticles are incorporated into the packaging film as mono- or multilayer (Viela et al., 2018; Busolo & Lagaron, 2012). An example of it can be bentonite and kaolinite modified with nano iron.

Other interesting application of nano iron is its use as oxygen scavenging agent. As it appeared, nano iron, in opposite to normal iron, reacts with oxygen under non-humid conditions (Foltynowicz et al., 2017). An example of nano iron based oxygen scavenging materials which have promising sorption properties are polypropylene nanocomposites containing montmorillonite (Khalaj et al., 2016). In turn, nano iron with kaolinite contained in composites reacts and removes oxygen and additionally makes a passive barrier slowing down gas diffusion (Busolo & Lagaron, 2012).

Conclusions

The metals and their oxide nanoparticles presented above are proposed for use in the production of packaging materials. In addition to meet technical requirements, they must fulfill current legal requirements and requirements that may appear in the future. The European Commission published its ambitious agenda for chemicals regulations in the European Green Deal in 2020 and the Plastics Strategy to reach the target of building a more sustainable, climate-neutral, and circular economy by 2050. Packaging using nanoparticles has many advantages, e.g., they extend the shelf life of food and improve the physicochemical properties of the packaging. On the other hand, there are concerns about the safety of these materials because the ability to evolve in response to external stimuli may pose additional risks to human health and the environment. How to measure the sustainability of nanomaterials and products needs to be determined. Conducting LCA studies as early in the development process as possible is critical to understanding the benefits and negative consequences (Gottardo et al., 2021). The EC's plastics strategy assumes that "all aging plastic packaging will be reusable or recyclable by 2030." There has yet to be a real industrial method for recycling, e.g., nanobiocomposites for packaging, even if they suit it. It can be assumed that similar problems will apply to packaging materials containing metal nanoparticles (Foltynowicz, 2020).

Using metal nanoparticles and their oxides as active components of polymer composites has many advantages, allowing the improvement of various properties of packaging materials. Firstly, the barrier properties, thermal stability, strength, and durability of packaging materials can be improved, expanding the areas of application and contributing to extending the shelf life of packaged products (Shukla et al., 2019). The second promising area of the use of nanoparticles is the possibility of obtaining unique features of packaging materials, allowing their use as active packaging (having antibacterial, antioxidative, and UV absorption properties) and smart/intelligent packaging (monitoring/controlling food conditions and actual state) (Promozic et al., 2021). Both synthetic polymers and biopolymers can be used as matrices for these composites. The latter is particularly desirable in the green/circular economy era.

In some cases, obtained composite materials can absorb unfavorable substances from the quality point of view of food products (e.g., oxygen, ethylene). In turn, using materials with such functions in the production of packaging may contribute to slowing down the processes of food spoilage, extending its shelf life, and, consequently, reducing food losses/waste, which is also part of the sustainable development strategy. Nanoparticles such as silver, gold, copper and its oxides, titanium oxide, zinc oxide, and iron and its oxides are most often used to achieve the effects mentioned above.

As the main drawback of the use of nanoparticles in packaging materials, first of all, the risk of the potential toxicity of such materials is mentioned. The area-to-surface ratio is considered the reason for potential toxicity. It makes the nanoparticles utterly different from their original forms, posing a risk when migrating from the packaging into the food and the consumer body (Quadri et al., 2018). Nanoparticles toxicity varies depending on their type, concentration, exposure duration, and individual organism susceptibility (Dimitrijevic et al., 2015). On the other hand, sufficient data on nanoparticles' toxicity and hazardous effects still needs to be available. Lately, research is being carried out on the migration of nanoparticles into food products, and most of these studies are focused on silver nanoparticle migration (Bumbudsanpharoke & Ko, 2015).

Nonetheless, it should be assured during the production process that nanoparticles are properly embedded into the polymer matrix of future composite packaging material., It is essential to conduct studies on the migration level, toxicity, and interaction between nanoparticles and the polymer before fabricating any packaging material intended for direct contact with food.

References

Abutalib, M.M., Rajeh, A. (2021). Enhanced structural, electrical, mechanical properties and antibacterial activity of Cs/PEO doped mixed nanoparticles (Ag/TiO2) for food packaging applications. Polymer Testing, 93, 107013.

Adeyeye, S.A.O., Ashaolu, T.J. (2021). Applications of nano-materials in food packaging: A review, Journal of Process Engineering, 44, 7, e13708.

Ali, S., Chen X., Ahmad, S., Shah, W., Shafique, M., Chaubey, P., Mustafa, G., Alrashidi, A., Alharthi, S. (2023). Advancements and challenges in phytochemical-mediated silver nanoparticles for food packaging: Recent review (2021-2023), Trends in Food Science & Technology, 141, 104197.

Ali, S., Sharma, A. S., Ahmad, W., Zareef, M., Hassan, M. M., Viswadevarayalu, A., et al., (2021). Noble metals based bimetallic and trimetallic nanoparticles: Controlled synthesis, antimicrobial and anticancer applications. Critical Reviews in Analytical Chemistry, 51, 454-481.

Alizadeh-Sani, M., Mohammadian, E., McClements D. J. (2020). Eco-friendly active packaging consisting of nanostructured biopolymer matrix reinforced with TiO2 and essential oil: Application for preservation of refrigerated meat. Food Chemistry, 322, 126782.

Anjum, A., Garg, R., Kashif, M., Eddy, N.O. (2023). Nano-scale innovations in packaging: Properties, types, and applications of nanomaterials for the future, Food Chemistry Advances 3, 100560.

Arshad, F., Deliorman, M., Sukumar, P., Qasaimeh, M. A., Olarve, J. S., Santos, G. N., et al., (2023). Recent developments and applications of nanomaterial-based lab-on-achip devices for sustainable agri-food industries. Trends in Food Science & Technology, 136, 145-158.

Athir, N., Shah, S.A.A., Shehzad, F.K., Cheng, J., Zhang, J., Shi, L. (2020). Rutile TiO2 integrated zwitterion polyurethane composite films as an efficient photostable food packaging material, Reactive and Functional Polymers 157, 104733.

Azizi-Lalabadi, M.A., Ehsani, A., Ghanbarzadeh, B., Divband, B. (2020). Polyvinyl alcohol/gelatin nanocomposite containing ZnO, TiO2 or ZnO/TiO2 nanoparticles doped on 4A zeolite: Microbial and sensory qualities of packaged white shrimp during refrigeration. International Journal of Food Microbiology, 312, 108375.

Barabaszová, K.Č.,·Holešová, S., Bílý, M., Hundáková, M. (2020). CuO and CuO/Vermiculite Based Nanoparticles in Antibacterial PVAc Nanocomposites. Journal of Inorganic and Organometallic Polymers and Materials, 30, 4218-4227.

Barage S., Lakkakula J., Sharma A., Roy A., Alghamdi S., Almehmadi M., Hossain J., Allahyani M., Abdulaziz O. (2022). Nanomaterial in Food Packaging: A Comprehensive Review, Journal of Nanomaterials, Volume 2022, Article ID 6053922.

Baysal, G., Demirci, C., & Ozpinar, H. (2023). Properties and synthesis of biosilver nanofilms for antimicrobial food packaging. Polymers, 15, 689.

Berrabah I., Dehouche N., Kaci M., Bruzaud S., Delaite Ch., Deguines C.H., Bououdina M., (2023).

A bionanocomposite of poly(3-hydroxybutyrate-co-3-hydroxyhexanoate)/ZnO-nanoparticles intended for food packaging. International Journal of Biological Macromolecules, 238, 124162

Bikiaris, D.N., Triantafyllidis, K.S. (2013). HDPE/Cu-Nanofiber Nanocomposites with Enhanced Antibacterial and Oxygen Barrier Properties Appropriate for Food Packaging Applications. Materials Letters, 93, 1-4.

Bodaghi, H., Mostofi, Y., Oromiehie, A., Zamani, Z., Ghanbarzadeh, B., Costa, C., Del Nobile, M.A. (2013). Evaluation of the photocatalytic antimicrobial effects of a TiO2 nanocomposite food packaging film by in vitro and in vivo tests. LWT-Food Science and Technology, 50, 702-706.

Brandelli, A., Ritter, A.C., Veras, F.F. (2017). Antimicrobial Activities of Metal Nanoparticles. M. Rai, R. Shegokar (eds.), Metal Nanoparticles in Pharma, Springer International Publishing AG.

Bumbudsanpharoke, N., Harnkarnsujarit, N., Ko, S. (2023)., Enhanced properties of PBAT/TPS biopolymer blend with CuO nanoparticles for promising active packaging. Food Packaging and Shel,f 37, 101072.

Busolo, M. A., & Lagaron, J. M. (2012). Oxygen scavenging polyolefin nanocomposite films containing an iron modified kaolinite of interest in active food packaging applications. Innovative Food Science & Emerging Technologies, 16, 211-217. https://doi.org/10.1016/j.ifset.2012.06.008

Carbone, M., Donia, D.T., Sabbatella, G., Antiochia, R. (2016). Silver nanoparticles in polymeric matrices for fresh food packaging. Journal of King Saud University – Science, 28(4), 273-279.

Castro-Mayorga, J.L., Fabra, M.J., Lagaron, J.M. (2016). Stabilized nanosilver based antimicrobial poly(3-hydroxybutyrate-co-3- hydroxyvalerate) nanocomposites of interest in active food packaging. Innovative Food Science & Emerging Technologies, 33, 524-533.

Cen C., Wang F., Wang Y., Li H., Fu L., Li Y., Chen J., Wang Y. (2023). Design and characterization of an antibacterial film composited by hydroxyethyl cellulose (HEC), carboxymethyl chitosan (CMCS), and nano ZnO for food packaging. International Journal of Biological Macromolecules 231, 123203.

Chadha U., Bhardwaj P., Selvaraj S.K., Arasu K., Praveena S., Pavan A., Khanna M., Singh P., Singh S., Chakravorty A., Badoni B., Banavoth M., Sonar P., and Paramasivam, V. (2022). Current Trends and Future Perspectives of Nanomaterials in Food Packaging Application, Journal of Nanomaterials, Volume 2022, Article ID 2745416.

Chen, H., Zhou, K., & Zhao, G. (2018). Gold nanoparticles: From synthesis, properties to their potential application as colorimetric sensors in food safety screening. Trends in Food Science & Technology, 78, 83-94. https://doi.org/10.1016/j.tifs.2018.05.027.

Cheng, Q, Li C, Pavlinek, V., Saha, P., Wang, H. (2006). Surface-modified antibacterial TiO2/Ag+ nanoparticles: preparation and properties. Applied Surface Science, 252, 4154-4160.

Chowdhury, S.; Teoh, Y.L.; Ong, K.M.; Zaidi, N.S.R.; Mah, S.-K. (2020). Poly(vinyl) alcohol crosslinked composite packaging film containing gold nanoparticles on shelf life extension of banana. Food Packaging Shelf Life, 24, 100463.

Cierpiszewski, R. (2016). Opakowania aktywne I inteligentne. Poznań, Wydawnictwo UEP.

Close, T., Tulsyan, G., Diaz, C.A., Weinstein, S.J., Richter, Ch. (2015). Reversible oxygen scavenging at room temperature using electrochemically reduced titanium oxide nanotubes. Nature Nanotechnology, 10, 418-422.

COMMISSION RECOMMENDATION of 18 October 2011 on the definition of nanomaterial (Text with EEA relevance) (2011/696/EU).

Conte, A., Longano, D., Costa, C., Ditaranto, N., Ancona, A., Cioffi, N., Scrocco, C., Sabbatini, L., Contò, F., & Del Nobile, M. A. (2013). A novel preservation technique applied to fiordilatte cheese. Innovative Food Science & Emerging Technologies, 19, 158-165. https://doi.org/10.1016/j.ifset.2013.04.010

Ćwiek-Ludwicka, K., Ludwicki, J.K. (2017). Nanomaterials in food contact materials; considerations for risk assessment, Annals of the National Institute of Hygiene, 2017; 68(4): 321-329.

Dash, K.K., Deka, P., Bangar, S.P., Chaudhary, V.; Trif, M., Rusu, A. (2022). Applications of Inorganic Nanoparticles in Food Packaging: A Comprehensive Review. Polymers, 14, 521.

de Moura, M. R., Mattoso, L.H.C., Zucolotto, V. (2012). Development of Cellulose-Based Bactericidal Nano-composites Containing Silver Nanoparticles and Their Use as Active Food Packaging. Journal of Food Engineering, 109, 520-524.

Dimitrijevic, M. et al., (2015). Safety aspects of nanotechnology applications in food packaging, Procedia Food Science. 5, 57-60.

Dobrucka, R., Długaszewska, J., Kaczmarek, M. (2019). Antimicrobial and cytostatic activity of biosynthesized nanogold prepared using fruit extract of Ribes nigrum, Arabian Journal of Chemistry, 12, 3902-3910.

Dobrucka, R., & Przekop, R. (2019). New perspectives in active and intelligent food packaging. Journal of Food Processing and Preservation, 43(11). https://doi.org/10.1111/jfpp.14194

Duncan, T.V. (2011). Applications of Nanotechnology in Food Packaging and Food Safety: Barrier Materials, Antimicrobials and Sensors. Journal of Colloid and Interface Science, 363, 1-24.

Echegoyen, Y. (2015). Nano-developments for Food Packaging and Labeling Applications. Chapter 7 in: Nano-technologies in Food and Agriculture, Springer International Publishing.

EFSA, 2011, European Food Safety Authority Guidance on the risk assessm, ent of the vapplication of nanoscience and nanotechnology in the food and feed chain, EFSA Journal, 9 (5) (2011), p. 2140.

EFSA, 2021, Safety assessment of the substance silver nanoparticles for use in food contact materials, Safety assessment of the substance silver nanoparticles for use in food contact materials, EFSA Journal (europa.eu).

EFSA CEF Panel (EFSA Panel on Food Contact Materials, E., Flavourings and Processing Aids), (2013a) Scientific Opinion on safety assessment of the active substance, iron (0) modified bentonite as oxygen absorber, for use in active food contact materials. EFSA Journal, 11(10), 3400, p. 12. 2013.

EFSA CEF Panel (EFSA Panel on Food Contact Materials, E., Flavorings and Processing Aids), (2013b) Scientific Opinion on safety assessment of the active food contact substance, iron (0) modified kaolinite as oxygen absorber, for use in active materials. EFSA Journal, 11(10), 3401, p. 12, 2013.

Espitia, P.J.P., Soares, N.D.F.F., Coimbra, J.S.D.R., De Andrade, N.J., Cruz, R. S., & Medeiros, E.A.A. (2012). Zinc oxide nanoparticles: Synthesis, antimicrobial activity and food packaging applications. Food and Bioprocess Technology, 5(5), 1447-1464. https://doi.org/10.1007/s11947-012-0797-6.

Farshchi, E., Pirsa, S., Roufegarinejad, L., Alizadeh, M., Rezazad, M. (2019). Photocatalytic/biodegradable film based on carboxymethyl cellulose, modified by gelatin and TiO2-Ag nanoparticles. Carbohydrate Polymers, 216, 189-196.

Gottardo, S., Mech A., Drbohlavová, J., Małyska, A., Bøwadt, S., Sintes, J. R., Rauscher, H. (2021). Towards safe and sustainable innovation in nanotechnology: State-of-play for smart nanomaterials, , 2021 Jan; 21: 100297.

Foltynowicz, Z. (2018). Nanoiron-Based Composite Oxygen Scavengers for Food Packaging in Giuseppe Cirillo, Marek A Kozlowski and Umile Gianfranco Spizzirri (eds.) Composites Materials for Food Packaging, (209-234) Scrivener Publishing LLC

Foltynowicz, Z. (2020). Polymer packaging materials – friend or foe of the Circular Economy, Polimer, 65, 1.

Foltynowicz, Z., Bardenshtein, A., Sängerlaub, S., Antvorskov, H., Kozak, W. (2017). Nanoscale, zero valent iron particles for application as oxygen scavenger in food packaging. Food Packaging and Shelf Life, 11, 74-83.

Gawande, M.B., Goswami, A., Felpin, F.X., Asefa, T., Huang, T., Silva, R., Zou, X., Zboril, R., Varma, R.S. (2016). Cu and Cu-based nanoparticles: synthesis and applications in catalysis. Chem Review, 116, 3722-811.

Ghule, K., Ghule, A. V., Chen, B.-J., & Ling, Y.-C. (2006). Preparation and characterization of ZnO nanoparticles coated paper and its antibacterial activity study. Green Chemistry, 8(12), 1034-1041.

Gruszka, J., Malejko, J., Godlewska-Żyłkiewicz, B. (2019). Nanocząsteczki tlenku tytanu (IV) – Zastosowanie w produktach użytkowych, badania właściwości i oznaczanie techniką spektrometrii mas z plazma indukcyjnie sprzężoną pracującą w trybie pojedynczej cząsteczki. Wiadomości Chemiczne, 73, 5-6.

Hayat, M.A. (2012). Colloidal Gold: Principles, Methods, and Applications; Elsevier: Amsterdam, The Netherlands.

Huang, Y., Chen, S., Bing, X., Gao, C., Wang, T., Yuan, B. (2011). Nanosilver Migrated into Food-Simulating Solutions from Commercially Available Food Fresh Containers. Packaging Technology & Science, 24, 291-297.

Islam, Md.A., Jacob, M.V., Antunes, E. (2021) A critical review on silver nanoparticles: From synthesis and applications to its mitigation through low-cost adsorption by biochar, Journal of Environmental Management, 281, 111918,

Ivask, A., George, S., Bondarenko, O., Kahru, A. (2012). Metal-Containing Nano-Antimicrobials: Differentiating the Impact of Solubilized Metals and Particles. w Nano-Antimicrobials. Springer, Berlin, Heidelberg.

Jaswal, T., Gupta, J. (article in press) A review on the toxicity of silver nanoparticles on human health, Materials Today: Proceedings.

Jo, Y., Garcia, C.V., Kob, S., Lee, W., Shin, G.H., Choid, J.Ch., Park, S-J., Kim, J.T. (2018). Characterization and antibacterial properties of nanosilver-applied polyethylene and polypropylene composite films for food packaging applications. Food Bioscience, 23, 83-90.

Jurewicz, M. (2017). Uregulowania prawne wykorzystania nanotechnologii w produkcji materiałów i wyrobów z tworzyw polimerowych przeznaczonych do kontaktu z żywnością, Polimery, 62, 2, 144-148.

Kahru, A., Dubourguier, H-C. (2010). From ecotoxicology to nanoecotoxicology. Toxicology, 269, 105-119.

Kędziora, A., Sobik, K. (2013). Oporność bakterii na srebro — problem stary czy nowy? Kosmos, 62, 557-570.

Khalaj, M.-J., Ahmadi, H., Lesankhosh, R., Khalaj, G. (2016). Study of physical and mechanical properties of polypropylene nanocomposites for food packaging application: Nano-clay modified with iron nanoparticles. Trends. Food Science and Technology, 51, 41-48.

Kim, B., Kim, D., Cho, D., Cho, S. (2003). Bactericidal Effect of TiO2 Photocatalyst on Selected Food-Borne Pathogenic Bacteria. Chemosphere, 52, 277-281.

Kosmala, K., Szymańska, R. (2016). Nanocząstki tlenku tytanu (IV). Otrzymywanie, właściwości i zastosowanie. Kosmos, Problemy Nauk Biologicznych, 65(2), 235-245.

Kumar, S., Basumatary, I.B., Sudhani, H.P.K., Bajpai, V.K., Chen, L., Shukla, S., Mukherje, A. (2021). Plant extract mediated silver nanoparticles and their applications as antimicrobials and in sustainable food packaging: A state-of-the-art review, Trends in Food Science & Technology, 112, 651-666

Kuswandi, B., & Moradi, M. (2019). Improvement of food packaging based on functional nanomaterial., in Nano-technology: Applications in energy, drug and food (pp. 309_344). Cham: Springer International Publishing.

Lan, W., Wang, S., Zhang, Z., Liang, X., Liu, X., Zhang J. (2021). Development of red apple pomace extract/chitosan-based films reinforced by TiO2 nanoparticles as a multifunctional packaging material., International Journal of Biological Macromolecules, 168, 105-115.

Lee, H-I., Kwon, Ri-Ye., Cho, S-J. (2023). Food Additive Solvents Increase the Dispersion, Solubility, and Cyto-toxicity of ZnO Nanoparticles, Nanomaterials 2023, 13(18), 2573.

Ligaj, M., Tichoniuk, M., Cierpiszewski, R., Foltynowicz, Z. (2020). Efficiency of Novel Antimicrobial Coating Based on Iron Nanoparticles for Dairy Products', Packaging. Coatings, 10, 156.

Longano, D., Ditaranto. N., Cioffi, N., Di Niso, F., Sibillano, T., Ancona, A., Conte, A., Del Nobile, M.A., Sabbatini, L., Torsi, L. (2012). Analytical characterization of laser-generated copper nanoparticles for antibacterial com-posite food packaging. Analytical and Bioanalytical Chemistry, 403, 1179-86.

Marrez, D.A., Abdelhamid, A.E., Darwesh, O.M. (2020). Eco-friendly cellulose acetate green synthesized silver nano-composite as antibacterial packaging system for food safety. Food Packaging and Shelf Life, 25, 100517.

Mary, T.R.N., Jayavel, R. (2022). Fabrication of chitosan/Cashew Nut Shell Liquid/plant extracts-based bio-formulated nanosheets with embedded iron oxide nanoparticles as multi-functional barrier resist eco-packaging material., Applied Nanoscience, 12, 1719-1730.

de Menezes, F.L.G., de Lima Leite, R.H., Gomes dos Santos, F.K., Aria, A.I., Aroucha, E.M.M., (2021). TiO2-enhanced chitosan/cassava starch biofilms for sustainable food packaging. Colloids and Surfaces A: Physicoche-mical and Engineering Aspects, 630, 127661

Mohammadalinejhad, S., Almasi, H., Esmaiili, M. (2021). Physical and release properties of poly(lactic acid)/nano-silver-decorated cellulose, chitosan and lignocellulose nanofiber composite films. Materials Chemistry and Physics, 124719.

Mouzahim, M.El., Eddarai, E.M., Eladaoui, S., Guenbour, A., Bellaouchou, A., Zarrouk, A., Boussen, R., (2023). Effect of Kaolin clay and Ficus carica mediated silver nanoparticles on chitosan food packaging film for fresh apple slice preservation, Food Chemistry, 410 (2023) 135470

Nicula, P.A., Mihaly-Cozmuta, C., Mihaly-Cozmuta, A., Indrea, L. E. (2012). Chemical and Sensory Changes of Diffe-rent Dairy Products During Storage in Packages Containing Nanocrystallised TiO2. International Journal of Food Science and Technology, 47, 1448-1456.

Onyeaka, H., Passaretti, P., Miri, T., Al-Sharify, Z. T. (2022). The safety of nanomaterials in food production and pack-aging, Current Research in Food Science, 5 (2022) 763-774.

Pagno, C.H., Costa, T.M., de Menezes, E.W., Benvenutti, E.V., Hertz, P.F., Matte, C.R., Tosati, J.V., Monteiro, A.R., Rios, A.O., Flôres, S.H. (2015). Development of active biofilms of quinoa (Chenopodium quinoa W.) starch containing gold nanoparticles and evaluation of antimicrobial activity. Food Chemistry, 173, 755-762.

Paidari, S., Tahergorabi, R., Ensieh Sadat Anari, E.S., Nafchi, A.M., Zamindar, N., Goli, M. (2021) Migration of Vari-ous Nanoparticles into Food Samples: A Review, Foods, 10(9), 2114.

Paidari, S., Ibrahim, S.A. (2021). Potential application of gold nanoparticles in food packaging: A mini review. Gold Bull. 2021, 54, 31-36.

Peter, A., Cozmuta, L.M., Nicula, C., Cozmuta, A.M., Talasman, C.M., Drazic, G., Pernas, A., Calahorro, A.J., Sagratini, G., Silvi, S. (2021). Chemical and organoleptic changes of curd cheese stored in new and reused active packaging systems made of Ag-graphene-TiO2-PLA. Food Chemistry, 363, 130341.

Phothisarattana, D., Wongphan, P., Promhuad, K., Promsorn, J., & Harnkarnsujarit, N. (2021). Biodegradable poly (butylene adipate-co-terephthalate) and thermoplastic starchblended TiO2 nanocomposite blown films as functional active packaging of fresh fruit. Polymers, 13(23), 4192.

Priyadarshi, R., Roy, S., Ghosh, T., Biswas, D., & Rhim, J. W. (2022). Antimicrobial nanofillers reinforced biopolymer composite films for active food packaging applications-a review. Sustainable Materials and Technologies, 32, e00353.

Primozic, M., Knez, Z., Leitgeb, M. (2021). (Bio)nanotechnology in food science—food packaging, Nanomaterials 11 (2), 1-31.

Przybyłowski, P., Chomaniuk, N., Reszka, M.M. (2016). Postrzeganie przez konsumentów jakości i bezpieczeństwa nanomateriałów. Zeszyty Naukowe Akademii Morskiej W Gdyni, nr 93.

Qadri, O. S., Younis, K., Srivastava, G. and Srivastava, A.K. (2018). Nanotechnology In packaging of fresh fruits and vegetables, in: Emerging Postharvest Treatment of Fruits and Vegetables, Apple Academic Press-New York.

Ren, G., Hu, D., Cheng, E.W.C., Vargas-Reusc, M.A., Reipd, P., Allaker, R.P. (2009). Characterisation of copper oxide nanoparticles for antimicrobial applications. International Journal of Antimicrobial Agents, 33, 587-590.

Rhim, J.-W., Park, H.-M., Ha, Ch.-S., (2013). Bio-nanocomposites for Food Packaging Applications. Progress in Polymer Science, 38, 1629- 1652.

Rodewald, D. (2013). Ocena trwałości mikrobiologicznej preparatów kosmetycznych w opakowaniach polimerowych modyfikowanych nanosrebrem, Praca doktorska, Uniwersytet Ekonomiczny w Poznaniu.

Sadeghi, B., Garmaroudi, F.S., Hashemi, M., Nezhad, H.R., Nasrollahi, A., Ardalan, S., Ardalan, S. (2012). Comparison of the Anti-bacterial Activity on the Nanosilver Shapes: Nanoparticles, Nanorods and Nanoplates. Advanced Powder Technology, 23, 22-26.

Sahu, G., Das, M., Sethy, Ch., Wazalwarc, R., Kundu, Ch.N., Raichur A.M., Tripathy, J. (2021). Ionic liquid-assisted fabrication of poly(vinyl alcohol)/nanosilver/graphene oxide composites and their cytotoxicity/antimicrobial activity. Materials Chemistry and Physics, 266(15), 124524.

Saral, Sarojini, K., Indumathi, M.P., Rajarajeswari, G.R. (2019). Mahua oil-based polyurethane/chitosan/nano ZnO composite films for biodegradable food packaging applications. International Journal of Biological Macromolecules, 124, 163-174.

Song, Z., Niu, C., Wu, H., Wei, J., Zhang, Y., Yue, T. (2019). Transcriptomic Analysis of the Molecular Mechanisms Underlying the Antibacterial Activity of IONPs@pDA-Nisin Composites toward Alicyclobacillus acidoterrestris. ACS Applied Materials & Interfaces, 11, 21874-21886.

Souza, V.G.L., Fernando, A.L. (2016). Nanoparticles in food packaging: Biodegradability and potential migration to food—A review. Food Packaging and Shelf Life, 63-70.

Stuparu-Cretu, M., Braniste, G., Necula, G.-A., Stanciu, S., Stoica, D., Stoica, M. (2023). Metal Oxide Nanoparticles in Food Packaging and Their Influence on Human Health. Foods, 12, 1882.

Shukla, P., Chaurasia, P., Younis, K., Qadri, O.S., Faridi, S.A., Srivastava, G. (2019). Nanotechnology in sustainable agriculture: studies from seed priming to post-harvest management. Nanotechnology for Environmental Engineering, 4, 11.

Suwała, G., Pietruszka, J. (2017). Consumers' Awareness of the Application of Nanotechnology in Food Production W: M. Miśniakiewicz, M. Halagarda, (red.) Towaroznawstwo w badaniach i praktyce – Jakość i bezpieczeństwo żywności – analizy, trendy, wyzwania, Polskie Towarzystwo Towaroznawcze, Kraków, s. 169-184. ISBN: 978-83-949236-4-8.

Tulsyan, G., Richter, Ch. Diaz, C.A. (2017). Oxygen Scavengers Based on Titanium Oxide Nanotubes for Packaging Applications, Packaging Technology & Science, 2017; 30: 251-256.

USFDA, 2014 [USFDA] United States Food and Drug Administration. 2014. Guidance for industry: assessing the effects of significant manufacturing process changes, including emerging technologies on the safety and regulatory status of food ingredients and food contact substances, including food ingredients that are color additives.

Wu, Z., Zhou, W., Pang, Ch., Deng, W., Xu, Ch., Wang, X. (2019). Multifunctional chitosan-based coating with liposomes containing laurel essential oils and nanosilver for pork preservation. Food Chemistry, 295, 16-25.

Virgili, A.H., Laranja, D.C., Malheiros, P.S., Pereira, M.B., Costa, T.M., de Menezes, E.W. (2021). Nanocomposite film with antimicrobial activity based on gold nanoparticles, chitosan and aminopropylsilane. Surface and Coatings Technology, 415, 127086.

Yaqoob, N., Zahira, A., Kamal, S., Almas, M., Rehman, S. (2023). Development of multifunctional bioactive food packaging based on silver nanoparticles/grape fruit peel extract reinforced PVA composites, Materials Today Communications, 37, 107529.

Yu, F., Fei, X., He, Y., Li, H. (2021). Poly(lactic acid)-based composite film reinforced with acetylated cellulose nanocrystals and ZnO nanoparticles for active food packaging. International Journal of Biological Macromolecules, 186, 770-779.

Zhang, W., Rhim, J-W. (2022). Titanium dioxide (TiO2) for the manufacture of multifunctional active food packaging films, Food Packaging and Shelf Life, 31, 100806.

SPENT AUTOMOTIVE CONVERTERS – VALUABLE SOURCES OF PLATINUM GROUP METALS

Anna Cieszyńska

Department of Technology and Instrumental Analysis, Institute of Quality Science, Poznań University of Economics and Business, Poznań, Poland
**Corresponding Author e-mail: anna.cieszynska@ue.poznan.pl*

DOI: 10.56091/CTQS.Innov-4

Abstract

Platinum, palladium, and rhodium are particularly irreplaceable in automotive catalytic converters, which are used to treat exhaust gas. A three-way automotive catalytic converter it is considered to have between 3-7 g of platinum, 1.5-5.0 g of palladium and 0.8-1.5 g of rhodium. Platinum group metals (PGM) have been classified as critical raw materials (CRM) in North America and Europe, thus a circular economy model should be implemented for their effective recovery. Secondary resources of PGM, such as spent automotive converters, contain considerably higher PGM concentrations than their corresponding ores. Recycling PGM from spent automotive converters has the potential to yield significant economic and environmental benefits. It is estimated that spent automotive catalytic converters deliver more than 57% of PGM European supply, being considered a crucial resource for PGM recovery. Novel recovery techniques focus not only on high recovery rates, but also on cost efficiency and environmental protection This paper reviews the main technologies for recycling PGM from spent automotive converters, including metallurgical extraction and solution purification techniques.

Keywords: platinum group metals (PGM), spent automotive converters, recycling, leaching, hydrometallurgical and pyrometallurgical methods

Introduction

Technological processes all over the world show relentless demand for platinum group metals (PGM), in particular palladium (Pd), rhodium (Rh) and platinum (Pt). The demand is still increasing, as these metals have been for many years used as catalysts in the organic technology processes, in jewelry products, in inorganic chemical, petrochemical, electrical, glass industry, dentistry and mainly in catalytic converters. In 2022, demand for palladium was 309.0 tons, platinum 194.8 tons and rhodium 31.0 tons, and their prices were 2,061.06 \$/oz, 958.06 \$/oz and 14,750.05 \$/oz, respectively (Fig. 1) (Hagelüken & Corti; 2010, Matthey 2023; Statista, 2023; World Gold Council, 2023).

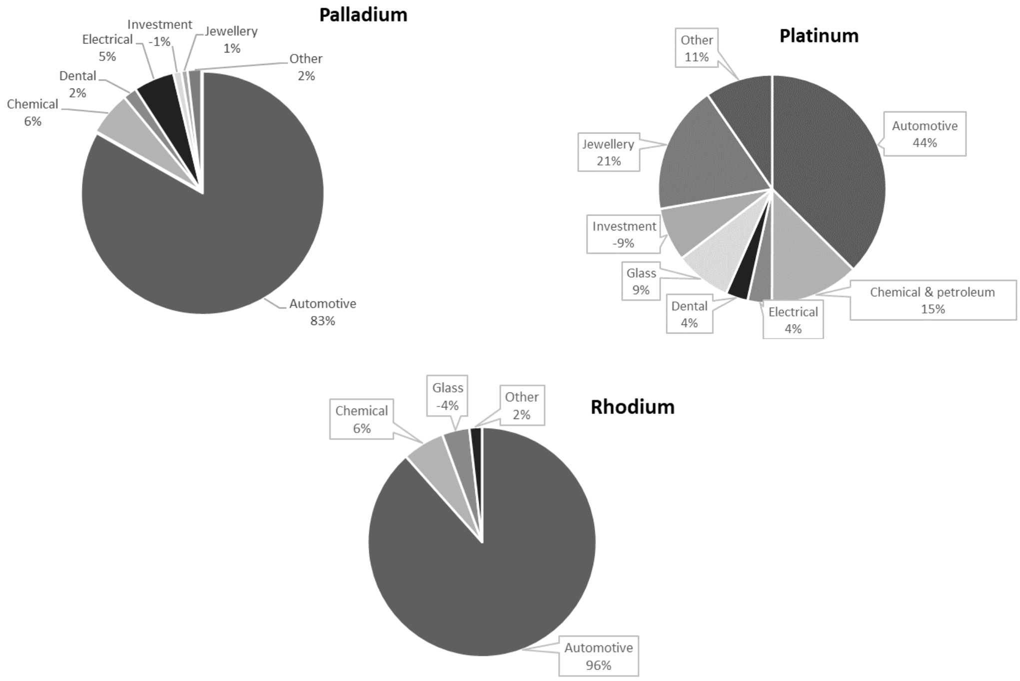


Fig. 1. Platinum group metals demand by applications in 2022

Source: own study based on Matthey, 2023; Statista, 2023; World Gold Council, 2023.

About 80% of the PGM demand is in automotive converters where platinum is used both as an oxidation and as a reduction catalyst, palladium as an oxidation catalyst and rhodium as a reduction catalyst (Kolliopoulos et al., 2014; Yakoumis et al., 2020). While platinum and palladium can be interchanged, they cannot substitute rhodium role in autocatalysts. PGM are also used in light duty diesel engines. Palladium substitution by platinum, which is low-price and abundant relative to palladium, has been investigated recently by many groups, especially due to the increase in the price of palladium and the improvement in fuel quality (less sulfur) (Omrani et al., 2019).

PGM price movements during the first half of 2022 largely reflected the extent of exposure to Russian supply, with palladium the most affected. Over the past five years, around 28% of combined primary and secondary palladium supplies originated from Russia, whereas this proportion is below 10% for all the other metals. As 2022 began, palladium moved swiftly through the \$2,000 level, spiking above \$2,600 when Russian troops entered Ukraine on 24th February. As the situation in Ukraine deteriorated, and widespread economic sanctions were imposed on Russia by the West, concerns about palladium availability intensified, driving the price to new all-time records. It peaked at \$3,339 on 7th March, as prices of a range of Russia-exposed commodities surged higher. Although it retreated below \$2,200 later that month as concerns about liquidity abated, the delisting of Russian refiners by the London Platinum and Palladium Market (LPPM) on 8th April reignited availability fears and spurred the price back above \$2,500. As a result of the LPPM decision, ingot and sponge produced by Russian refineries since 8th April 2022 has no longer been accepted for 'Good Delivery' into the London and Zurich bullion market. As availability fears began to ease, palladium fell back to trade between $1,800 and $2,200 for most of the second half. Sentiment was affected by an increasingly gloomy economic picture, with surging inflation, rising interest rates, and slack palladium demand from the automotive sector, although constrained primary and secondary supplies provided some support. The mood turned more negative during December, with palladium falling through $1,800 at the year end.

Platinum and rhodium also reacted to increased supply risks, despite Russia accounting for only a minor share of primary production. Platinum climbed steadily from around $960 in early January to an eight-month high of $1,151 on 8th March, although it subsequently fell back as supply fears eased, trading below $1,000 for most of the April to October as the US dollar weakened and NYMEX investors added to long positions, but the rally was ultimately short-lived.

Rhodium moved higher during the first quarter: with memories of the extreme supply squeeze of 2021 still fresh, industrial consumers moved to secure their metal needs, spurring the price from $14,500 as the year opened to over $22,000 on 7th March. It gradually gave up these gains, falling back to trade either side of $14,000 between June and November, before sinking to a 27-month low of $12,250 in December. Ongoing sales of rhodium by Chinese glass fibre producers have added liquidity to the market over the past two years, but until recently the price impact had been muted, because Chinese market participants were generally willing to hold surplus rhodium. This willingness evaporated in early 2023, when falling prices prompted Chinese rhodium holders to dispose of their metal, often at a discount to world market prices (Fig. 2.) (Matthey, 2023).

Fig. 2. Palladium, platinum and rhodium prices

Source: Matthey, 2023.

A large numbers of PGM applications have increased the demand for these metals, whereas the natural resources are limited. Therefore, the gap between the demand and supply from natural sources, must be replenished by recycling of spent materials.

Recent studies have shown interest in the recovery of platinum, palladium and rhodium from automotive converters (Manjunath, 2021; Morcali, 2020; Padamata, 2020; Paiva et al., 2022; Tang et al., 2021; Yakoumis et al., 2020 & 2021). Most petrol and diesel vehicles, including automobiles, trucks, buses, trains, motorcycles, and planes, have exhaust systems employing a catalytic converter and platinum, palladium, and/or rhodium are active components of PGM that convert harmful gases emitted from vehicle engines to relatively harmless gases by both the reduction of nitrogen oxides (NOx) into nitrogen N_2 and the oxidation of hydrocarbons and CO to CO_2. The cumulative PGM concentration in an automotive converters ranges between 0.1% and 0.2%, and in the commercial operations 95% of PGM recovery rates are achieved from a charge with very low concentrations of PGM (<0.1%) (Benson et al., 2000; Diaz et al., 2020; Jimenez De Aberasturi et al., 2011).

PGM in automotive converters

The situation on the automotive market has not yet completely returned to precrisis tracks, but it is clearly visible that it is gradually improving. This is evidenced by data from OICA (Organisation Internationale des Constructeurs d'Automobiles). Last year, just over 85 million passenger cars, vans, trucks and buses were manufactured in 47 countries. This is a result that is nearly 6.3% better than in 2021 and 10.4% better than in 2020. China has the largest share in world production (27 million pieces). Among European countries, Germany is clearly the leader – with over 16 million vehicles. Last year, passenger cars accounted for over 72% of all vehicles produced in the world (~ 61.5 million units, an increase of 8%), light duty vehicles over 23% (~ 19.9 million units, +7%), heavy duty vehicles over 3,9% (~ 3.3 million units, -23%) and buses over 0.3% (~ 0.26 million units, +28%) (OICA, 2023).

Spent automotive catalysts are the richest PGM secondary resource, being widely exploited for the PGM recovery. It is estimated that processing 2 mg of spent automotive catalysts can prevent the mining of 150 kg PGM ores. Spent Light-Duty Vehicles (LDV) catalysts contain about 1-3 g PGM (i.e., Pt, Pd, Rh), while Heavy-Duty Vehicles (HDV) catalysts contain 12-15 g PGM (Fornalczyk & Saternus, 2009).

A modern three-way auto-catalyst contains a skeleton with a honeycomb structure made of cordierite ($2MgO·2Al_2O_3·5SiO_2$), which is coated with a thin layer of washcoat (90% -Al_2O_3), catalytic metals (PGM) and other additives (oxides of Ce, Zr, La, Ni, Fe and alkaline earth metals) (Omrani et al., 2019, Xia & Ghahreman, 2023, Chaudhari & Arakerimath, 2020) (Fig. 3).

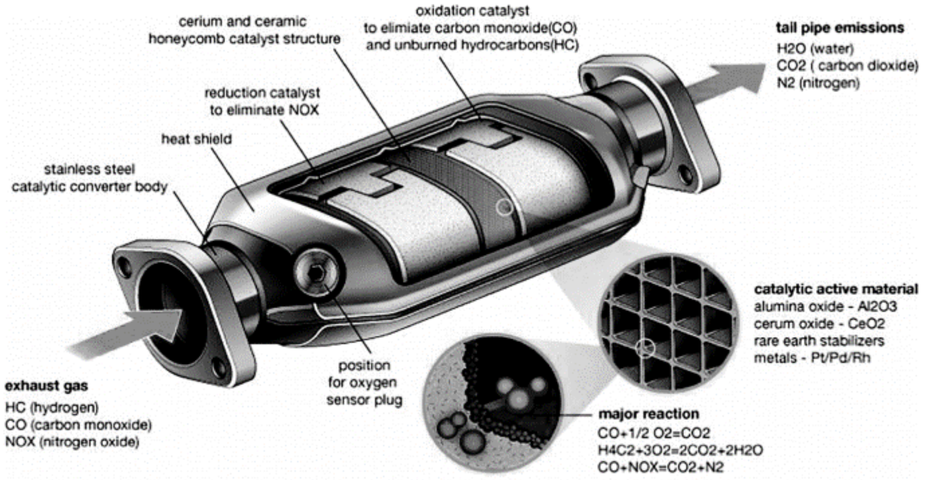


Fig. 3. Scheme of automotive converter

Source: Chaudhari & Arakerimath, 2020.

The proportion of PGM in catalysts depends on several factors: the manufacturer, the characteristics of the vehicle, including the engine power, the weight of the vehicle, the type of fuel consumed by the vehicle (gasoline or diesel), as well as the required catalytic functions. Through a series of oxidation reactions platinum and palladium convert CO and HC to CO_2 and H_2O, and the reduction of NO to N_2 is accomplished by rhodium. The catalytic efficiency of each element is influenced by several factors such as the engine temperatures, the type of fuel used, the quality of the fuel and the durability of the autocatalyst washcoat. A three-way automotive catalytic converter it is considered to have between 3-7 g platinum, 1.5-5.0 g palladium and 0.8-1.5 g rhodium (Eskina et al., 2020; Moschovi et al., 2021; Ormani et al., 2019; Kolliopoulos et al., 2014).

Recently, governments around the world have been implementing increasingly stringent emission standards. As an example, in China the regulations regarding emission control limits implemented by the State Environmental Protection Administration (SEPA) have become recently more stringent to reduce pollution. It was confirmed in July 2022 that another round of amendments to Euro 6 light duty legislation will be phased-in starting in September 2023. This new stage, Euro 6e, further reduces allowable error margins for emissions measured during Real Driving Emissions testing using portable emissions measurement systems (‘PEMS error margins’, formerly known as ‘conformity factors’), to 1.10 for NOx and 1.34 for particulates. However, the impact on PGM demand is expected to be not too high, because in EU most aftertreatment systems are already designed to meet or exceed Euro 6e requirements. Euro 6e reduces the UF to 50% (from 2025 for private cars and from 2027 for company vehicles) and allows for this figure to be reviewed again in 2024. This change (and the prospect of further amendments) is expected to disincentivize growth of the PHEV market in Europe, with industry forecasts suggesting that European output of these vehicles could peak within the next two years.

Automotive PGM consumption will see only marginal gains in 2023, with battery electric vehicles expected to capture all the growth in light vehicle production. Although emissions legislation is set to tighten again, with the implementation of real driving emissions (RDE) testing in India and China in April and July 2023 respectively, and the phase-in of Euro 6e regulations starting in September, most automakers can meet the new requirements without any material increases to PGM loadings. In the heavy duty sector – where demand has been boosted in the past two years by the enforcement of China 6 limits on heavy diesel trucks – thrifting of PGM loadings will partly offset underlying growth in vehicle volumes. World auto PGM demand is forecast to rise by just 1% to 12.2 million oz this year. The individual PGM will see divergent demand trends, as platinum-for-palladium substitution on gasoline vehicles gains momentum, reflecting catalyst fitment decisions taken over the past three years when palladium prices were exceptionally high. Platinum automotive demand is forecast to rise by 11%, to exceed 3 million oz for the first time since 2017, while palladium use will contract by 2%. Rhodium consumption is not directly affected by substitution decisions, and will remain flat, with thrifting efforts broadly offset by the on-going legislative focus on NOx emissions under real driving conditions (Fig. 4).

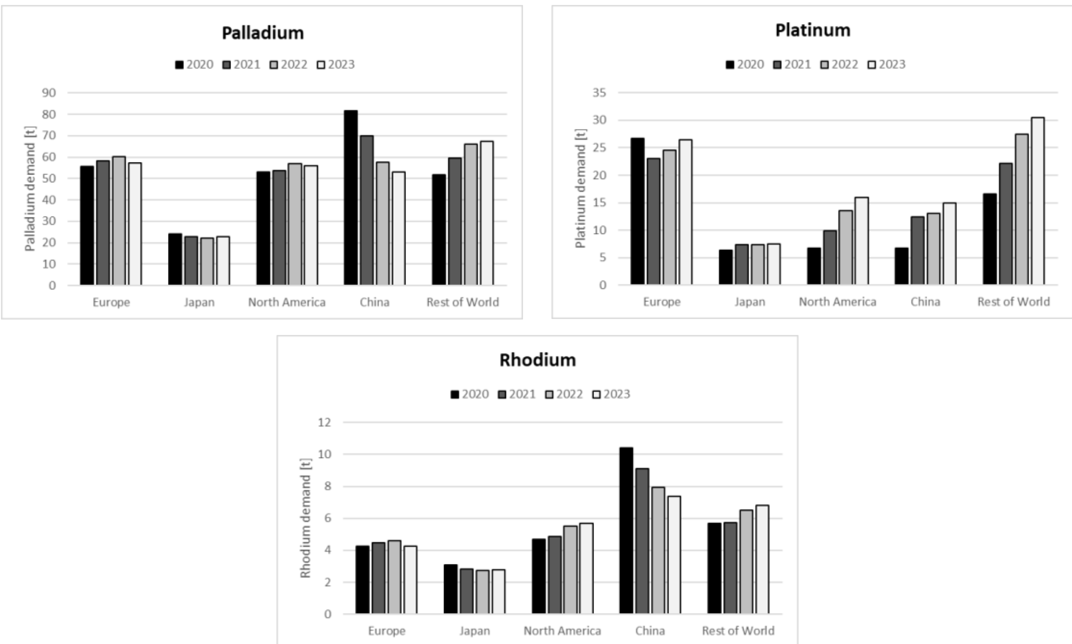


Fig. 4. Automotive demand for platinum group metals

Source: own study based on Matthey, 2023.

At the peak of 2017, 86 million combustion engine passenger cars were sold, including traditional hybrids such as the Toyota Prius. Electric and plug-in hybrid models were a small part of the market at the time, totalling just over 1 million vehicles. In 2022, the market picture was completely different. Sales of combustion vehicles dropped by almost 20%. from a peak of 69 million, and sales of plug-in vehicles jumped to 10.4 million (Statistica, 2023). The automotive market is actually dominated by vehicles with internal combustion engines powered by fossil fuels, but achieving carbon neutrality by 2050 is essential replacement of conventional fossil fuels in various segments of the economy. Down achieve the goal of CO_2 neutrality by 2050, starting in 2035 in Europe, all new cars that placed on the market must not emit CO_2. Considering that the service life of the car is about 15 years, the PGM source from the automotive converters can be expected to last until at least 2050 for a car with a petrol engine. However, the automotive converter will still be equipped branded for use in plug-in hybrid cars, and even if the automotive industry is still growing away from fossil fuels, the ICE footprint will continue for decades to come (Wang et al., 2022).

According to the International Energy Agency (IEA), about 6.6 million electric vehicles (EVs) were sold in 2021, and the trend is expected to increase in the next years towards a final transition from ICEs to EVs powered by batteries or H_2 (fuel cells.) The near future trend for light vehicles is mostly towards battery-electric vehicles, because the total cost of ownership is lower than the hydrogen and e-fuels alternatives. However, because batteries are heavy, ships, planes or heavy-duty vehicles cannot easily be battery-powered and therefore hydrogen or e-fuels can be good alternative solutions. Some EVs based on polymer electrolyte membrane fuel cells (PEMFC), phosphoric acid fuel cells (PAFC), direct methanol fuel cells (DMFC) and alkaline fuel cells (AFC) rely on the use of PGM. Despite Pt and Pd are not key components in a battery, next-generation lithium-ion battery technologies will probably need platinum and palladium to enhance overall battery performance (Hughes et al., 2021; Wang et al., 2022; Grilli et al., 2023). Instead, the technologies for the production of green hydrogen by using water electrolysis powered by renewable energy sources, at present the most promising way to produce green hydrogen potentially free of greenhouse gas emissions, mainly rely on PGMs.

PGM recycling

Since the automotive converters have started to be used, the demand for platinum group metals has dominated the market for palladium, platinum and rhodium. Different sizes of automotive converters contain different amounts of platinum group metals. However, this consumption corresponds to amounts of 44% of globally produced platinum, 83% of globally produced palladium and 96% globally produced rhodium.

Although the world is transitioning away from fossil fuel vehicles and most countries plan to prohibit the sales of new fossil fuel vehicles by 2035. However, this process is slow and there will still be many fossil fuel vehicles in use until at least 2050. The recycling of spent catalytic converters is a large industry that will continue for many years. PGMs are classified as critical metals in North America and Europe. They also play important roles in the petroleum and chemical production industries. Furthermore, platinum is used as an electrochemical catalyst in fuel cells Toyota Mirai and Hyundai Nexo are two commercial hydrogen fuel cell vehicles with platinum adopted in their engines as the catalyst, the global sales of these two vehicles both exceeded 10,000 units. PGM are valuable resources that need to be properly managed and recycled (Xia et al., 2023).

Recycling of PGM is very important because it provides a supplementary source to the mining of these metals, therefore protecting environment by limiting the number of waste disposal, savings of natural resources exploitation, limiting the electricity consumption, diminishing pollutant emission. In 2022 near 46 tons of platinum, 96.5 tons of palladium and 10.5 tons of rhodium were recycled (World Gold Council, Matthey, 2023). Table 1 presents the total net demand for platinum, palladium and rhodium and the value of their recycled.

Table 1. Total net demand for platinum, palladium and rhodium and the value of their recycled (in tons, t).

Year	Demand	Recycling			Total recycling
		Automotive	Electrical & electronics	Jewellery	
PLATINUM					
2018	244.7	41.5	1.2	21.7	64.6
2019	260.9	43.2	1.3	20.6	65.1
2020	222.3	36.0	1.2	15.7	52.9
2021	210.8	38.4	1.4	11.4	51.2
2022	194.8	36.0	1.7	8.2	45.8
PALLADIUM					
2018	322.0	81.7	14.8	0.3	96.8
2019	357.3	90.7	14.9	0.3	105.9
2020	310.8	83.6	13.3	0.2	97.1
2021	318.9	89.8	13.8	0.3	103.9
2022	309.0	81.9	14,1	0.3	96.3
RHODIUM					
2018	32.8	10.3	–	–	10.3
2019	36.4	11.1	–	–	11.1
2020	32.3	10.5	–	–	10.5
2021	32.1	11.5	–	–	11.5
2022	31.0	10.5	–	–	10.5

Source: own study based on Matthey 2023.

Currently in the world for the recovery of PGM from spent catalytic converters pyrometallurgical or hydrometallurgical methods are used. In both technologies many of intermediates, which lead to obtain pure material are carried out. These operations can be broadly divided into: homogenization, concentration, dissolution and separation of metals and their purification. The final refining let to obtain very high purity metal, but it is very expensive. It consumes also large quantities of energy and can create dangerous solutions. Frequently for the PGM purification are applied processes such as calcinations, ion exchange, solvent extraction, hydrolysis, oxidation and reduction processes or precipitation. Figure 5 presents the main steps in PGM recovery from spent catalytic converters.

In the hydrometallurgical methods PGM contained in the used catalytic converters were dissolved in an aqueous solutions of chloride, chlorate, chlorine, hydrogen peroxide, bromate, nitrate and aqua regia. The obtained solution contains low concentrations of PGM, that is why their concentration is necessary before extraction. In pyrometallurgical methods broken-up carriers covered by the PGM are melted with the addition of other metal which has a special function – to be a liquid matrix. PGM pass into the alloy, while carriers are separated and scrapped.

Obtained metal is rich in PGM, so the next stage is the PGM purification. Both methods are very effective and let to recover about 95% of platinum and palladium and 70% of rhodium. Recently, many studies have focused on the possibility of using biometallurgical processes for recycling and recovery of PGM from automotive converters. In the case of biohydrometallurgy, the same similar principles apply, but the leachates are biological products. The leaching rates of biohydrometallurgical processes are slower than those of hydrometallurgical ones, however, they are more environmentally friendly and have a low cost. All methods have advantages and disadvantages, which are presented in Table 2.

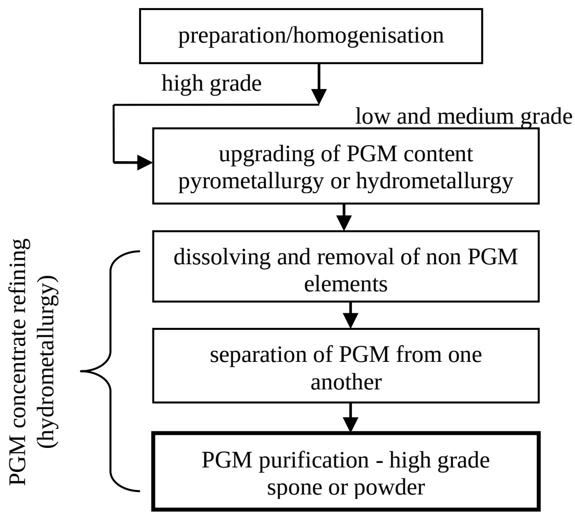


Fig. 5. Main steps in PGM recovery from the spent automotive converters

Source: own study.

In the world there are some firms which recover PGM metals from the used automotive converters. For example, Umicore, at its integrated smelter-refinery in Antwerp, Belgium, currently recovers and supplies back to the market via its main process route precious metals. Johnson Matthey, at its refineries in Brimsdown and Royston, UK, recovers platinum, palladium, iridium, rhodium and ruthenium from secondary materials using the traditional refining route (Table 3).

Table 2. Characteristics of metallurgical methods using for PGM recycling

Type of Process	Advantages	Disadvantages
Pyrometallurgical processes	used for upscaling recovery of PGM, offers promising recovery yields (99% Pt, 99% Pd, 97% Rh)	special equipment, high temperatures, high energy consumption, cost of continuous furnace operation, production of significant waste (e.g., volatile waste, slag)
Hydrometallurgical processes	milder process temperatures than pyrometallurgy, process control, high selectivity, minimal energy consumption, ability to be used at both small and large scale	attention to waste management (liquid waste, gas emissions), process duration, cost and nature of reagents
Biotechnological processes	lower carbon footprint, low energy consumption, the use of more ecological solvents than in hydrometallurgy, the absence of dangerous gases	extensive PGM extraction methodology

Source: own study based on Saguru et al., 2018; Yakoumis et al., 2021; Wiecka et al., 2022.

Table 3. Major PGM recycling companies in the world

Company	Process	Type of waste
Umicore	smelter, the copper leaching and electrowinning plant and the precious metals refinery	e-scrap, spent automotive converters, spent industrial catalysts
BASF	smelting and refining	spent catalyst
Multimetco	smelting and refining	spent automotive converters and industrial catalyst
Johnson Matthey	pyrometallurgy, advanced hydrometallurgy processing	spent process catalysts, automotive converters, fuel cell catalysts, secondary mine residues and jewellery or scrap metal
Hensel recycling	smelting	automotive converters, e-scrap or other materials containing precious metals

Source: Grilli et al., 2023.

Although the hydrometallurgical route represents an innovative and promising method for PGM recycling, its adoption in the industry is rather slow.

However, the recycling rates of end-of-life vehicles and spent automotive catalysts remain low in many countries, including China. China has a very large automobile market, which generates a significant number of end-of-life vehicles every year, but the recycling rate of scrapped cars is only 30%, which is much lower than some developed countries such as the United States.

Challenges in regulations and collection, as well as limitations in recycling technology, can impede the success of recycling end-of-life vehicles. Developing and implementing efficient and cost-effective recycling technologies is crucial (Xia et al., 2023).

The circular economy advocates designing products to be more durable, repairable, and recyclable, maximizing the reuse of materials and therefore ensuring they are kept in circulation for as long as possible. It seeks to reduce waste and reinforces the importance of managing impacts and consuming fewer resources to deliver sustainable outcomes, lowering both demand for raw materials and the environmental impact associated with obtaining them. Platinum is highly recyclable, and as products, which contain platinum or other platinum group metals (PGMs) reach their end-of-life, the PGM-content can be extracted through a process of smelting and refining. This provides a sustainable secondary source of supply of these limited natural resources. Recently, the evolution of the circular economy concept is focused not only on higher PGM recovery rates, but also on higher economic and environmental standards by following green principle rules. Nowadays, the research and innovation efforts are focused on greening and optimization of conventional PGM recovery methods toward decrease of their acid dependence, energy consumption and the increase of the efficiency of simultaneous recovery of target metals. One of the emerging recycling technologies is based on mechanochemical treatment as numerous advantages of the method are beneficial for recycling secondary PGM resources with high recovery yields in a sustainable, environmentally friendly and technoeconomically feasible processing (Chen et al., 2020). Circularity of PGMs is an essential part of the net zero transition. With limited quantities of these critical minerals available, recycling plays a crucial role in securing the metal needed to supply existing and future demand.

Developing products for circular economy of automotive catalysts offers another point of view on the way to reap the rewards of going circular by eliminating waste, recycling and creating value. Recycling PGM has many advantages compared to primary ore mining, including lower energy consumption, environmental impact, and operational cost. The PGM grades in automotive converters are significantly higher than primary ore, leading to lower energy consumption, operational costs, and waste generation. For example, it takes 150 tonnes of primary ore from 1000 m underground and 400 tonnes of total waste to produce 1 kg of platinum, whereas the same amount of platinum can be recycled from only 2 tonnes of automotive converters. Additionally, the energy consumed for recycling PGMs is 70-100 times less than primary ore mining. On the other hand, mining industries are also facing the problem of decreasing average ore grades, making it more challenging to mine PGM (Xia et al., 2023).

Conclusions

In recent years there is visible increase in interest in noble metals, especially platinum group metals (PGM), such as palladium(II), rhodium(III) and platinum(IV) due to their wide range of industrial applications. They are mainly used as automotive converters. A gap between demand and natural sources, which are limited, must be replenished by recycling of spent materials containing these precious metals. Use of spent vehicle catalysts, electronic scrap, spent catalysts and waste solutions, e.g., sludge from copper electrorefining, as potential sources for recovery of PGM is still increasing Therefore the recovery of PGM from waste solutions is an important ecological and economical issue. The recycling process is an important source of winning of precious metals, which contributes to natural sources protection and stabilization of PGM prices. The efficiently recycling of spent materials containing PGM today is insurance for the future. Regarding the pyrometallurgy's drawbacks, hydrometallurgy has been developed, offering promising recovery yields for PGM, as well as higher purity' level achieved. Compared to pyrometallurgy, less energy is consumed, and lower temperature process is required, affecting both the process cost and environmental footprint. The most crucial stage in hydrometallurgy, namely leaching process, is being further improved, by adopting green chemistry requirements.

References

Benson, M., Bennett, C.R., Harry, J.E., Patel, M.K., & Cross, M. (2000). The recovery mechanism of platinum group metals from catalytic converters in spent automotive exhaust systems. *Resources, Conservation and Recycling*, *31*(1), 1-7. https://doi.org/10.1016/S0921-3449(00)00062-8

Chaudhari, P.B., & Arakerimath, R.R. (2020). Failure and performance elements of catalytic converter in multi cylinder engine. In V. K. Gunjan, S.N. Singh, T. Duc-Tan, G.J. Rincon Aponte, & A. Kumar (Red.), *ICRRM 2019 – System Reliability, Quality Control, Safety, Maintenance and Management* (s. 190-195). Springer Singapore. https://doi.org/10.1007/978-981-13-8507-0_29

Chen, T.-L., Kim, H., Pan, S.-Y., Tseng, P.-C., Lin, Y.-P., & Chiang, P.-C. (2020). Implementation of green chemistry principles in circular economy system towards sustainable development goals: Challenges and perspectives. *Science of The Total Environment*, *716*, 136998. https://doi.org/10.1016/j.scitotenv.2020.136998

Diac, C., Maxim, F.I., Tirca, R., Ciocanea, A., Filip, V., Vasile, E., & Stamatin, S.N. (2020). Electrochemical recycling of platinum group metals from spent catalytic converters. *Metals*, *10*(6), 822. https://doi.org/10.3390/met10060822

Eskina, V.V., Dalnova, O.A., Filatova, D.G., Baranovskaya, V.B. & Karpov, Y.A. (2020). Direct precise determination of Pd, Pt and Rh in spent automobile catalysts solution by high-resolution continuum source graphite furnace atomic absorption spectrometry. *Spectrochimica Acta Part B: Atomic Spectroscopy*, *165*, 1057-84. https://doi-.org/10.1016/j.sab.2020.105784

Fornalczyk A., Saternus M. (2009) Removal of platinum group metals from the used auto catalytic converter. *Metalurgija* 48.

Grilli, M.L., Slobozeanu, A.E., Larosa, C., Paneva, D., Yakoumis, I., & Cherkezova-Zheleva, Z. (2023). Platinum group metals: Green recovery from spent auto-catalysts and reuse in new catalysts—a review. *Crystals*, *13*(4), 550. https://doi.org/10.3390/cryst13040550

Hagelüken, C., & Corti, C.W. (2010). Recycling of gold from electronics: Cost-effective use through 'Design for Recycling'. *Gold Bulletin*, *43*(3), 209-220. https://doi.org/10.1007/BF03214988

Hughes, A.E., Haque, N., Northey, S.A., & Giddey, S. (2021). Platinum group metals: A review of resources, production and usage with a focus on catalysts. *Resources*, *10*(9), 93. https://doi.org/10.3390/resources-10090093

Ilyas, S., & Kim, H. (2022). Recovery of platinum-group metals from an unconventional source of catalytic converter using pressure cyanide leaching and ionic liquid extraction. *JOM*, *74*(3), 1020-1026. -https://doi.org/-10.1007/s11837-021-05119-6

Jimenez De Aberasturi, D., Pinedo, R., Ruiz De Larramendi, I., Ruiz De Larramendi, J. I., & Rojo, T. (2011). Recovery by hydrometallurgical extraction of the platinum-group metals from car catalytic converters. *Minerals Engineering*, *24*(6), 505-513. https://doi.org/10.1016/j.mineng.2010.12.009

Kolliopoulos, G., Balomenos, E., Giannopoulou, I., Yakoumis, I., & Panias, D. (2014). Behavior of platinum group during their pyrometallurgical recovery from spent automotive catalysts. *OALib*, *01*(05), 1-9. https://doi.org-/10.4236/oalib.1100736

Manjunath, N., Rajashekhar, C.R., Venkatesh, J., Khan, T.M.Y., Tirth, V., & Badruddin, I.A. (2021). Forensic studies on spent catalytic converters to examine the effect of diesel and b100 pongamia biodiesel on emiss-ions. *Sustainability*, *13*(19), 10729. https://doi.org/10.3390/su131910729

Matthey J. (2023 July) PGM Market Reports May 2023, http://www.platinum.matthey.com

Morcali, M.H. (2020). A new approach to recover platinum-group metals from spent catalytic converters via iron matte. *Resources, Conservation and Recycling*, *159*, 104891. https://doi.org/10.1016/j.resconrec.2020.104891

Moschovi, A.M., Giuliano, M., Kourtelesis, M., Nicol, G., Polyzou, E., Parussa, F., Yakoumis, I., & Sgroi, M.F. (2021). First of its kind automotive catalyst prepared by recycled pgms-catalytic performance. *Catalysts*, *11*(8), 942. https://doi.org/10.3390/catal11080942

OICA (Organisation Internationale des Constructeurs d'Automobiles) (2023 November) https://www.oica.net

Omrani, M., Goriaux, M., Liu, Y., Martinet, S., Jean-Soro, L., & Ruban, V. (2020). Platinum group elements study in automobile catalysts and exhaust gas samples. *Environmental Pollution*, *257*, 113477. https://doi.org/-10.1016/j.envpol.2019.113477

Padamata, S. K., Yasinskiy, A. S., Polyakov, P. V., Pavlov, E. A., & Varyukhin, D. Yu. (2020). Recovery of noble metals from spent catalysts: A review. *Metallurgical and Materials Transactions B*, *51*(5), 2413-2435. https://doi-.org/10.1007/s11663-020-01913-w

Paiva, A.P., Piedras, F.V., Rodrigues, P.G., & Nogueira, C.A. (2022). Hydrometallurgical recovery of platinum-group metals from spent auto-catalysts – Focus on leaching and solvent extraction. *Separation and Purification Technology*, *286*, 120474. https://doi.org/10.1016/j.seppur.2022.120474

Saguru, C., Ndlovu, S., & Moropeng, D. (2018). A review of recent studies into hydrometallurgical methods for recovering PGMs from used catalytic converters. *Hydrometallurgy*, *182*, 44-56. https://doi.org/10.1016/j.hydromet.2018.10.012

Statista. (2023 July), https://www.statista.com

Tang, H., Peng, Z., Li, Z., Ma, Y., Zhang, J., Ye, L., Wang, L., Rao, M., Li, G., & Jiang, T. (2021). Recovery of platinum-group metals from spent catalysts by microwave smelting. *Journal of Cleaner Production*, *318*, 128266. https://doi.org/10.1016/j.jclepro.2021.128266

Wang, L., Wang, D., & Li, Y. (2022). Single-atom catalysis for carbon neutrality. *Carbon Energy*, *4*(6), 1021-1079. https://doi.org/10.1002/cey2.194

Wiecka, Z., Cota, I., Tylkowski, B., & Regel-Rosocka, M. (2022). Recovery of platinum group metals from spent automotive converters and their conversion into efficient recyclable nanocatalysts. *Environmental Science and Pollution Research*, *30*(39), 90168-90179. https://doi.org/10.1007/s11356-022-24593-2

World Gold Council. (2023 July) http://www.gold.org

Xia, J., & Ghahreman, A. (2023). Platinum group metals recycling from spent automotive catalysts: Metallurgical extraction and recovery technologies. *Separation and Purification Technology*, *311*, 123357. https://doi.org/-10.1016/j.seppur.2023.123357

Yakoumis, I., Moschovi, A., Panou, M., & Panias, D. (2020). Single-step hydrometallurgical method for the platinum group metals leaching from commercial spent automotive catalysts. *Journal of Sustainable Metallurgy*, *6*(2), 259-268. https://doi.org/-10.1007/s40831-020-00272-9

Yakoumis, I., Panou, M., Moschovi, A. M., & Panias, D. (2021). Recovery of platinum group metals from spent automotive catalysts: A review. *Cleaner Engineering and Technology*, *3*, 100112. https://doi.org/10.1016-/j.clet.2021.100112

THE APPLICATION OF NEAR – INFRARED SPECTROSCOPY IN AUTHENTICITY ASSESSMENT OF HERBAL TEAS

Anna Dankowska

Department of Food Quality and Safety, Institute of Quality Science,
Poznań University of Economics and Business, Poznań, Poland
**Corresponding Author e-mail: anna.dankowska@ue.poznan.pl*

DOI: 10.56091/CTQS.Innov-5

Abstract

Herbal teas have been popular for centuries as a beverage with broad health benefits and an aromatic bouquet of flavour. The food industry is a fast-growing industry worldwide. With the ever-increasing consumer interest in tea drinks, there is also the problem of potential adulteration of ingredients, which negatively affects the safety and quality of the product. Blends (rosehip – coriander, coriander – cumin, green tea – dandelion root, licorice – lemongrass) and unadulterated raw materials were tested by near-infrared spectroscopy followed by statistical analysis.

NIR spectra were measured in the range between 12500 and 4000 cm^{-1}. Spectra were analysed using the multiple linear regression method (PCA-MLR). The reduction of the number of variables (PCA) was carried out for two ranges of wavenumbers. In both wave ranges, the correlation coefficient between the level of adulteration and absorbance, was close to 1, with a lower standard error of estimation in the second range compared to the first range. The use of the PCA-LDA analysis of previously obtained spectra made it possible to distinguish more expensive and cheaper raw materials and their mixtures. In the case of models that included 30%, 50% and 70% adulterants, the effectiveness of the LDA method was 100%. In addition, in the case of models created for two ranges of wavenumbers (12489-4775 cm^{-1} and 11309-4000 cm^{-1}), covering all mixtures (from 5% to 95%), the result of 100% efficiency was again achieved for three series of mixtures. However, in the case of dandelion root – green tea, the effectiveness was 90% for the first range and 88% for the second range.

Based on the conducted research, it can be concluded that the measurements of near-infrared (NIR) spectra, together with the statistical analysis of the obtained results, are an effective method of detecting adulteration of herbal teas.

Keywords: quality assessment, adulteration, herbal teas, NIR spectroscopy

Introduction

In recent years, herbal teas have become increasingly popular due to their natural properties and potential health benefits. Herbal tea, according to popular belief, resembles traditional tea in appearance and brewing process. However, it is not actually considered a true tea as it does not come from the Camellia Sinensis plant – the plant from which all types of tea are made. Herbal teas are in fact a mixture of different ingredients and are produced by combining dried raw materials such as leaves, seeds, grasses, nuts, barks, fruits, flowers and other botanicals that give them a unique flavour and provide the benefits of herbal infusions. We can distinguish different types of tea, such as black, green, red and white tea (Baffou & Quidant, 2014). Herbal teas adulteration refers to the act of intentionally replacing the substances with undeclared alternative herbs, adding some undeclared non-herb substances, or by the removal of some valuable herbs. This is usually done to lower the cost or increase the bulk.

Herbal-fruit teas, both single-ingredient and multi-ingredient, are widely available on the market. Until recently, single-ingredient herbal teas were treated only as simple herbal remedies and could be found mainly in pharmacies. Bioactive compounds found in herbal teas and drinks have been found to have beneficial properties in preventing metabolic diseases such as diabetes, glucose intolerance and obesity (Pyrzynska & Sentkowska, 2019, Chapter 5). In herbal raw materials, you can find many different chemical compounds that affect their characteristics and health properties. Among these compounds, several dozen substances are mentioned, such as purine alkaloids, amino acids, polyphenolic compounds, vitamins and microelements. However, special attention should be paid to polyphenolic compounds that are important for herbal teas, including flavonoids, tannins and catechins (Chung et al., 1998). In the past, the use of these teas was motivated by their impact on human health, but nowadays more and more attention is paid to their taste and aroma (Newerli-Guz & Kobylańska, 2013).

The production process of herbal teas is diverse and more advanced than the production process of teas derived from Camellia Sinensis leaves, because the raw materials used are processed at different times of the year and with various techniques (Nguyen & Chuyen, 2020). Nevertheless, a general process can be distinguished, which includes: collection of raw materials, drying, mixing, storage. The production process of herbal infusions is strictly controlled to ensure the quality of the product. It is worth noting, however, that the production process of herbal teas may vary depending on the raw material and method of preparation. Some herbs may require additional steps, such as fermentation or grinding, to achieve the desired properties. The main producers of herbal tea are primarily such countries as Kenya, Rwanda, Tanzania, Uganda, Zimbabwe, Argentina and Brazil (Hicks, 2009).

Separation techniques such as liquid chromatography, gas chromatography, mass spectrometry, high-performance capillary electrophoresis etc., have been employed for the identification and quantification of compounds present in different plant matrices (Huck, 2015). The most commonly used procedures for the analysis of herbal classification are analytical techniques, based on chromatographic methods (Lucci et al., 2017, Tistaert et al., 2011). This technique is very useful for the identification of examined material but it is time-consuming and demands careful sample preparation process. However, spectroscopic techniques are often applied in routine food analyses. These procedures are being developed to complement or replace chromatographic methods in the rapid assessment of sample similarity – for the quality control of herbal raw material (Bunaciu et al., 2011; Rohman et al., 2014; Huang et al., 2016). An important advantage of NIR spectroscopy is the ability to directly measure the spectra of the samples in different forms. The spectral bands in the NIR range are less intense than those in the MIR range, which is beneficial for the samples with a high optical density and allows them to be measured directly without the need for dilution or other preparations. Methods based on the spectral analysis cannot provide information about the chemical composition of the sample. The spectral pattern of a food product may also be affected by the physical properties of the sample. Therefore, the use of chemometrics in the analysis of spectral data is necessary due to the limited selectivity of signals. Chemometrics is used qualitatively for grouping or classifying unknown samples with similar characteristics and quantitatively for determining components or adulterant analytes in samples (Moore et al., 2010). The combination of spectral data with chemometrics analysis extracts information useful for authenticity tests or detection of the presence of undesired components. Spectroscopic techniques are well known for their high efficiency, fastness, reliability and easy use. They commonly do not demand sample pre-treatments nor reagents, showing to be green analytical tool alternatives (Winkler-Moser et al., 2015; Brondi et al., 2016; Correia et al., 2018) .

Considering the lack of information on some of the most recent materials used for herbal tea fraud, and the increased use of multiple adulterations, this work aimed to study the feasibility to classify different herbal tea ingredients, based on NIR spectral information.

Materials and methods

Experimental material

The research objects were plant samples – wild rose, coriander, cumin, green tea, dandelion root, licorice and lemongrass. The raw materials were obtained from a Poznań-based company dealing, among others, in the production of teas and herbal teas. The blends were made from plants such as wild rose, coriander, cumin, green tea, dandelion root, licorice and lemongrass. 4 series of mixtures were prepared (rosehip – coriander, coriander – caraway, green tea – dandelion root, licorice – lemongrass). The first three series of 11 samples each (5, 20, 30, 40, 50, 60, 70, 80, 90 and 95% adulteration), and the 4th series of mixes contained 7 samples (30, 40, 50, 60, 70, 90% adulteration), making the total number of experimental mixtures equalled 40. In the mixtures, the more expensive raw material was adulterated in various percentages with cheaper raw material., Rosehip was adulterated with coriander, and in the second mix, cumin was adulterated with coriander. The more expensive raw material in the third blend was dandelion root and the cheaper green tea. The licorice was adulterated with lemongrass. The division into more expensive and cheaper raw material results from the difference in the prices of these herbs.

Near-infrared spectra measurement

In order to evaluate the analysis of the teas, measurements in the near-infrared (NIR) range were performed to detect adulterations in previously prepared experimental blends. Spectrophotometer MPA/FT-NIR, manufactured by Brüker, was used to measure spectra in the near infrared. A total of 40 experimental mixtures were prepared, which were measured in four repetitions, obtaining a total of 160 spectra. In addition, spectral measurements were carried out for pure raw materials, which gave a total of 28 spectral measurements. The number of spectra with mixtures and pure raw materials was 188. Experimental samples were placed into a measuring vessel. Vessel was removed and cleaned before performing the next measurement. In the next stage of the analysis, the spectra of the prepared samples were measured in the near-infrared (NIR) range, which covers the range of 12500-4000 cm^{-1}. The resolution of the spectrum was 4 cm^{-1} and the number of interferograms was 16. The spectra were presented as the ratio of absorbance to wavenumber. The measurement was repeated four times. The study was carried out using the MPA/FT-NIR Spectrophotometer. The determination consists in measuring spectra in the near-infrared range (12500-4000 cm^{-1}) of the tested mixtures, which consist of the more expensive raw material (wild rose, cumin, dandelion root) and the cheaper raw material (coriander, green tea, lemongrass). The purpose of these detailed analyzes was to detect adulteration.

Statistical analysis

In order to perform the statistical analysis, principal components analysis (PCA), a multiple linear regression (MLR) and linear discriminant analysis (LDA) were used. Principal component analysis (PCA) was used, among other things, to reduce the number of variables used to describe phenomena and to discover the relationships between these variables. Statistical analyzes were performed using Statistica 13.0 software.

Results and discussion

During the experiment, near-infrared (NIR) spectra were plotted for rosehip, coriander, cumin, green tea, dandelion root, licorice, lemongrass and experimental blends. The near-infrared spectra for un-adulterated raw materials and experimental mixtures were obtained in the next step. The mixtures included: wild rose – coriander, green tea – dandelion root, cumin – coriander and licorice – lemongrass.

Analyzing the spectra, it can be seen that wild rose shows a higher absorption intensity than coriander in the range of 3600-7500 cm^{-1}. On the other hand, the absorption spectrum for dandelion root is characterized by higher absorption intensity in the entire near-infrared range. Coriander and cumin show a similar intensity of absorption in the NIR range, while the absorption spectrum of licorice shows a higher intensity than lemongrass (Fig. 1).

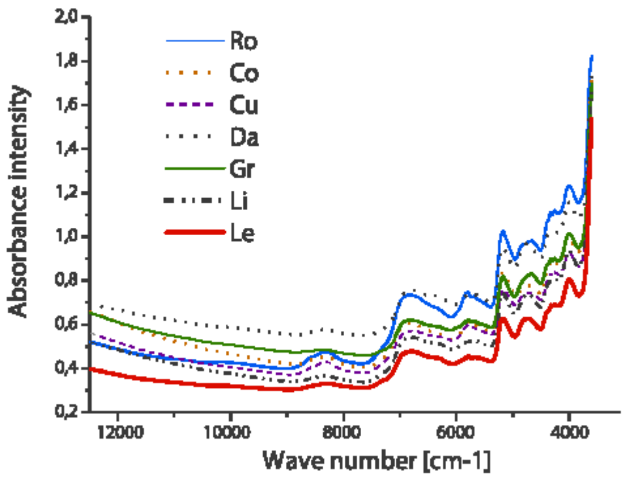


Fig. 1. Average spectra in near-infrared range of different herbs

Source: own study.

Statistical methods – PCA-MLR

In order to reduce the number of variables, principal components analysis (PCA) and then multiple linear regression (MLR) were used to assess the effectiveness of predicting the level of adulteration in the prepared series of mixtures. Multiple linear regression models were highly predictive.

The data presented in table 1 refer to the first (12489-4775 cm^{-1}) and second (11309-4000 cm^{-1}) range. The average correlation coefficient for the four series was 1, the coefficient of determination was 0.9, the root mean standard estimation error was 8% and root mean square error of cross validation equalled 8.7%.

Table 1. Parameters of PCA-MLR models built on the basis of NIR spectra in two wavenumber ranges

Raw Materials	R	R^2	RMSEC [%]	RMSECV [%]	R	R^2	RMSEC [%]	RMSECV [%]
	Range (12489-4775 cm^{-1})				Range (11309-4000 cm^{-1})			
I series: Wild rose – coriander	1.0	0.9	10.2	11.1	0.9	0.9	9.2	9.7
II series: Cumin – coriander	1.0	1.0	4.5	5.1	1.0	1.0	4.4	5.3
III series: Dandelion root – green tea	1.0	1.0	4.6	4.9	1.0	1.0	5.7	6.3
IV series: Licorice – lemongrass	0.9	0.8	12.8	13.5	0.9	0.9	8.5	9.1
Average value	1.0	0.9	8.0	8.7	1.0	0.9	6.9	7.6

Where: R – correlation coefficient, R^2 – coefficient of determination, RMSEC – root mean standard error of calibration, RMSECV – root mean square error of cross validation.

Source: own study.

In the case of data obtained for the second range (11309-4000 cm^{-1}), it can be seen that the correlation coefficient is also close to 1 and the coefficient of determination is 0.9. The standard estimation error is lower than in the first range (8%) and amounted to 6.9%. The root mean square error of cross validation equalled 7.6% and was also lower than in the first range (8.7%).

The PCA-LDA method (linear discriminant analysis) was used to assess the classification capabilities of the spectroscopic method used. Four series of mixtures were analyzed in two wavenumber ranges: 12489-4775 cm^{-1} and 11309-4000cm^{-1}. First, pure raw materials and mixtures of 30%, 50% and 70% of the adulterant were analyzed. Analyzing Figure 2, it can be noticed that unadulterated raw materials and mixtures form separate classes. The LDA method used in this study achieved 100% classification efficiency. The analysis resulted in clear subgroups of unadulterated products and their blends for all four batches of blends and two measurement ranges. Then, PCA-LDA models were built, which included mixtures with different levels of adulteration (5, 20, 30, 40, 50, 60, 70, 80, 90 and 95%). The graphic arrangement of the samples in space is shown in the Figure 2.

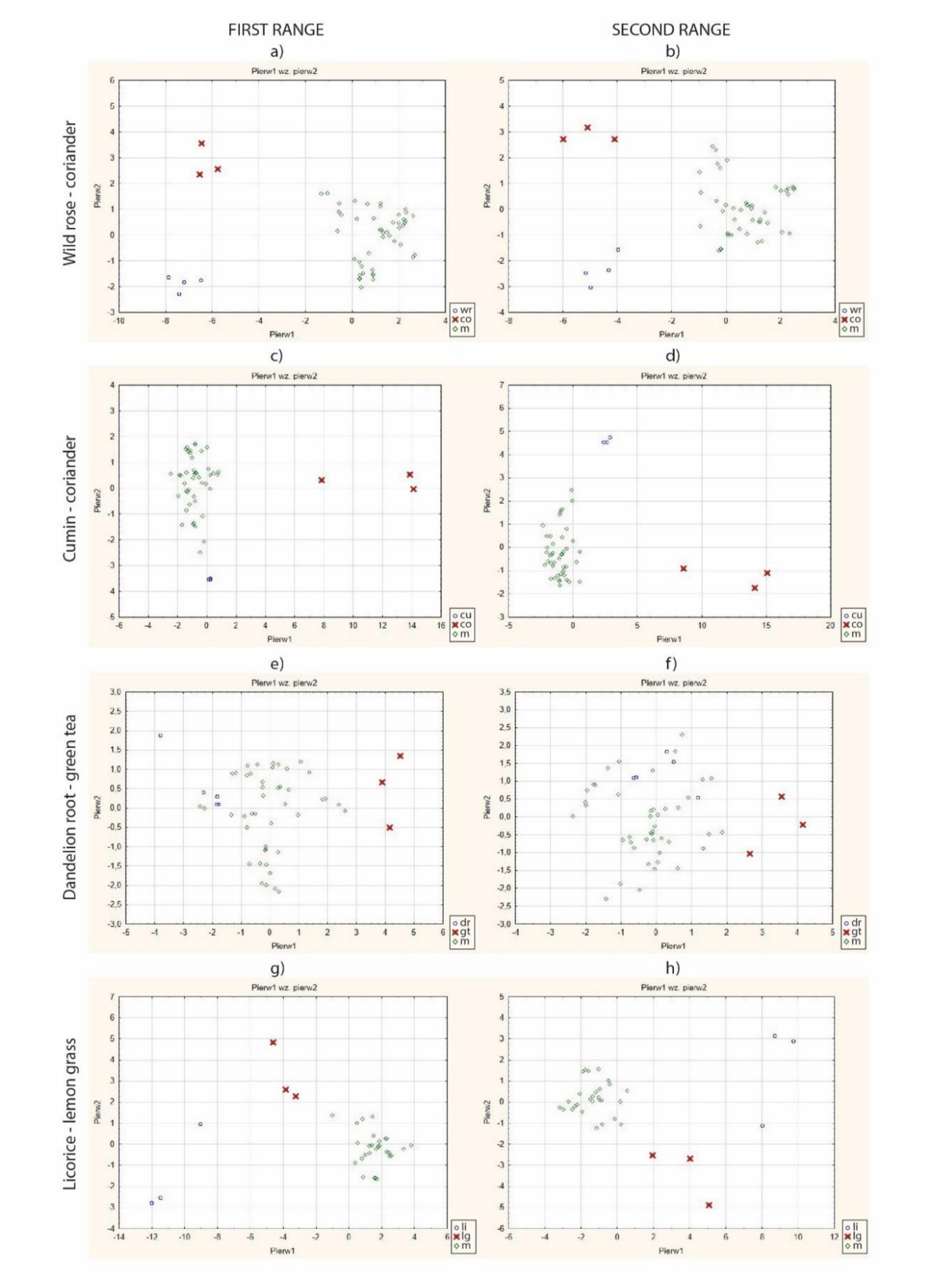


Fig. 2. Scores plot of the PCA-LDA models developed for two ranges of wavenumbers and with samples containing distinct herbs and herbal mixtures: (**A**), (**B**) Wild rose – coriander; (**C**), (**D**) Cumin – coriander; (**E**), (**F**) Dandelion root – green tea; (**G**), (**H**) Licorice – lemongrass

Source: own study.

Table 2 shows the percentage of tea samples that were correctly classified into different subgroups: rosehip, coriander, cumin, dandelion root, green tea, licorice, lemongrass and their blends (5, 20, 30, 40, 50, 60, 70, 80, 90 and 95%). Using the PCA-LDA model, 100% classification was obtained for the 1st series (rosehip – coriander), for the 2nd series (cumin – coriander) for the second range and for the 4th series (licorice – lemongrass). In the case of 3 series (dandelion root – green tea), a slightly lower classification was obtained – in the first range 90%, and in the second range 88%. It can be considered that these are still high results, which confirms that the LDA method is an effective tool.

Table 2. Percentage of correctly classified samples of blends and unadulterated raw materials in two ranges.

Percentage of correctly classified samples [%]		
Raw Materials	First range (12489-4775 cm^{-1})	Second range (11309-4000 cm^{-1})
I series: Wild rose – coriander	100	100
II series: Cumin – coriander	98	100
III series: Dandelion root – green tea	90	88
IV series: Licorice – lemongrass	100	100

Source: own study.

For comparison, Lai et al., (2011) examined the potential of NIR spectroscopy methods for the discrimination of Rhizoma Corydalis according to its geographical origins using LS-SVM, radial BP-ANN, PLS-DA and k-nearest neighbour (KNN) methods. LS-SVM performed best with a correct discrimination rate of over 95%. Chen et al., (2014) used NIR spectroscopy combined with machine learning techniques for the classification of three Chrysanthemum species and obtained achieved similar accuracy rates (between 86% and 95%). Linear discriminant analysis (LDA) and partial least squares-discriminant analysis (PLSDA) was applied by Fu et al., (2015) to identify two common kinds of herbal medicines, *Hibiscus mutabilis L.* and *Berberidis radix*, on the basis of NIR spectra. Excellent forecasted results were obtained, all with the recognition rate of 100%.

Conclusions

The aim of this research work was to evaluate the effectiveness of near-infrared (NIR) spectral measurements in the context of detecting adulteration of herbal tea ingredients. By carefully examining the spectral differences between the more expensive raw materials wild rose, cumin, dandelion root and the cheaper raw materials coriander, green tea and lemongrass, it was possible to detect potential adulterations.

PCA-LDA models were used to predict the level of adulteration in four series of experimental mixtures. The reduction of the number of variables (PCA) was carried out for two ranges of wavenumbers (12489-4775 cm^{-1} and 11309-4000 cm^{-1}). In both wavenumber regions the correlation coefficient was close to 1, with a lower standard error of estimation and validation in the second range (11309 -4000 cm^{-1}) compared to the first range (12489-4775 cm^{-1}).

PCA-LDA analysis was used to examine the possibility to distinguish more expensive and cheaper raw materials and their mixtures on the basis of NIR spectra. LDA method was 100% effective for models that included 30%, 50% and 70% adulterant. In addition, in the case of models created for two ranges of wavenumbers, covering all mixtures (5, 20, 30, 40, 50, 60, 70 , 80, 90 and 95%), 100% efficacy was again achieved for 1, 2 and 4 series of mixtures (for the second range). However, in the case of 3 series (dandelion root – green tea), a slight decrease in classification was observed (90% for the first range and 88% for the second range). Classification accuracy of 90% can be considered as satisfying, as the level of adulteration are usually higher.

On the basis of the conducted tests and statistical analysis of the obtained results, it was clearly stated that the method of measuring near-infrared (NIR) spectra is an effective tool for detecting adulteration of more expensive raw materials (rosehip, cumin, dandelion root) by cheaper raw materials (coriander, green tea, grass lemon).

References

Baffou, G., & Quidant, R. (2014). Nanoplasmonics for chemistry. *Chemical Society Reviews*, *43*(11), 3898. https://doi.org/10.1039/c3cs60364d

Brondi, A., Torres, C., Garcia, J., & Trevisan, M. (2016). Differential scanning calorimetry and infrared spectroscopy combined with chemometric analysis to the determination of coffee adulteration by corn. *Journal of the Brazilian Chemical Society*. https://doi.org/10.21577/0103-5053.20160296

Bunaciu, A.A., Aboul-Enein, H.Y., & Fleschin, S. (2011). Recent applications of fourier transform infrared spectrophotometry in herbal medicine analysis. *Applied Spectroscopy Reviews*, *46*(4), 251-260. https://doi.org/-10.1080/05704928.2011.565532

Chen, C., Yan, H., & Han, B. (2014). Rapid identification of three varieties of Chrysanthemum with near-infrared spectroscopy. *Revista Brasileira de Farmacognosia*, *24*(1), 33-37. https://doi.org/10.1590/0102695X2014241-3387

Chung, K.-T., Wong, T.Y., Wei, C.-I., Huang, Y.-W., & Lin, Y. (1998). Tannins and human health: A review. *Critical Reviews in Food Science and Nutrition*, *38*(6), 421-464. https://doi.org/10.1080/10408699891274273

Correia, R. M., Tosato, F., Domingos, E., Rodrigues, R. R. T., Aquino, L. F. M., Filgueiras, P. R., Lacerda, V., & Romão, W. (2018). Portable near-infrared spectroscopy applied to quality control of Brazilian coffee. *Talanta*, *176*, 59-68. https://doi.org/10.1016/j.talanta.2017.08.009

Fu, H., Fan, Y., Zhang, X., Lan, H., Yang, T., Shao, M., & Li, S. (2015). Rapid discrimination for traditional complex herbal medicines from different parts, collection time, and origins using high-performance liquid chromatography and near-infrared spectral fingerprints with aid of pattern recognition methods. *Journal of Analytical Methods in Chemistry*, *2015*, 1-10. https://doi.org/10.1155/2015/727589

Hicks, A., (*2009)* Current Status and Future Development of Global Tea Production and Tea Products. *AU Journal of Technology, 12*, 251-264.

Huang, C.-C. (2016). Applications of Raman spectroscopy in herbal medicine. *Applied Spectroscopy Reviews*, *51*(1), 1-11. https://doi.org/10.1080/05704928.2015.1092154

Huck, C., (2015) Infrared Spectroscopic Technologies for the Quality Control of Herbal Medicines. *In Evidence-Based Validation of Herbal Medicine*; Elsevier: Berlin/Heidelberg, Germany. doi: 10.1016/B978-0-12-800874-4.00022-2

Lai, Y., Ni, Y., & Kokot, S. (2011). Discrimination of Rhizoma Corydalis from two sources by near-infrared spectroscopy supported by the wavelet transform and least-squares support vector machine methods. *Vibrational Spectroscopy*, *56*(2), 154-160. https://doi.org/10.1016/j.vibspec.2011.01.007

Lucci, P., Saurina, J., & Núñez, O. (2017). Trends in LC-MS and LC-HRMS analysis and characterization of polyphenols in food. *TrAC Trends in Analytical Chemistry*, *88*, 1-24. https://doi.org/10.1016/j.trac.2016.12.006

Moore, J. C., Spink, J., & Lipp, M. (2012). Development and application of a database of food ingredient fraud and economically motivated adulteration from 1980 to 2010. *Journal of Food Science*, *77*(4). https://doi.org-/10.1111/j.1750-3841.2012.02657.x

Newerli-Guz, J., & Kobylańska, A., (2013) Ocena jakości jednoskładnikowych herbatek ziołowych na przykładzie Mentha piperita. *Problemy Higieny Epidemiologicznej*, 94(4), 862-865.

Nguyen Q.V. & Chuyen H.V., (2020) Processing of Herbal Tea from Roselle (*Hibiscus sabdariffa* L.): Effects of Drying Temperature and Brewing Conditions on Total Soluble Solid, Phenolic Content, Antioxidant Capacity and Sensory Quality. *Beverages*.;6 (1) 2. https://doi.org/10.3390/beverages6010002

Pyrzynska, K., & Sentkowska, A., (2019) Herbal Beverages as a Source of Antioxidant Phenolics In A. M. Grumezescu & A. M. Holban *Natural Beverages,* pp. 125-142, Academic Press. https://doi.org/10.1016/-C2017-0-02387-X

Rohman, A., Nugroho, A., Lukitaningsih, E., & Sudjadi. (2014). Application of vibrational spectroscopy in combination with chemometrics techniques for authentication of herbal medicine. *Applied Spectroscopy Reviews*, *49*(8), 603-613. https://doi.org/10.1080/05704928.2014.882347

Tistaert, C., Dejaegher, B., & Heyden, Y.V. (2011). Chromatographic separation techniques and data handling methods for herbal fingerprints: A review. *Analytica Chimica Acta*, *690*(2), 148-161. https://doi.org/10.1016/-j.aca.2011.02.023

Winkler-Moser, J.K., Singh, M., Rennick, K.A., Bakota, E.L., Jham, G., Liu, S.X., & Vaughn, S.F. (2015). Detection of corn adulteration in brazilian coffee (*coffea arabica*) by tocopherol profiling and near-infra-red s(Nir)pectroscopy. *Journal of Agricultural and Food Chemistry*, *63*(49), 10662-10668. https://doi.org/-10.1021/acs.jafc.5b04777

THE USE OF EMERGING METHODS IN DETERMINING THE INFORMATION EFFECTIVENESS OF NUTRITION LABELS

Jakub Berčík, Jana Gálová*, Adriana Rusková, Patrik Jurčišin

Institute of Marketing, Trade and Social Studies, Faculty of Economics and Management,
Slovak University of Agriculture in Nitra, Nitra, Slovakia
**Corresponding Author e-mail:* jana.galova@uniag.sk

DOI: 10.56091/CTQS.Innov-6

Abstract

In general, consumers are increasingly choosing foods based on their health benefits, if their income allows it. Therefore, knowledge of the nutritional value of foods can motivate consumers to change their dietary habits, and nutrition labels can offer guidance in this choice. However, there are several types of nutrition labels, which differ in visual attractiveness and comprehensibility. Within testing the perception of these labels using eye tracking, although the more direct labels attract less visual attention, they lead to better ratings and understanding of nutritional quality. Other research suggest that these labels are mostly unable to influence dietary behaviour change. The study aimed to reveal the impact of the effectiveness of nutrition labels on consumer decision-making in choosing healthier alternatives for selected food types. Traditional research methods (questionnaire) with emerging methods (eye tracking and face recognition) enabled a more comprehensive view of consumer decision-making through the collection of implicit feedback. Research suggests that there are significant differences between implicit and explicit feedback when examining the impact of nutrition labels. The study also presents ideas for future research in real-world settings using emerging methods.

Keywords: emerging methods, front-of-pack nutrition label (FOPL or FOPNL), Nutri-score, NutrInform, nutrition labelling

Introduction

There are many different divisions of factors influencing consumer behaviour available in scientific literature. Stávková et al., (2008) surveyed the influence of factors biasing purchase decisions connected with measurement of consumers' involvement, based on the classification of factors into three basic categories by Brown (2006): personal, psychological, and social factors, to which Kotler (2001) added the cultural factors. Horská and Sparke (2007) defined personal factors as those that are unique for each consumer, and include age, sex, place of domicile, occupational and economic conditions, personality and self-consciousness.

Some of these factors have direct impact on the consumer’s buying process, for example age and (family) life-cycle influence consumer behaviour because of changing the purchase of goods and services with time, occupation and economic situation decide about the costs and quantity of goods and services consumers can afford or personality that can be useful to determine the consumer behaviour for particular product or service (Jisana, 2014). The personality of the consumer plays an important role in the real store but also in the online environment, where they may use different identities or alter egos to increase their chances of socializing and communicating with others (Cetină et al., 2012). Ramya and Ali (2016) expressed that the lifestyle of a consumer shows the person interacting with the environment, and that is why marketing managers should design various marketing strategies to suit consumer lifestyles. Therefore, according to a study by Rehman et. al., (2017), personal characteristics have huge impact on consumer behaviour towards buying decisions, as consumers often hunt for and decide due to their personal options, also in the case of healthy eating.

A good understanding of the physiological and emotional response of consumers to food products is essential for success in food product design and food service (Songsamoe et al., 2019). Although food labels offer an increasing amount of information about the nutritional value of the product, Tarabella and Voinea (2013) noted that many consumers have difficulties in understanding the complex nutritional information presented on them. A simpler way to receive this information is more helpful for rapid evaluation of the nutritional characteristics of food products, in order to make healthy choices. Nutrition labels of food composition or ecological parameters of packaging have therefore come to the fore within current food market trends which influence consumer food choices. Ultimately, however, price is still much more important in purchasing decisions than nutritional composition or environmentally friendly packaging.

A comprehensive review of nutrition labelling is offered by Bonsmann et al., (2020). Azman and Sahak (2014) defined nutrition labelling as a description used for informing customers about the nutritional properties of food, which also helps customers to purchase nutritious foods and consume nutritionally balanced meals. The WHO (2022) highlights that the labelling of packaged foods is considered to be the main means of communication both between the food producer and food seller, as well as between the buyer and consumer. According to Neal et al., (2017), nutrition labelling is a policy tool that can be used to promote healthy food choices and better eating habits.

More than 30 types of front-of-pack nutrition labels (FOPL or FOPNL) already exist (have been proposed or are in place) around the world to inform consumers about the overall energy and nutritional value of a food or beverage (Nohlen et. al., 2022). FOPL are usually classified into two main types: directive and semi-directive using colour schemes (such as the Nutri-Score label) and informative (such as the NutrInform label) (Donini et al., 2023). Some of the FOPL types express the nutritional value of a product using some or all of the information from the Nutrition Facts or other nutritional elements (e.g., Nutri-score), while others display specific numerical information from the mandatory nutrition label in a so-called neutral manner (e.g., NutrInform) (Angelino et al., 2023).

The Nutri-Score is a graphical nutrition scheme based on the UK Food Standards Agency model that divides nutrition scores into five coloured categories (dark green, light green, yellow, orange, red) associated with letters from A to E, based on both the "negative" and "positive" elements per 100 g or 100 ml of food (EUFIC, 2022). The system was introduced by the French National Agency for Public Health and the French government in March 2017 (Berčík, 2021).

The NutrInform battery is based on the Guideline Daily Amounts – Reference Intake (GDA/RI) label with an added battery symbol that indicates the amounts of energy and nutrients in a single serving as a percentage of the daily intake (Muller & Ruffieux, 2020). It was developed in Italy and involved nutritionists from the Italian Institute of Health and the Food and Economic Research Council, with representatives of category associations of the food and agricultural sectors and consumers as well, under the leadership of four ministries. The label is voluntary and not compulsory, and each of the five batteries indicates the percentage and amount of the variable it displays in relation to a portion of the product purchased (NutrInform Battery, 2022).

It should be noted that the Nutri-score rating is based on 100 g or 100 ml of a product (not per estimated portion/food serving as according to NutrInform), and gives the evaluation based on the composition and characteristics of the food, but which often does not correspond to the actual portion, which is either significantly higher or lower for the consumer (Carruba et al., 2022). A disadvantage can be a negative impact on the perception of foods from the category labelled worst, despite the fact that Nutri-score does not explicitly suggests their consumption is bad, but the amount consumed should be considered (e.g., in case of prosciutto ham or parmesan cheese). The implementation of Nutri-score was also assessed by Hau and Lange (2023) and considered an inexpensive public policy that can bring some positive benefits to a country, but this should not prevent a country from seeking more effective measures leading to a reduction in obesity and promoting healthier product choices.

These informative tools have not only their supporters but also their detractors among EU countries. An example is shown in the research of Garrido Fernández & López-López (2022), aimed at comparing the aforementioned two label types. Since olive oil produced in Spain reached deficient classification based on Nutri-score, there were initiatives developed for selecting a more appropriate FOPL, considering the numerous health benefits internationally recognised for this product type.

Finding the right FOPL is still a major challenge for public policy makers seeking to facilitate healthier food choices when shopping and at the same time to effectively counteract the growing obesity pandemic (De Temmerman et al., 2021). Furthermore, the evidence linking the application of FOPL to improvements in consumer health is still scarce and without causal association yet (Donini et al., 2023).

Materials and methods

The aim of the study was to reveal the influence and effectiveness of selected nutrition labels (Nutri-Score – NS and GDA in NutrInform) on consumer decision-making in choosing healthier alternatives for selected food types. The research was conducted in two phases. The first, quantitative survey focused on the perception of health aspect in food purchasing, conducted on a sample of 700 respondents from each region in Slovakia (52% men and 48% women, aged 18 to 75 years). The survey was carried out from 19 February 2023 to 25 February 2023 via the SAMO Europe full managed access panel. Respondents also provided information on their weight and height in order to calculate BMI. This survey also aimed to investigate the influence of the aforementioned two nutrition labels in the choice of a protein/muesli bar. Altogether 3 bars (one muesli bar and two protein bars) were chosen as test subjects. The bars were labelled with the fictitious brand "Faim" to avoid biasing the data. The design of this survey was based on the methodology used in the study of Egnell et al., (2020) on the efficiency of FOPL labels and nutritional quality of food products among Swiss consumers.

The second, qualitative research was carried out in laboratory conditions at the Laboratory of Consumer Studies (Faculty of Economics and Management, Slovak University of Nitra, Slovakia) using emerging methods (stationary eye tracker by Tobii and FaceReader by Noldus). The visual of the 3 bars of the fictitious brand "Faim" were tested, which differed in nutritional composition and were displayed sequentially, first without nutrition labels, then with NS and with GDA in the end. The intention was to obtain information on visual and emotional attractiveness.

During testing, conscious feedback was obtained through a guided interview in addition to unconscious feedback. The research was conducted in April 2023 and involved 15 healthy respondents (8 females and 7 males) who consume functional foods.

We have developed the following research assumptions:
1. Nutrition labelling influences consumer decision-making.
2. Nutrition labelling influences visual attention.
3. Nutritional information has an impact on arousal levels.

All primary data collected were processed by descriptive statistics (mean and median) and inductive statistics (Mann Whitney U-test and McNemar test using XLSTAT 2022). The MannWhitney test is a nonparametric test that allows two independent samples to be compared. It can only be used to investigate the samples' relative locations. Spearman correlation coefficients is used to analyse relationships between ordinal variables. We also used the McNemar test to analyse changes in binary paired samples. This is also known as a test of difference between two correlated for proportions, it is a special case of the Cochran's Q test (in the case where there are 2 treatments), used on randomized complete blocks of binary data.

Results and discussion

Nutrition labelling can simplify the whole concept of healthy diet by helping customers observe and track their intake of nutrients such as fat and sugar, sodium and fibre, protein and carbohydrates. It also helps consumers to make an informed judgement about the overall value of the product. Customers are increasingly interested not only in the appearance of products but also in their nutritional information. The use of nutrition labelling mainly influences the purchasing behaviour since consumers want to avoid the adverse nutrients in products (Azman & Sahak, 2014).

Graham et al., (2012) synthesized the existing findings from research using eye-tracking methodology to assess consumer attention to nutrition labels and discussed the studies' implications for design of nutrition labels and food packages. In the study of Siegrist et al., (2015), the effectiveness of three formats of nutrition labelling (the nutrition table format, the GDA format, and the traffic light format) was examined by using the eye-tracking method combined with an experimental approach. Mušura Gabor et al., (2020) carried out a study with 76 Croatian participants on eight different chocolate snack bars using eye tracker. Ma and Zhuang (2021) reviewed 45 eye-tracking studies on nutrition label processing. The research of Van Loo et al., (2021) utilized eye-tracking measures to quantify the visual attention paid to claims for nutrition and sustainability on food concepts.

In our study, the quantitative survey measured consumers' attitudes towards healthy eating. 90% of respondents indicated that healthy eating was important to them, with 35% indicating that it was very important. Only 25 respondents (4%) stated that healthy eating was not important at all for them. These results suggest that at a declarative level, healthy eating is important to most respondents (see Fig. 1).

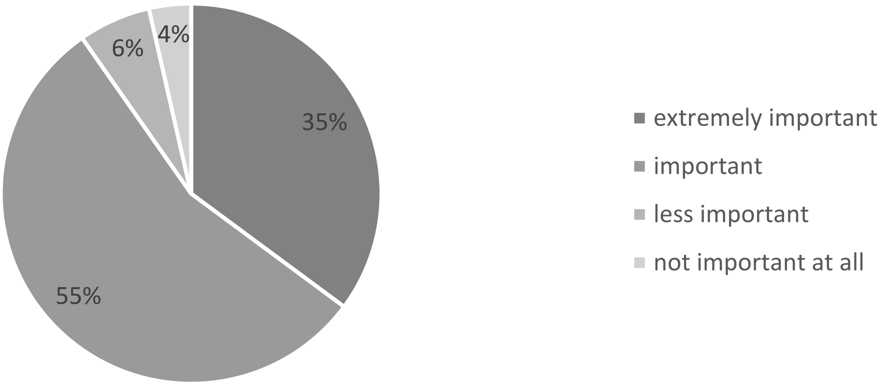


Fig. 1. The importance of healthy eating

Source: own elaboration based on own research (2023).

Related to this is the attention paid to buying healthy food (see Fig. 2). Of the 700 respondents, 46% stated that they pay high and 23% even very high attention to buying healthy food, which is not reflected in the data based on the calculated BMI of the overweight (34.5%) and obese sample (28.5%).

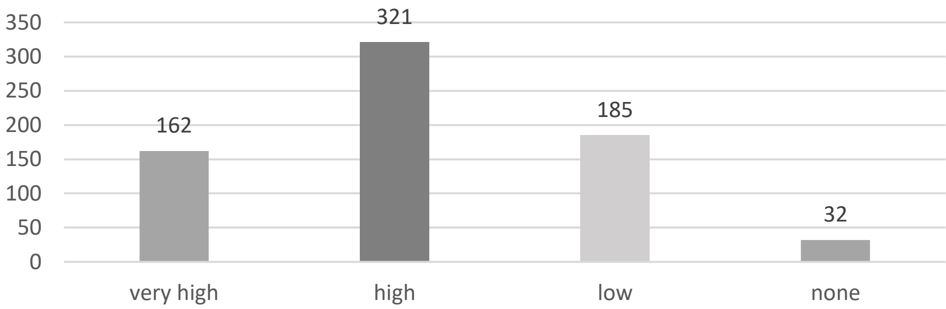


Fig. 2. Mindfulness when buying healthy food

Source: own elaboration based on own research (2023).

As mentioned above, the aim of the study was to investigate the influence of nutrition labels in the selection of functional foods with the "Faim" fictitious brand. In terms of frequency of purchase, muesli/protein bars are purchased regularly by 56 respondents and frequently by 123 respondents out of the total sample of 700 respondents. As many as 505 respondents said that they buy this type of product sometimes (see Fig. 3).

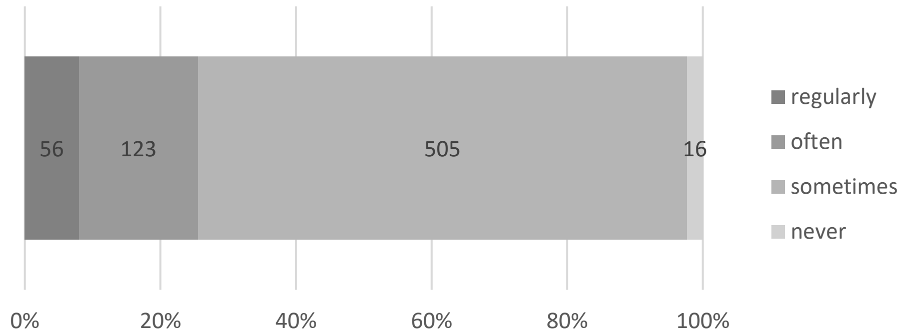


Fig. 3. Frequency of purchase of functional foods

Source: own elaboration based on own research (2023).

In addition to the general questions, preference for a specific product was tested (see Table 1). Respondents first made their choice based on packaging alone. Subsequently, pictures of nutrition labels with Nutri-score and NutrInform were added. For the Nutri-score label, there was a better effect of influence on consumer choice (a 6.2% increase for the nutritionally superior variant and a 35.8% decrease for the least superior variant of the product).

Table 1. Choice of labelled vs. unlabelled products (bars)

Choice without label			**Choice with label (Nutri-Score)**		**Choice with label (NutrInform)**	
Product	Absolute frequency	Relative frequency	Absolute frequency	Percentage change	Absolute frequency	Percentage change
Muesli bar cocoa	245	35%	88	**decrease by 35.8%**	90	decrease by 33.5%
Protein bar chocolate	259	37%	54	**decrease by 14.1%**	62	decrease by 12.3%
Protein bar nougat	196	28%	208	**increase by 6.2%**	198	increase by 1.0%

Source: own elaboration based on own research (2023)

In the product category of bars, there was a clear effect of the influence of the Nutri-score label on consumer choice as it ensured the largest increase in preference for the nutritionally highest quality variant – Protein bar nougat (6.2%) and at the same time the largest decrease (35.8%) of the nutritionally lowest quality bar – Muesli bar cocoa (which is a best seller with the most popular flavour in the country) in terms of the compared versions.

If we consider the sample with both consumers and non-buyers, we can confirm at the standard significance level (α = 0.05) a significant improvement of the Swiss model score for the bar product in favour of Nutri-score and for the sample after excluding respondents who do not buy for the bar product we can only confirm at a weaker significance level (α = 0.10). Thus, we confirmed the first research assumption.

The quantitative survey with eye tracker and FaceReader compared 3 visuals showing the bars without and with nutrition labels. Each of the 3 visuals showed 3 different bars with different nutritional composition (muesli bar, protein bar chocolate, protein bar nougat). The nutritional composition was recalculated based on the respective formulas and after consultation with a nutritional expert.

The results from the eye tracking camera are presented via heat maps. These aggregate data on the most viewed locations, but also on the locations where the respondent spent the most time looking. As seen on the heat map (Fig. 4), the name of the product and the flavour itself attracted the most visual attention. The weight of the product was also an important element of visual appeal., Respondents also noticed the brand name "Faim", probably because they were not familiar with it.

Fig. 4. Heat map of visual attention in the selection of bars without a nutrition label
Source: own elaboration based on own research (2023).

After adding the nutrition label NutrInform to the bars (Fig. 5), they represented a significant element of visual attractiveness. This label was the most eye-catching in the case of the Protein bar chocolate. The information on fat and sugars was of particular interest to the respondents, with higher levels of visual attention for this information seen for all three products. The actual nutrition label placed on the product was only noticed by the respondents on the bar placed in the middle of the visual, which may also be due to the digital display of the product.

Fig. 5. Heat map of visual attention in the selection of bars with the NutrInform FOPL

Source: own elaboration based on own research (2023).

Figure 6 shows the visual attention when looking at the bars with the Nutri-score nutrition label. In this case, respondents also viewed the label directly on the products. In terms of visual attractiveness, the ones with the nutrition label category "E" and "C" were the most eye-catching. This may be due to the respondents' desire to associate the products with their nutritional composition. In this case, we confirmed the second research assumption.

Fig. 6. Heat map of visual attention when selecting bars with the Nutri-score FOPL

Source: own elaboration based on own research (2023).

In addition to visual attention, the emotional response of the respondents was also monitored through FaceReader (see Fig. 7). The object of interest was the level of arousal when viewing each visual., The highest level, based on mean values (0.52), was recorded for the bars with Nutri-score. This may also be largely indicative of a better comprehension rate for this label compared to NutrInform (0.48). The lowest level of arousal was observed for the bars without the nutrition labels (0.36). This confirmed the third research assumption.

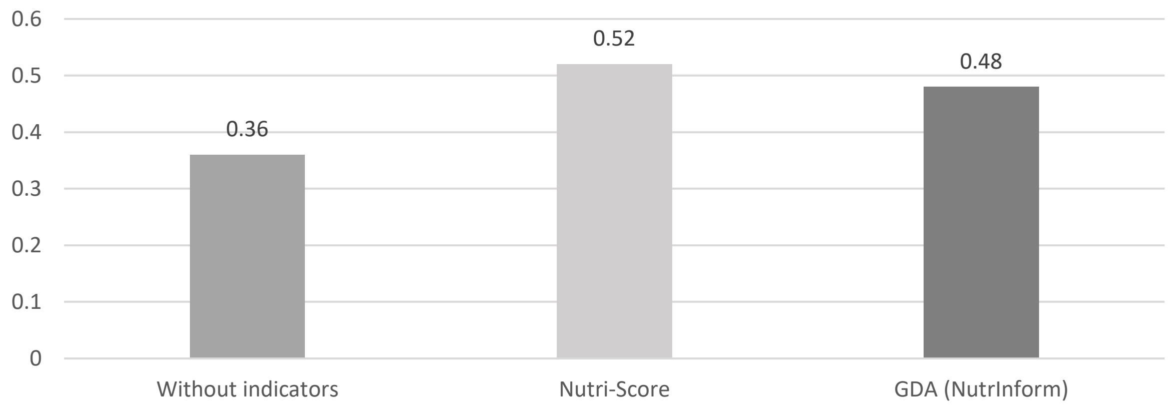


Fig. 7. Level of arousal when selecting functional bars without labelling and using nutrition labels (Nutri-score and NutrInform)

Source: own elaboration based on own research (2023).

Conclusions

Despite higher BMI values (34.5% overweight, 28.5% obese), reflecting the state of the population, 90% of respondents reported that healthy eating was important to them, with 35% reporting that it was very important. At the same time, 46% declared a great deal and 23% even a very great deal of attention to buying healthy food. In the product category of bars, there was a clear effect of the Nutri-score label on consumer choice as it provided the largest increase in preference for the nutritionally highest quality option – Protein bar nougat (6.2%) and at the same time the largest decrease (35.8%) in preference for the nutritionally lowest quality bar – Muesli bar chocolate in terms of the compared versions. Within qualitative testing of the visuals of the bars, nutrition labels were an important element of attention. In terms of comparing nutrition labels, an interesting finding was that the Nutri-score label was more noticed by respondents directly on the product itself compared to NutrInform. In terms of monitoring the emotional response, a higher level of arousal was evident for the visual with the Nutri-Score label (0.52) compared to NutrInform (0.48). In terms of statistical validation, the nutrition labels had no effect on preference change, nor was there a statistically significant difference in emotional response. The results show that in putting the FOPL model (e.g., Nutri-Score) into practice, there is a need to continue to educate consumers through campaigns, blogs, expert articles, discussions and examples of good practice. We also plan to conduct a similar study with an emphasis on surveying the level of knowledge/awareness of the label, comparing perceptions of different models and identifying reasons for choice. Last but not least, we plan to conduct a qualitative study in a real store setting in order to uncover the actual impact of the Nutri-score label on consumer purchasing behaviour using eye tracking and electroencephalography (EEG).

Acknowledgements

The research was supported by the project VEGA 1/0624/22 "Neurogastronomy: Application of Implicit and Explicit Approaches in Modern Experience Gastronomy and their Influence on Consumer Behavior".

References

Angelino, D., Dinu, M., Gandossi, B., Pellegrini, N., & Martini, D. (2023). Processing and Nutritional Quality of Breakfast Cereals Sold in Italy: Results from the Food Labelling of Italian Products (FLIP) Study. Nutrients, 15(8), 2013. https://doi.org/10.3390/nu15082013

Azman, N., & Sahak, S.Z. (2014). Nutritional Label and Consumer Buying Decision: A Preliminary Review. Procedia – Social and Behavioral Sciences, 130(15), 490-498. https://doi.org/10.1016/j.sbspro.2014.04.057

Berčík, J. (2021, February 18). Potravinový semafor – Ideme hlavou proti múru? tovarapredaj.sk https://-www.tovarapredaj.sk/2021/02/18/jakub-bercik-potravinovy-semafor-ideme-hlavou-proti-muru/

Bonsmann, S.S.G., Marandola, G., Ciriolo, E., van Bavel, R., & Wollgast, J. (2020). Front-of-Pack Nutrition Labelling Schemes: A Comprehensive Review. EUR 29811 EN; Publications Office of the European Union: Luxembourg. https://dx.doi.org/10.2760/436998

Brown, A. (2006). Chapter 6 Class Notes. Available at http://www.udel.edu/alex/chapt6.html

Carruba, M.O., Caretto, A., De Lorenzo, A., Fatati, G., Ghiselli, A., Lucchin, L., Maffels, C., Malavazos, A., Malfi, G., Riva, E., Ruocco, C., Santini, F., Silano, M., Valerio, A., Vania, A., & Nisoli, E. (2021). Front-of-pack (FOP) labelling systems to improve the quality of nutrition information to prevent obesity: NutrInform Battery vs Nutri-score. Eating and Weight Disorders-Studies on Anorexia, Bulimia and Obesity, 27, 1575-1584. https://doi.org-/10.1007/s40519-021-01316-z

Cetină, I., Munthiu, M.-C., & Rădulescu, V. (2012). Psychological and social factors that influence online consumer behavior. Procedia – Social and Behavioral Sciences, 62, 184-188. https://doi.org/10.1016/j.sbspro.2012.09.029

De Temmerman, J., Heeremans, E., Slabbinck, H., & Vermeir, I. (2021). The impact of the Nutri-score nutrition label on perceived healthiness and purchase intentions. Appetite, 157, 104995. https://doi.org/10.1016/j.appet.-2020.104995

Donini, L.M., Berry, E.M., Folkvord, F., Jansen, L., Leroy, F., Şimşek, Ö., Fava, F., Gobbetti, M., & Lenzi, A. (2023). Front-of-pack labels: “Directive” versus “informative” approaches. Nutrition, 105, 111861. https://doi.org/10.-1016/j.nut.2022.111861

Egnell, M., Galan, P., Farpour-Lambert, N.J., Talati, Z., Pettigrew, S., Hercberg, S., & Julia, C. (2020). Compared to other front-of-pack nutrition labels, the Nutri-score emerged as the most efficient to inform Swiss consumers on the nutritional quality of food products. PLOS ONE, 15(2), e0228179. https://doi.org/10.1371/journal.,pone.-0228179

EUFIC. (2022). Front-of-pack nutrition labelling. https://www.eufic.org/en/healthy-living/article/front-of-pack-nutrition-labelling

Garrido Fernández, A., & López-López, A. (2022). Application of NutriScore and NutrInform Battery to Spanish table olives. Symposium Toward the International Society for Gastronomic Sciences and Studies. http://hdl.handle.net/10261/307104

Graham, D.J., Orquin, J.L., & Visschers, V.H.M. (2012). Eye tracking and nutrition label use: A review of the literature and recommendations for label enhancement. Food Policy, 37(4), 378-382. https://doi.org/10.1016/-j.foodpol.2012.03.004

Hau, R.C., & Lange, K.W. (2023). Can the 5-colour nutrition label “Nutri-score” improve the health value of food? Journal of Future Foods, 3(4), 306-311. https://doi.org/10.1016/j.jfutfo.2023.03.002

Horská E., & Sparke K. (2007). Marketing attitudes towards the functional food and implications for market segmentation. Agricultural Economics, 53(8), 349-353. https://doi.org/10.17221/1148-AGRICECON

Jisana, T.K. (2014). Consumer behaviour models: an overview. Sai Om Journal of Commerce & Management, 1(5), 34-43. https://citeseerx.ist.psu.edu/document?repid=rep1&type=pdf&doi=ef54146370ef2e3e015f182092d8b-816efbf4306

Kotler, P. (2001). Marketing Management. Grada Praha.

Ma, G., & Zhuang, X. (2021). Nutrition label processing in the past 10 years: Contributions from eye tracking approach. Appetite, 156(January 2021), 104859. https://doi.org/10.1016/j.appet.2020.104859

Muller, L., & Ruffieux, B. (2020). What Makes a Front-of-Pack Nutritional Labelling System Effective: The Impact of Key Design Components on Food Purchases. Nutrients, 12(9), 2870. https://doi.org/10.3390/nu12092870

Mušura Gabor, A., Stojnić, B., & Ban-Ostić, D. (2020). Effects of different nutrition labels on visual attention and accuracy of nutritional quality perception – results of an experimental eye-tracking study. Food Quality and Preference, 84(September 2020), 103948. https://doi.org/10.1016/j.foodqual.,2020.103948

Neal, B., Crino, M., Dunford, E., Gao, A., Greenland, R., Li, N., Ngai, J., Ni Mhurchu, C., Pettigrew, S., Sacks, G., Webster, J., & Wu, J. (2017). Effects of different types of front-of-pack labelling information on the healthiness of food purchases — A randomised controlled trial., Nutrients, 9(12), 1284. https://doi.org/10.3390/nu9121284

Nohlen, H., Bakogianni, I., Grammatikaki, E., Ciriolo, E., Pantazi, M., Alves Dias, J., Salesse, F., Moz Christofoletti, M., Wollgast, J., Bruns, H., Dessart, F.J., Marandola, G., & Van Bavel, R. (2022). Front-of-pack nutrition labelling schemes: an update of the evidence. Publications Office of the European Union, Luxembourg. https://doi-.org/10.2760/932354

NutrInform Battery. (2023). NutrInform Battery – Additional information. https://www.nutrinformbattery.it-/en/home

Ramya, N., & Ali, M. (2016). Factors affecting consumer buying behavior. International Journal of Applied Research, 2(10), 76-80. https://www.allresearchjournal.,com/archives/2016/vol2issue10/PartB/2-9-151281.pdf

Rehman, F.U., Yusoff, R.B. M., Zabri, S.B. M., & Ismail, F.B. (2017). Determinants of personal factors in influencing the buying behavior of consumers in sales promotion: a case of fashion industry. Young Consumers, 18(4), 408-424. https://doi.org/10.1108/YC-06-2017-00705

Siegrist, M., Leins-Hess, R., & Keller, C. (2015). Which front-of-pack nutrition label is the most efficient one? The results of an eye-tracker study. Food Quality and Preference, 39, 183-190. https://doi.org/10.1016/j.foodqual.,2014.07.010

Songsamoe, S., Saengwong-ngam, R., Koomhin, P., & Matan, N. (2019). Understanding consumer physiological and emotional responses to food products using electroencephalography (EEG). Trends in Food Science & Technology, 93, 167-173. https://doi.org/10.1016/j.tifs.2019.09.018

Stávková, J., Stejskal, L., & Toufarová, Z. (2008). Factors influencing consumer behaviour. Agricultural Economics, 54(6), 276-284. https://doi.org/10.17221/283-AGRICECON

Tarabella, A., & Voinea, L. (2013). Advantages and Limitations of the Front-of-Package (FOP) Labeling Systems in Guiding the Consumers' Healthy Food Choice. Amfiteatru Economic, 15(33), 198-209.

Van Loo, E. J., Grebitus, C., & Verbeke, W. (2021). Effects of nutrition and sustainability claims on attention and choice: An eye-tracking study in the context of a choice experiment using granola bar concepts. Food Quality and Preference, 90(June 2021), 104100. https://doi.org/10.1016/j.foodqual.,2020.104100

WHO. (2022). Nutrition labelling: policy brief. https://www.who.int/publications/i/item/9789240051324

BEVERAGE CONTAINER DEPOSIT RETURN SYSTEM FROM CONSUMERS POINT OF VIEW

Malgorzata A. Jarossová*[1], Renáta Ševčíková[1], Tomáš Mešťanik, Katarína Chomová[1]

Department of Marketing, University of Economics in Bratislava, Slovakia

**Corresponding Author e-mail: malgorzata.jarossova@euba.sk*

DOI: 10.56091/CTQS.Innov-7

Abstract

The aim of the article is to investigate the opinions and behaviour of Slovak consumers towards the deposit return system for beverage containers. Primary data was collected using the survey method, an electronic questionnaire. The survey was carried out in March 2023. 107 respondents took part in the survey (66% women and 34% men). Based on the survey, we can say that consumers in Slovakia are actively involved in the deposit return system for beverage containers, that they prefer to return packaging in this way rather than sorting it, and that they think that the introduction of this system makes sense. Three-quarters of respondents would choose a store with a deposit return machine over other locations, which can be seen as a competitive advantage for those retailers that have one. Respondents are dissatisfied with the current one-way packaging return system because of the small number of locations (stores) where the return machines are located, the overcrowding of the machines, the frequent breakdowns of these machines, the long queues at the machines and the need to carry used packaging to the store. A major benefit cited by respondents was that there would be less waste, thus helping to protect the environment.

Keywords: deposit return system, beverage packaging, consumer, Slovakia

Introduction

Until now, there is still much freely thrown plastic and tin packaging from drinks in nature, on the streets and in waterways. In connection with environmental protection, the European Commission has decided that the member states of the European Union must ensure the collection of at least 90% of produced PET bottles and aluminium cans by 2025. As a result of this decision, the Ministry of the Environment of the Slovak Republic decided to reserve plastic PET bottles and aluminium beverage cans in Slovakia. In connection with the introduction of the backup system for disposable packaging in Slovakia, the legislator had to create laws that will regulate this newly introduced system in Slovakia. One such law is Act No. 302/2019 Coll. on the deposit of disposable packaging for beverages (Ministry of Environment of the Slovak Republic, 2019a).

This law introduced a deposit system for disposable beverage packaging in Slovakia. The newly introduced backup system for disposable packaging imposes new obligations on packaging manufacturers and beverage retailers, but this law also affects consumers. A well-designed deposit refund system is an individual matter for each country, and its implementation requires time and an extensive information campaign. It guarantees the fulfilment of obligations arising from EU directives, i.e., handing over the necessary amount of used packaging for reuse and recycling and reducing the fees paid by residents for waste management. This regulation came into force in Slovakia from January 1, 2022. Another relevant law in Slovakia is Act No. 347/2019 Coll. of 14^{th} October 2019, which implements some of the provisions of the Act on the deposit of disposable beverage packaging (Ministry of Environment of the Slovak Republic, 2019b).

The deposit return system serves as a means of extended producer responsibility, which uses the collection of single-use beverage packaging as a means to eliminate litter and to mobilize for environmental protection. The returnability of packaging, or the change from disposable to reusable packaging, increases the costs of handling, collection, washing and customer effort (Smejková & Dobiaš, 2004). The functioning of the deposit return system in Slovakia can be divided into six stages.

The first step starts with the packaging manufacturer, who has to register his newly produced packaging with the deposit return system administrator. He has to pay a deposit and a fee for every single package that he puts on the market. In the second step, the retailer buys the produced drinks from the manufacturer, paying not only for the product but also packaging fee. In the third step, the merchant sells the drink to the consumer, who pays for beverage and packaging fee. In the fourth stage, the consumer returns the empty packaging (disposable PET or aluminium packaging) to the packaging deposit return machines. The machine gives consumers a bill with the amount of money received for the empty packaging. The consumer can use this bill to purchase the goods or ask the retailer to refund the money. In the fifth stage, the retailer returns the collected packaging to the administrator, who pays him an advance and a handling fee as compensation for handling the packaging. The deposit return system administrator provides for the inspection, counting, transport and processing of packaging. The empty packaging is then transported to the recycler. In the final step, the material is processed and the manufacturer can use it to produce new bottles and cans. In the last step, the material is processed and the manufacturer can use it to produce new bottles and cans (Správca záloh, 2022).

According to the Ministry of the Environment, approximately one billion plastic bottles and approximately 350 million cans are introduced to the Slovak market annually, therefore the aim of this legislation is to reduce the total amount of PET bottles and also clay cans, which in several cases in the past were thrown freely by people into nature, rivers or on the road and at the same time increase the volume of recycling of these packaging and used as a way of motivating consumers to return the packaging the sum of €0.15 per returned packaging, which can then be used by consumers to reduce the total price of the purchase or as a cash payment to the consumer (Ministry of Environment of the Slovak Republic, 2023c). Another reason to recycle this kind of packaging is the value of the material., Plastic bottles and cans are valuable enough that it makes sense to recycle them and then put them back into circulation (Morvai, 2021). The Ministry of the Environment of the Slovak Republic states that Slovakia used the Scandinavian model as a basis, which was an excellent example due to its high efficiency, this system was also used as a basis in other countries within the European Union when creating a large part of mandatory backup systems (Dráb & Slučiaková, 2018).

According to Act No. 302/2019 Coll. on the deposit of disposable beverage packaging and on the amendment of certain laws, disposable packaging or PET bottles or aluminium cans with a volume of 0.1 to 3 litres inclusive, in which mineral water, sweetened drinks, fruit juices, iced teas, beer, energy drinks, wine or other mixed alcoholic beverages are packaged, are subject to deposit in Slovakia. The deposit does not apply to milk packaging, various drinks containing milk or its substitutes (e.g., coconut milk, almond milk, etc.), syrups and alcoholic drinks with an increased alcohol content (over 15%), plastic and metal non-beverage packaging (e.g., cooking oils, vinegar and drugstore products) (Jarossová & Gubíniová, 2022; Removčíková, 2022).

Slovakia voluntarily made a legal commitment to achieve a 90% collection rate of all packaging that reaches the Slovak market by 2025. This percentage collection rate was voluntarily accepted by our government and is higher than the rate that would have been established by the Backup Act, if we had not decided to voluntarily accept a higher collection rate (Morvai, 2021).

However, practice has shown that it will not be so easy. According to the association Reloop Platform (2018) in which 39 countries from around the world had implemented a deposit return packaging system only 30% of them achieved a return of at least 90%. The best example of a country which gained good results is Estonia, which introduced a deposit return system in 2005 and achieved a collection rate of 82.7% for the calendar year 2017. This analysis was carried out in the following countries: Croatia, Denmark, Estonia, Finland, Germany, Iceland, Latvia, Netherlands, Norway, Sweden, 10 states of the United States of America, 12 states of Canada, Australia, Israel, Costa Rica, Kiribati, Palau (Reloopplatfrom, 2018).

At the moment, around 71% of the packaging that was put on the Slovak market has been collected. According to former Minister of the Environment Jan Budaj, plastic and aluminium packaging have already disappeared from nature, especially from river flows. The proof should be the photographs taken and evaluated by the Slovak Water Management Company. Last year, there was no need to make such interventions on watercourses, as in the past. Consumers' willingness to buy products with returnable packaging has not diminished either (Kazda, 2023). The table 1 shows information on the deposit return system as of 13 February 2023.

Table 1. Basic information regarding the deposit return system in Slovakia as of February 13th, 2023

Amount of subjects	Subjects
99 608 373	pieces of collected PET bottles (59%) and cans (41%)
292	active registered producers
3686	active registered barcodes (which are located on the returnable packaging)
265	active registered traders
3031	registered collection points
1190	mandatory collection points (store area over 300m^2)
1841	voluntary collection points (sales area less than 300m^2)
2256	automated collection points with automatic deposit
775	collection points with a hand-held scanner

Source: https://www.odpady-portal.,sk/Dokument/107300/zalohovanie-napojovych-obalov-plnenie-cielov-2023.aspx

Packaging marked “Z” (Fig. 1) is returned by consumers to automatic collection points or collected manually by employees of the selected store. It is necessary to return the packaging uncompressed with a lid and a readable barcode for the system to work properly, and there is no time limit on the return period. In the image below, you can see how the label of the backed-up packages looks like.

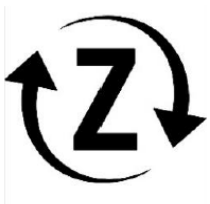


Fig. 1. Markings found on return packaging

Source: Ministry of Environment of the Slovak Republic, 2019b.

As part of the deposit return system in Slovakia, a barcode is used as an identifier; it is a unique identifier intended to mark the deposit packaging registered in the deposit system (Removčíková, 2022). According to the administrator's proposal from 2020, he plans to establish up to 6,500 collection points in Slovakia by 2025, which were also established by the law on backup. In practice, however, it turns out to be a difficult goal., All large retailers, chains, i.e., businesses with a sales area of over 300 m^2, which the law requires to register as a collection point, have already become collection points, but not enough small traders voluntarily register, which can be a problem for the goals set by the law on backup. It is necessary to create alternative collection points in the future, which will be necessary to achieve the goals. The administrator of the reserve system in Slovakia estimates that the number of collection points could increase to 3,700 by the end of 2023 (Potočár, 2022).

Malindzakova, Štofková and Majernik (2022) in their article provide an analysis and description of the deposit and recycling system for non-reusable beverage packaging introduced in the Slovak Republic in 2022 but there is no information in this article and the relevant literature on the opinions of Slovak consumers on the functioning of the deposit system. The aim of this study is to investigate the opinions and behaviour of Slovak consumers towards the deposit return system for beverage containers.

Material and methods

107 respondents took part in the survey, of which (66%) were women and (34%) were men. The majority of respondents (55.9%) came from the city and (44.1%) respondents from the countryside. The respondents who took part in the survey mainly came from Žilina Region (39.6%), Bratislava Region (14.2%), Prešov Region (12.3%) and Trnava Region (10.4%) and other regions (23.5%). The respondents were between 19 and 72 years old. The respondents had the following education: primary education (2 respondents), secondary education without a matura exam (8 respondents), secondary education with a matura exam (45 respondents), and higher education (52 respondents). 46 respondents said they lived in the country and 61 in the city.

In the survey, we asked consumers about their opinions and behaviour after the introduction of the deposit return system for disposable beverage packaging in Slovakia. The collection of primary data was carried out using the inquiry method, specifically a questionnaire in electronic form. The questionnaire intended for consumers consisted of 16 questions. The survey was conducted in March 2023. In this research it was used analytical and statistical methods to evaluate the results of our research and analyse the data. We examined the relationships between variables using correlation coefficients, which were tested for statistical significance of the model. Due to the nature of our data under study, we used correlation coefficient – Cramer's V (VC).

Cramér’s statistic facilitates the interpretation of nominal-variable association estimates, given this index ranges from 0 to +1. A higher VC indicates a stronger association (Kearney, 2017; Bergsma, 2013). We also used Eta (η) correlation ratio in analysing strongly nonlinear relationship between variables. Eta squared measures the proportion of the total variance in a dependent variable that is associated with the membership of different groups defined by an independent variable. Partial eta squared is a similar measure in which the effects of other independent variables and interactions are partially out. The development of these measures is described and their characteristics compared (Richardson, 2011). The IBM SPSS Statistics 29 software was used to calculate the statistical relationships between the variables.

Results and discussion

Most studies have shown that the adoption of the deposit refund system has positive economic results and identified and suggested several “best practices” to increase the effectiveness of the initiatives. For example, Dráb and Slučiaková examined the deposit refund system initiative in Slovakia (Dráb, Slučiaková, 2018) and (Brizga et. all., 2019) in Latvia. The deposit-refund system is a means of gathering a significant amount of beverage containers for the purpose of reuse, promoting awareness of sorting waste, and adding value to the waste. Furthermore, it includes a wider range of materials and other types of packaging (EuroCham, 2023).

In the first question in the our research, we asked the respondents if they returned disposable returnable packaging. Respondents could answer the question only “Yes” and “No”. Up to 94.4% of consumers use the option of returning disposable returnable packaging, which represents 101 respondents out of a total of 107 respondents, and only 5.6% of respondents or 6 respondents do not return disposable beverage packaging. Respondents answered that they do not use the deposit return system because they are satisfied with the system of separate packaging sorting, they do not want to store returnable packaging at home, and they do not want to wait in queues to return empty packaging. In research conducted by ARC Rynek i Opinia in Poland in 2022, as many as 88% of Poles admitted that they liked the idea of introducing a deposit system, but their use depended on two factors: a) the place of returning the packaging, b) profitability. The preferred form of returning packaging is to return it to vending machines.

In the third question, we wanted to know how regularly the respondents return the returnable packaging. Respondents could answer by marking the following answers: regularly (once a week), regularly (2-3 times a month), irregularly (once a month) or they could write their answer by using “other”. 65% of respondents regularly return returnable packaging, which represents 41% of all responses (2-3 times a month) or once a week (23.8%).

About 32% of respondents said that they return returnable packaging irregularly, and 3% of respondents said that they do not return these packages. The proximity of deposit return machines to where you live may affect your return therefore we asked respondents if there is a store in their vicinity where they can return returnable packaging. Respondents could answer this question by indicating a “Yes” or “No” response. Up to 92.2% of respondents have a store in their vicinity where they can return returnable packaging. The remaining 7.8% of respondents stated that there is no store in their vicinity with the possibility of returning returnable packaging. Using Cramer's V correlation coefficient, we confirmed a statistically significant moderate positive correlation between a store with a deposit return machine where respondents could return returnable packaging and a respondent's place of residence (Fig. 2). It can be concluded that urban respondents have access to more stores with deposit return machines than rural consumers.

Crosstab

Count

		S2		
		0	1	Total
Q3	0	8	0	8
	1	37	57	94
Total		45	57	102

Symmetric Measures

		Value	Approximate Significance
Nominal by Nominal	Phi	,328	<,001
	Cramer's V	,328	<,001
N of Valid Cases		102	

Fig. 2. Cramer's V correlation coefficient

Source: own survey processing in the IBM SPSS Statistics 29 software.

With the help of the fourth question, we wanted to find out whether consumers prefer a store with the option of returning returnable packaging or a store that does not have such an option. Three-quarters of respondents prefer a store that offers the option of returning returnable packaging for beverages. This can give merchants a competitive advantage over stores without such an option.

Consumers can return returnable packaging in one of three ways. There is the fully automated collection, manual collection and semi-automated packaging collection. In the next question, the respondents had to choose one between 3 answers that represented the methods of collection packaging that they use. Up to 97.1% of respondents chose the answer using the special deposit return machine located in the store, 2% answered manual collection and 0.9% answered semi-automated collection.

The vast majority of respondents (92.2%) most often return packaging to the deposit return machine, which is located in the store. A very small part of the respondents (7.8%) stated that they return their used disposable packaging for beverages in separate places designated for collecting prepaid packaging, which is located outside the store.

The aim of the next question was to find out if the respondents prefer the current deposit return system or if they preferred the previous system of separate packaging sorting. The majority of respondents, 80.2%, prefer the new deposit return system of disposable packaging over the previous system of separate packaging sorting. Additionally, the overwhelming majority (93.5%) of the respondents answered that they think that the new deposit return system makes sense and is a good step from the point of view of the circular economy. The other respondents (6.5%) indicated this system is pointless. Consumers (78.4%) are satisfied with the current collection methods for single-use beverage packaging only every fifth respondent (21.6%) answered that they were not satisfied.

In the eleven question, respondents were able to express why they are not satisfied with the current deposit return system. Respondents mentioned the most common problems related to this system in which were repeated the most: a) deposit return machines not working very often, b) long queues at deposit return machines, c) low capacity of these machines. The vast majority of respondents stated (82.7%) that they had already encountered the fact that a deposit return machine for empty disposable packaging did not work. The remaining (17.3%) respondents said that they have not yet encountered the fact that the machine did not work. In a study conducted by (Konstantoglou, A et. all, 2023), respondents identified the main problems with deposit machines as follows: the machine was full, the place where the machine was located was far from their home, the machine was often broken.

For each package returned to the machine, the customer receives the sum of €0.15. We were interested if this amount of money is motivating enough for them, so they are willing to return the returnable packages in stores. Respondents had to mark either the answer “Yes” or “No”. More than three-quarters (77.5%) of the respondents answered positively on this question and one-quarter of the respondents (22.5%) considered this sum not to be sufficiently motivated to return packaging at collection points. At the time of shopping, the vast majority of respondents (94.2%) will use the paid amount to reduce the price of their purchase in the store, and only 5.8% of respondents will have the amount for returning the packaging paid in cash.

The aim of the next question was to find out whether the introduction of the deposit return system in Slovakia in any way affected the purchasing process of consumers. For this question, consumers had to mark one of three answers. The majority of respondents (61.5%) did not notice any change in their purchasing process. 26.9% of respondents answered that the introduction of the deposit return system for disposable packaging had a positive effect on their shopping process, and only 11.5% of respondents said that their purchase process was negatively affected after the introduction of the deposit system in Slovakia. Additionally, we verified with the ETA correlation coefficient, the dependence between the variables – how the introduction of the law on deposit return system in Slovakia affected the purchasing process of respondents from different age groups (Fig. 3). Based on the obtained results (ETA=0.406, Fig. 3), we can conclude that more older respondents (average age 38 years) answered that the introduction of the deposit system negatively affected their purchasing process compared to younger respondents (average age 27 years).

Report

S3

Q13	Mean	N	Std. Deviation
0	26,16	63	7,062
1	27,64	28	10,552
2	38,82	11	12,416
Total	27,93	102	9,515

ANOVA Table

			Sum of Squares	df	Mean Square	F	Sig.
S3 * Q13	Between Groups	(Combined)	1504,042	2	752,021	9,744	<,001
	Within Groups		7640,478	99	77,177		
	Total		9144,520	101			

Measures of Association

	Eta	Eta Squared
S3 * Q13	,406	,164

Fig. 3. ETA correlation coefficient

Source: own survey processing in the IBM SPSS Statistics 29 software.

* the average age is on the Fig. 3 as the word "Mean", ** variables: 0 – mean did not influence, 1 – influenced positively, 2 – influenced negatively

We also asked the respondents to indicate any advantages or disadvantages resulting from the current deposit return system. The respondents mentioned the following as the main benefits: protecting the environment by returning bottles, a smaller number of packaging lying freely in nature, financial motivation to return prepaid packages. Respondents saw the greatest disadvantage in storing packaging in their homes, the need to carry packaging to stores and the fullness of deposit return machines and regular standing in line for respondents to get to the machine.

The changes associated with the introduction of a new backup system for single-use packaging intended for drinks affected consumers, but primarily concerned traders and manufacturers, who had to find spaces in stores where the machines can work (technical security), train people, spend huge amounts of money to buy machines and wait for refund from the system administrator. We wanted to find out the respondents' opinions about how the introduction of the new deposit return system affected manufacturers and traders in Slovakia. Respondents think that the main disadvantage for manufacturers and traders lies in the increased costs associated with the purchase of deposit return machines and storage empty packages and the higher price of manufacturing products. According to the respondents, the biggest advantage for businesses and manufacturers is the increased frequency of visits to stores which is a deposit return machine, which is their competitive advantage. Consumers prefer visiting a store with a deposit return machine and improving the image of their company.

Conclusions

The consequence of current and previous ways of using resources is a high level of pollution, deterioration of the quality of the environment and depletion of natural resources. EU waste policy has a long history and has traditionally focused on waste management that is more environmentally sustainable. This trend should reverse the plan for a resource-efficient Europe and the circular economy package by transforming the EU economy into a sustainable economy by 2050. Four new waste directives under the new circular economy package introduce new waste management targets in the areas of prevention, reuse, recycling and landfilling. As part of the European Green Deal, the new Circular Economy Action Plan sets out a forward-looking agenda to achieve a cleaner and more competitive EU and fully contribute to climate neutrality (European Parliament, 2023).

The European Union is also putting more and more emphasis on the recycling of PET bottles, other plastic packaging and aluminium cans. In Slovakia, the deposit return system for disposable beverage packaging such as PET bottles and aluminium cans has been operating since January 1, 2022. The system achieved better results in the first year of operating than the proponents had anticipated.

The intention of the legislator was to achieve at least 60% of the collection of beverage packaging in the first year of the system's operation the result was 70%. In 2023, the collection rate was supposed to reach 80%. The main goal in 2025 is to gain up to 90% of all plastic bottles and beverage cans.

The functioning of the deposit-refund system in Slovakia encounters some problems, but consumers see it as a benefit, above all, because of the natural environment protection. Over 90 % of consumers who took part in the survey positively assess the functioning of the deposit return system, and about 60% of respondents regularly return disposable packaging to deposit return machines located in stores. More than three-quarters (77.5%) of the respondents answered that €0.15 motivates them to return the returnable packaging. Cash for returned packaging is most often used on purchasing new goods. The first year of operation of the deposit return system in Slovakia was successful, which bodes well for the coming years and, above all, consumers are already used to such a collection of packaging.

Acknowledgement

The paper is a partial output of the VEGA research task no. 1/0398/22 "The current status and perspectives of the development of the market of healthy, environmentally friendly and carbon-neutral products in Slovakia and the European Union" conducted at the University of Economics in Bratislava.
DUT – Driving Urban Transitions. HORIZON – CL5-2021-D2-01-16

References

Allen, M.R., & Cramér's V. (2017). *Sage Encyclopedia of Communication Research Methods*. Publisher: Sage.

Bergsma, W. (2013). A bias-correction for Cramér's and Tschuprow's. *Journal of the Korean Statistical Society*, *42*(3), 323-328. https://doi.org/10.1016/j.jkss.2012.10.002

Brizga, J.; Moora, H. & Balcers, O. (2019). DRS for beverage containers in Latvia: Learnings within the Baltic States, April, Society. Technology. Solutions. *In Proceedings of the International Scientific Conference*, Florence, Italy, 5-6 September 2019; p. 21.

Dráb, J., & Slučiaková, S. (2018). *The actual price of the deposit*. Retrieved August 9, 2023, from -https://www.-minzp.sk/files/iep/skutocna_cena_zalohy.pdf

EuroCham. (2023*). Unpacking Deposit Refund Schemes for Singapore. 2021*. Retrieved December 21, 2023, from https://eurocham.org.sg/wp-content/uploads/2021/12/EV21-1207-Unpacking-Deposit-Refund-Scheme-for-Singapore-KPMG-paper-V3-1.pdf

European Parliament. (2023). *Resource efficiency and circular economy*. Retrieved August 8, 2023, from https://-www.europarl.europa.eu/factsheets/sk/sheet/76/efektivnost-vyuzivania-zdrojov-a-obehove-hospodarstvo

G.N. (2022). *Study-88-percentage-of-Poles-in-favour-of-the-introduction-of-a-deposit-system-in-Poland*. Retrieved December 21, 2023, from https://www.pap.pl/aktualnosci/news%2C1379153%2Cbadanie-88-procentpola-kow-za-wprowadzeniem-systemu-kaucyjnego-w-polsce

Jarossová, M.A., & Gubíniová, K. (2022). Beverage Container Deposit Return System in Slovakia: Insights after One Year of Its Introduction. *Nauki Inżynierskie i Technologie*, 75-89. DOI: 10.15611/nit.2022.38.05

Každa, R. (2023). *More than 70 percent of the packaging is returned from backup, Budaj is satisfied*. https://www.odpady-portal.,sk/Dokument/107300/zalohovanie-napojovych-obalov-plnenie-cielov-2023.aspx

Konstantoglou, A. et. all. (2023). Accessing Consumer Perceptions of the Effectiveness of the Deposit Refund System. *Sustainability* 2023, 15 (12), 9429; https://doi.org/10.3390/su15129429.

Ministry of Environment of the Slovak Republic. Act no. 302/2019 Coll on returning disposable packaging for drinks and on amendments to certain laws. (September 11, 2019a)

Ministry of Environment of the Slovak Republic. Act no. 347/2019 Coll. which implements some provisions of the law on depositing disposable packaging for beverages (October 14, 2019b)

Ministry of Environment of the Slovak Republic. Frequently asked questions, Retrieved August 9, 2023, from https://www.minzp.sk/zalohovanie/najcastejsie-otazky.html

Potočár, R. (2023). *It will be fair, the deposit return system manager promises, and increases handling fees*, Retrieved August 9, 2023, from https://www.odpady-portal.,sk/Dokument/107283/zalohovanie-manipulacne-poplatky-obchody.aspx

Reloopplatfrom. (2018). *Deposit systems for one-way beverage container: global overview*, Retrieved August 9, 2023, from https://www.reloopplatform.org/wp-content/uploads/2018/05/BOOK-Deposit-Global-27-APR2018.pdf

Removičíková, L. (2022). *Returnable PET bottles and cans in Slovakia from 2022: answers to practical questions*, Retrieved August 9, 2023, from https://www.podnikajte.sk/zakonne-povinnosti-podnikatela/zalohovanie-pet-flias-plechoviek-na-slovensku

Richardson, J.T.E. (2011). Eta squared and partial eta squared as measures of effect size in educational research. *Educational Research Review*, 6, 2, 135-147.

Smejtková, A., & Dobiáš. (2004). *Packaging and packaging technology*. 1st edition. Praha : Czech University of Agriculture.

Spravca zaloh. (2023). *How the deposit retutn system works?* Retrieved August 10, 2023, from https://-www.spravcazaloh.sk/

QUALITY OF PUMPKIN SEED TEMPEH AS A SUBSTITUTE FOR SOY TEMPEH

Iwona Jasińska-Kuligowska[1], Maciej Kuligowski[2], Kornelia Karpiuk[2]*

[1]*Department of Food Quality and Safety, Institute of Quality Science,*
Poznań University of Economics and Business, Poznań, Poland
[2]*Department of Food Technology of Plant Origin, Faculty of Food Science and Nutrition,*
Poznań University of Life Sciences Poznań, Poland
**Corresponding Author e-mail: iwona.jasinska-kuligowska@ue.poznan.pl*

DOI: 10.56091/CTQS.Innov-8

Abstract

In the last decades, the demand for new nutritionally, especially protein-rich and sustainable food, has increased considerably. Consumers are seeking new sources of protein and sensory attractive alternatives to meat products. The technology of meat substitutes and high-protein plant-based foods is still a challenge for the food industry. Pumpkin seeds are a natural source of protein, unsaturated fatty acids and an excellent source of phytosterols and antioxidants vitamins such as tocopherols and carotenoids. The main aim of this study was to identify selected quality parameters of pumpkin seed tempeh as a soy tempeh alternative. The physical features and sensory analysis of tempeh produced from soybean and pumpkin seeds by using *Rhizopus oligosporus* were compared. Sensory and instrumental analysis results were compared. The conducted research allowed to conclude that pumpkin seeds can be an alternative raw material for tempeh production as a meat alternative. Between tested parameters, differentiation of the quality assessment was best described by the sensory evaluated fracturability (r=0.83) and grainy (r=0.73), and among the instrumental texture assessment parameters, hardness work (r=-0.31), and hardness (r=-0.42). The fermentation time has a greater extent than the layer thickness of the material on the pumpkin tempeh sensory evaluation.

Keywords: food quality, meat substitutes, texture analysis, pumpkin seeds, sustainable consumption, tempeh

Introduction

In Western societies, the trend to avoid meat in the diet is increasing. Consumption of red and pro-cessed meat is positively associated with mortality, particularly due to cardiovascular disease and cancer. Using protein derived from plant sources is more sustainable for the planet (Bouvard, et al., 2015; Mbow et al., 2019; Rohrmann, et al., 2013; The Royal Society, 2019). Consumers are seeking new sources of protein and sensory attractive alternatives to meat products. Tempeh (tempe) is a tradition-nal Indonesian food produced by the fermentation of soybeans using Rhizopus species. In the plant kingdom, soybean seeds are one of the richest sources of protein.

Freshly fermented tempeh has a clean, mushroom-like aroma, but during fermentation, the flavor becomes stronger. Tempeh is usually consumed fried, boiled or roasted. After frying, the flavor becomes nut-like. Thanks to the high protein content and easy preparation for direct consumption, the interest in this product has been increasing. The best recognized tempeh is made solely from soy, but other leguminous and cereals can also be used (Ahnan-Winarno et al., 2021; He, et al., 2020; Nowak & Kuligowski, 2017). The main limitation of the use of soybean is the fact that it is classified as an allergenic ingredient. Manufacturers are more likely to choose raw materials that do not require declaring the allergen content on the label. Pumpkin seeds can be an alternative for the production of tempeh as a plant-based meat alternatives (PBMAs) to soy. They contain many valuable, health-promoting ingredients like phenolic compounds, tocopherols, phytoestrogens, cucurbitacins, phytosterols, unsaturated fatty acids and valuable minerals, while being a rich source of protein (roughly 35%). Pumpkin seed protein isolates have a quality similar to soybeans, and are also characterized by high bioavailability of amino acids (Dotto & Chacha, 2020; Lemus-Mondaca et al., 2019; Lestari & Meiyanto, 2018).

In assessing the quality of plant-based meat alternatives, in addition to smell and taste, the texture of the product is also very important. Texture is one of the basic and most complex attributes of food. It is a multi-parameter value depending on the chemical composition, structure and molecular, microscopic and macroscopic structure as well as the rheological properties of the product. The relationship between the structure of food and its sensory perception is very important. Texture has been described as 'the sensory and functional manifestation of the structural, mechanical, and surface properties of foods detected through the senses of vision, hearing, touch, and kinesthetics' (Surmacka-Szczesniak, 2002). It comprises such features as hardness, elasticity, moisture, chewiness, brittleness.

According to this definition, texture is a sensory property and only a human being is able to perceive and describe it. Instrumental texture measurement methods, on the other hand, measure specific physical parameters. The correlation between instrumental measurements and sensory analysis enables a more complete interpretation of the results of sensory properties of products. The results of the instrumental analysis of the texture of food products are characterized by high variability of mechanical tests, which indicates a high sensitivity of the measurements compared to the sensory assessment (Dolik & Kubiak, 2013; Surmacka-Szcześniak, 2002). The main aim of this study was to identify selected quality parameters of pumpkin seed tempeh as a soy tempeh alternative. The sensory quality and instrumental texture analysis of tempeh produced from soybean and pumpkin seeds by using *Rhizopus oligosporus* were compared.

Materials and methods

Materials

Hull-less pumpkin seeds from Polish crops were purchased at a local health food store. Inoculum was the starter ragi tempeh originated from Raprima (Bogor, Indonesia).

Tempeh preparation

Seeds of pumpkin were boiled for 15 minutes, cooled and inoculated with 1 g of ragi tempeh and placed into Petri dishes in a 1 cm thick layer (single layer fermentation) or glass vessel in a 2.5 cm thick layer (double layer fermentation). The fermentation was carried out at 30°C for 24 and 48 h (Kuligowski et al., 2022). Tempeh samples were prepared in triplicates, and were named as described in Figure 1, A and B for petri dishes fermentation (single layer), C and D for glass vessel fermentation (double layer). Commercial soy tempeh (sample E) was obtained from a local market in Poznań, Poland. Samples were frozen and before the analyses were cut into cubes of 2.5 × 2.5 × 1.0 cm and fried in rapeseed oil.

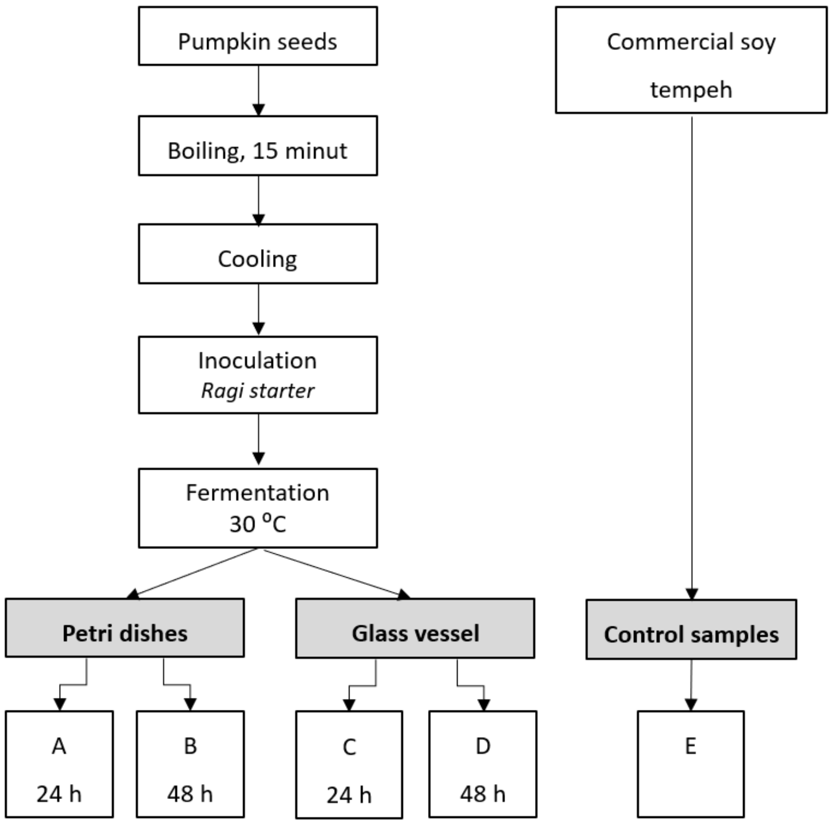


Fig. 1. Samples subjected to texture and sensory analysis

Source: own study.

Sensory analysis

The Quantitative Descriptive Analysis test was performed by 10 panel members. The descriptors for colour, aroma, taste and texture were determined based on the literature and recommendations of the expert panel from the Department of Food Quality and Safety, Institute of Quality Science, Poznań University of Economics and Business. The sensory panel members (10 person) were chosen based on their ability to discriminate between samples during the sensory acuity screening. The order of the sample presentation was randomized. The sensory attributes were as follows: for aroma – nutty, mouldy, mushroom, bread, cooked vegetables, fried, roasted, yeasty; for taste – nutty, sweet, bitter, umami; and for texture – hardness, fracturability, spongy, crispy, grainy, adhesiveness. Moreover, the colour and overall quality of each sample were assessed. The sensory panel members were educated about the sensory evaluation of fried tempeh. 10-centimeter nonstructured line scales with labelled ends ("not detectable" – "strongly detectable", "low" – "high") were applied. Five samples of freshly-fried tempehs were evaluated in each session. Water was provided to rinse the mouth between evaluations. Based on the obtained results, radar plots of the tested samples were created (Gawęcki & Baryłko-Piekielna, 2007; Stone & Sidel, 2004).

Instrumental texture analysis

Texture analysis was performed by the cutting sample of fried tempeh using Brookfield Texture CT3 10 kg analyser and Warner-Bratzler type knife at a rate of 10 mm/s. The graph's peak and area under the curve were reported (Fig. 2).

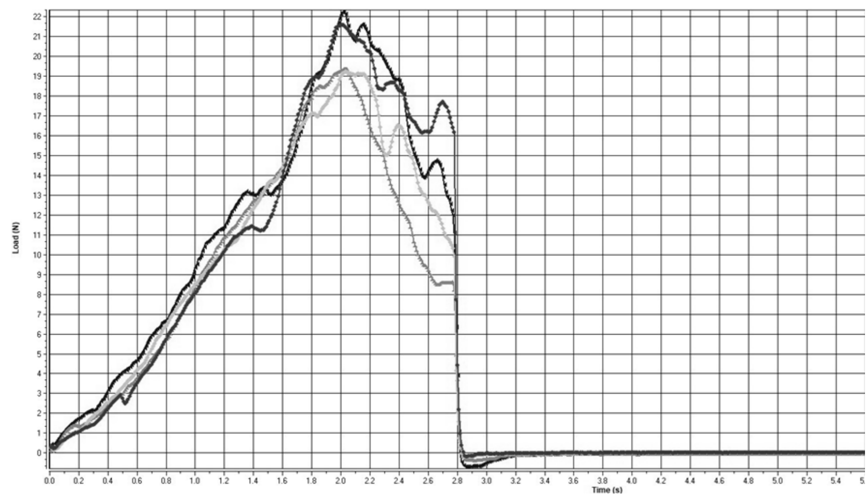


Fig. 2. An exemplary graph obtained for tempeh from pumpkin seeds fermented for 48 h (sample B)

Source: own study.

Values of hardness [N], hardness work [mJ], quantity of fractures, and fracturability [N] of the tempehs were recorded and analysed.

Statistical analysis

Statistical analyses were performed in Statistica 13.3 StatSoft software. Corelation, F-statistic and Tukey multiple comparison test were used. The criterion of significance was set at the level α<0.05.

Results and discussion

The colour of the obtained products depended largely on the raw material used, the brightest being commercial soybean tempeh (Fig. 3). A statistically important difference was observed for pumpkin tempeh for variants B and C as well as between A, B, C, D and E (p=0.05 level, Tukey test). Fermentation time had little effect on the colour of tempeh after culinary treatment. For the taste descriptors: nutty, sweet, umami, statistical analysis showed no significant variation. The bitter taste for pumpkin tempeh after the first 1 day of fermentation was at the same level regardless of layer size and was not significantly different from that sensed in commercial soy tempeh. On the contrary, extending the fermentation time of pumpkin tempeh by 24 h led to a significant intensification of the bitter taste.

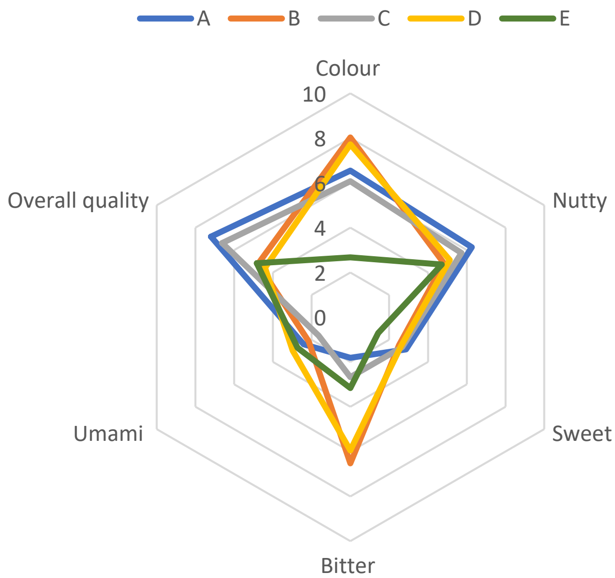


Fig. 3. Profile of taste and overall quality of tempeh (QDA result)

Source: own study.

The aroma discriminants like nutty, mushroom, cooked vegetable, and roasted aroma discriminant were judged by the evaluation panel to occur at a very similar level, with no significant statistical differences (Fig. 4). The mouldy smell in the pumpkin tempeh was judged to be more intense in the product after 48 hours of fermentation than after 24 hours. The soy tempeh tested in the study was not statistically different in the intensity of this descriptor from the pumpkin tempeh after 24 hours of fermentation, regardless of the size of the layer of fermented material., A slightly higher bread and yeast aroma descriptors were found in soybean tempeh, but it was not statistically significantly different from pumpkin tempeh after 24 h of single-layer fermentation for the bread discriminator and was statistically significantly different only for yeast aroma.

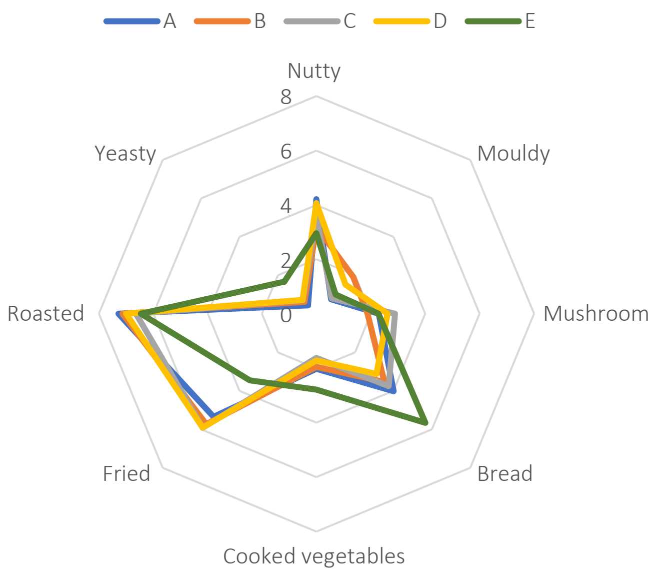


Fig. 4. Aroma profile of tempeh (QDA result)

Source: own study.

Sensory texture analysis showed that for the hardness descriptor, the fermentation time of the pumpkin raw material influenced a statistically significant reduction of this factor in tempeh fermented in single and double layer (Fig. 5). Soy tempeh possessed hardness at the level of 24-hour fermented pumpkin products. A similar reduction was observed with prolonged fermentation for the fracturability discriminant. Soy tempeh was ranked at the level of pumpkin tempeh after 48 hours of fermentation for this parameter. The spongy discriminator was judged to be statistically significantly higher for tempeh after 48 hours of fermentation, with the highest values recorded for tempeh fermented in a single layer. Soy tempeh and pumpkin tempeh fermented in single and double layers for 24 hours had low ratings for this distinguishing feature with no statistically significant differences. The crispy descriptor was rated highest in pumpkin tempeh fermented in a single layer.

A similar situation was observed for the grainy descriptor rating, for which the other tempeh variants tested (single layer fermentation by 48 hours and double layer fermented by 24 and 48 hours) and soy tempeh were not statistically significantly different. For the adhesiveness attribute, no significant differences were found for all tempeh products evaluated.

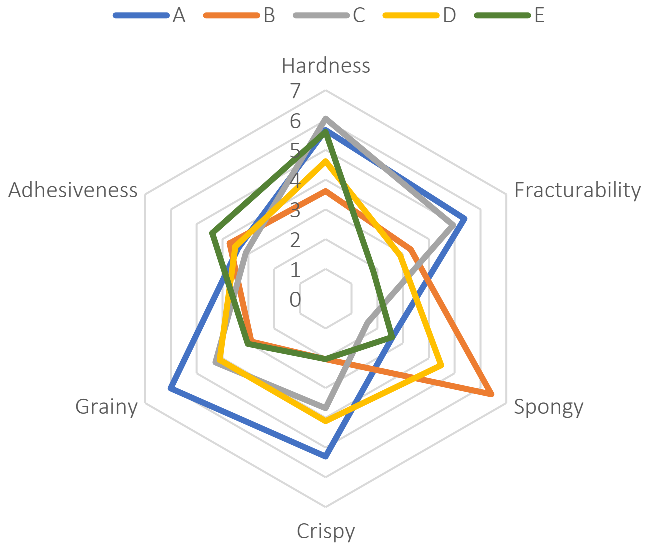


Fig. 5. Profile of texture of tempeh (QDA result)

Source: own study.

The highest overall quality rating was given to pumpkin tempeh fermented in a single layer for 24 hours, whose rating was not statistically significantly different from tempeh fermented in a double layer at the same time. Tempeh from pumpkin seeds after 48 h of fermentation, and soybean tempeh, and 24-hour fermented in a double layer were not statistically significantly different (Fig. 3, Table 1). The produced pumpkin tempeh turned out to be, in terms of sensory quality, not different from the soy tempeh present in the Polish market.

Table 1. The tempeh overall quality value

Tempeh code	Quality assessment value
A	7.20 ± 0.78^{c}
B	4.77 ± 1.11^{ab}
C	6.62 ± 1.6^{bc}
D	4.41 ± 1.36^{a}
E	4.83 ± 1.37^{ab}

Source: own study.

Averages are marked with different letters differ significantly (α<0.05, Tukey test). Values are the mean ± standard deviation of three replicates.

Tempeh is most often evaluated in terms of its bioactive content and its sensory or commercial quality is not often described in publications. Soy (Glycine max) tempeh has been compared with bean (Phaseolus vulgaris) tempeh, where it has been noted that it is rated slightly lower than soy tempeh. (Kuligowski & Nowak, 2010). There is a lack of accurate (unambiguous) descriptions of the taste characteristics of the most commonly consumed soy tempeh, which is characterised as nutty, savory, umami, firm, and salty whereas other sensory variables were noticed mushroom-like, grass, rancid, earthly, buttery, chewy, soapy, bitter, oily, and sour taste (Ahnan-Winarno et al., 2021; Fibri & Frøst, 2020). This may indicate differences due to the preferences of local communities or entire ethnic groups, which may characterise similar sensory attributes in a different way. Hence, a quite frequent description of the sensory characteristics of tempeh as a product with a unique texture and a panorama of new flavours and aromas (Nout & Kiers, 2005).

The greatest variation in the evaluated parameters was observed (Fig. 3-5) for the sensory evaluation of texture. Therefore, this parameter was subjected to an additional instrumental analysis (Table 2). The results indicate that the hardness after frying increased statistically significantly with fermentation time. For the hardness work parameter, this increase also occurred, but there were no statistically significant differences. The evaluation panel did not observe an increase in hardness with fermentation time (Fig. 5). Parameter quantity of fractures was lower for tempeh fermented in a single layer of raw material, while 1st fracture load drop off was higher (Table 2). Quantity of fractures is related to the sensory evaluation parameter referred as crispy. Similar to the panel assessing sensory qualities, the instrumental texture analysis showed that in terms of the characteristic defined as fracturability, no statistically significant differences were found between soybean and pumpkin seed tempeh (Fig. 5, Table 2).

Table 2. The texture analyses of tempeh

Sample name	Hardness [N]	Hardness Work [mJ]	Quantity of Fractures	Fracturability [N]
A	14.38 ± 1.74^{a}	222.25 ± 20.86^{a}	5.88 ± 0.83^{a}	$10{,}92 \pm 5{,}26^{b}$
B	20.09 ± 1.98^{bc}	263.41 ± 16.79^{a}	4.86 ± 1.07^{a}	$11{,}38 \pm 3{,}04^{b}$
C	17.08 ± 3.83^{ab}	209.78 ± 24.16^{a}	8.43 ± 2.57^{b}	$0{,}44 \pm 0{,}08^{a}$
D	24.30 ± 4.53^{c}	257.63 ± 66.65^{a}	7.33 ± 1.86^{ab}	$0{,}44 \pm 0{,}03^{a}$
E	31.37 ± 2.67^{d}	387.15 ± 14.56^{b}	6.33 ± 1.21^{ab}	$0{,}96 \pm 0{,}05^{a}$

Source: own study.

Values are the mean ± standard deviation of three replicates. Averages in the same column are marked with different letters differ significantly (α<0.05, Tukey test).

The highest statistically significant correlation between the quality assessment and the studied discriminants of sensory evaluation and instrumental texture analysis was observed for the discriminant fracturability r=0.83, followed by grainy r=0.73, nutty flavour r=0.69, crispy r=0.67 and hardness r=0.66. The lowest significant correlation between the overall evaluation and the studied discriminants was shown for hardness r=-0.42 and hardness work r=-0.31. We also analysed the F-statistic for examining the effect of tested parameters on the overall grade (Fig. 6).

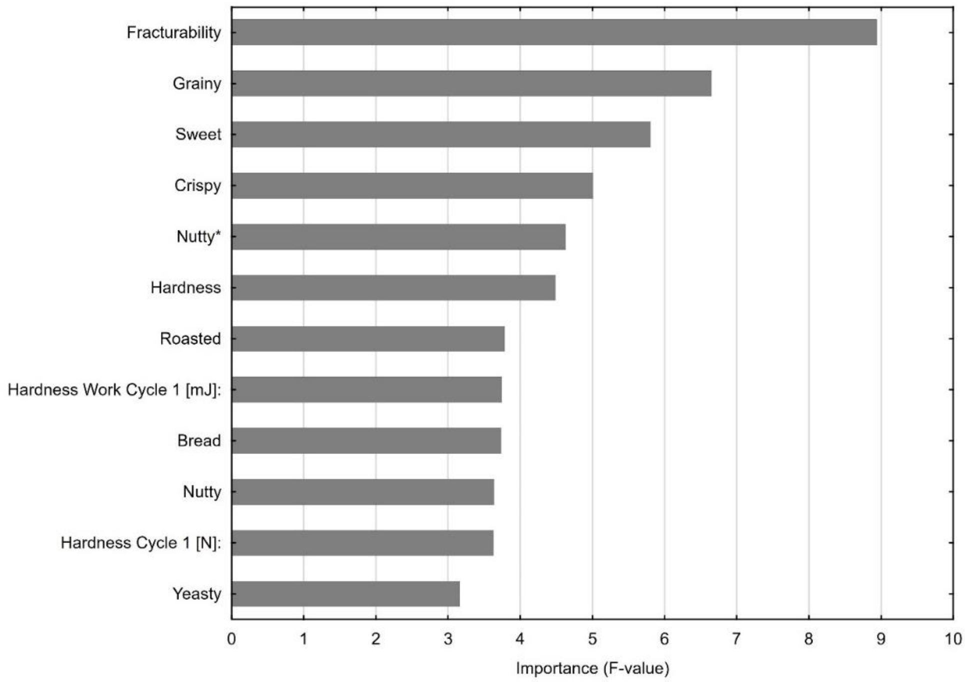


Fig. 6. The influence of the tested factors on the overall quality of tempeh. * – the descriptor of aroma
Source: own study.

It shows the variability of the quality assessment is best described by the sensory texture parameters fracturability and grainy, and among the instrumental texture assessment parameters, hardness work and hardness.

Nursiwi et al., (2021), using the same Raprima starter as in our study, found that tempeh made from cassava, rice or tapioca did not show significant differences in terms of texture; however, they tested one parameter with a texture analyser, and analysed non-cooked tempeh. In our study, we chose to give the analysis of tempeh subjected to cooking treatment. Frying in previous studies appeared to be the most suitable due to culinary preferences (Kuligowski & Nowak, 2010). Some researchers have added spices to the sensory analysed tempeh (Aderibigbe & Osegboun, 2006), but it seems, depending on their amount and reaction with the new material, could become an additional factor disturbing in the evaluation of the influence of fermentation, especially in the new raw material type.

Attempts to produce tempeh from raw materials other than soya have been ongoing for many years, with legume seeds often used, including broad beans (Polanowska et al., 2020), chickpea, lentils, beans (Erkan et al., 2020), pea (Miszkiewicz, Okrajni, & Bielecki, 2008). Other publications describing the use of non-bean raw materials, including moringa (Puspitasari et al., 2023), flaxseeds (Duliński et al., 2017), barley (Feng et al., 2007), maize (Cuevas-Rodríguez et al., 2004), oats (Nowak, 1992) and sorghum (Mugula & Lyimo, 2000), rather focus on investigating nutritional values.

The assessment of the influence of raw material type on texture quality parameters is not yet well defined. Some tempeh parameters correlated with firmness tested by instrumental methods were correlated with the size of the soybean seeds, but not all showed such correlations (Yuliani et al., 2022). Soybeans, chickpea, lentils (red and green), and beans (white, black, and broad) were tested for texture and tempeh from soybean and chickpea did not show significant differences after fermentation (Erkan et al., 2020). The reason for the similarities could be because of the raw material belonging to the same legume (Fabaceae) family. Although, by the texture profile analysis (TPA) were found that chickpea, white bean, red lentil, and broad bean tempeh showed harder structure than soybean tempeh while black bean and green lentil tempeh indicated softer structure than soybean tempeh (Erkan et al., 2020). In this research, soy tempeh hardness on the level 16,99 N was observed, while we found it as 31,37 N (Table 2). Nevertheless, different type of device and tools for texture analysis were used in both studies. A method of testing tempeh texture similar to use in our study was performed (Abdurrasyid et al., 2023). They observed that the hardness decreased with fermentation time in soybean tempeh. In our research, we observed an opposite relationship, which may have been influenced by the use of a different raw material (pumpkin seeds) and because we used fried tempeh. We have not found information about tempeh from pumpkin, hence the difficulty in comparing texture results.

Besides the fragmentary texture description, only volatile compounds, after frying, have been well investigated by instrumental analysis methods (Jeleń et al., 2013). Interestingly, from these studies, there is an increase in the levels of the compounds responsible for the mushroom smell with fermentation time and after the frying process. In contrast, Feng, Ostenfeld et al., (2007) found that fungal odour is produced during fermentation of soybeans and is absent in oats tempeh. Inferring from this the influence of fermentation time and type of fermented raw material on the mushroom aroma discriminator, in our study, the sensory panel found a similar concentration of volatile compounds responsible for the mushroom aroma impression in pumpkin and soy tempeh.

Scientific articles written by tempeh homeland authors, in the descriptions of the soybean tempeh manufacturing, omit the aspect of the thickness of the layer of fermented material (Abdurrasyid et al., 2023; Ahnan-Winarno et al., 2021; Nursiwi et al., 2021). Single articles on soybean seeds state it is 3-5 cm (Nout & Kiers, 2005), but a layer of material of about 12 mm has been also used (Kuligowski et al., 2022). For materials other than soy, the details about layer of fermented materials were sometimes placed, e.g., flaxseed oil cakes also used small layers (11 mm) of material (Duliński et al., 2017), while tempeh composed with grass pea seeds solely or with addition of flaxseed oil-cake, the 3 cm high layer where used (Stodolak, Starzyńska-Janiszewska & Mickowska, 2013). This was the reason for testing two types of layers of fermented pumpkin raw material in our study. The results show that the thickness of the layer, probably linked to the arrangement of a specific type of seeds, can affect the quality parameters of the finished product treated in the culinary process.

The overall quality of pumpkin tempeh in our research was on the same level as soybean tempeh, which indicates the possibility of using pumpkin seeds to produce pumpkin tempeh as meat alternatives.

Conclusions

Sensory evaluation showed that pumpkin seeds could be an attractive raw material to replace soy for the tempeh production. The fermentation time of the pumpkin tempeh influenced the sensory evaluation of the product to a greater extent than the layer thickness of the material in the solid state fermentation. Texture descriptors seem to be the proper method to assess the quality of tempeh products.

References

Abdurrasyid, Z., Astawan, M., Lioe, H. N., & Wresdiyati, T. (2023). Physicochemical and antioxidant properties of germinated soybean tempe after two days additional fermentation time. *Biointerface Research in Applied Chemistry*, *13*(3). https://doi.org/10.33263/BRIAC133.238

Aderibigbe, E. Y., & Osegboun, A. O. (2006). Acceptability of tempeh among health workers in Ado-Ekiti, Nigeria. *Pakistan Journal of Nutrition*, *5*(2), 122-124. https://doi.org/10.3923/PJN.2006.122.124

Ahnan-Winarno, A. D., Cordeiro, L., Winarno, F. G., Gibbons, J., & Xiao, H. (2021). Tempeh: A semicentennial review on its health benefits, fermentation, safety, processing, sustainability, and affordability. *Comprehensive Reviews in Food Science and Food Safety*, *20*(2), 1717-1767. https://doi.org/10.1111/1541-4337.12710

Bouvard, V. Loomis, D. Guyton, K.Z., Grosse, Y. Ghissassi, F.E., Benbrahim-Tallaa, L., Guha, N., Mattock, H. & Straif, K. (2015). *Carcinogenicity of consumption of red and processed meat. Lancet Oncology, 16,* 1599-600.

Cuevas-Rodríguez, E. O., Milán-Carrillo, J., Mora-Escobedo, R., Cárdenas-Valenzuela, O. G., & Reyes-Moreno, C. (2004). Quality protein maize (*Zea mays* L.) tempeh flour through solid state fermentation process. *LWT – Food Science and Technology*, *37*(1), 59-67. https://doi.org/10.1016/S0023-6438(03)00134-8

Dolik, K. & Kubiak, M. S. (2013). Instrumentalny test analizy profilu tekstury w badaniu jakości wybranych produktów spożywczych. *Nauki Inżynierskie i Technologie – Engineering Sciences and Technologies, 2013, 3*(10), s. 35-44

Dotto, J., M. & Chacha, J., S. (2020). The potential of pumpkin seeds as a functional food ingredient: A review. *Scientific African, 10*, e00575. https://doi.org/10.1016/j.sciaf.2020.e00575

Duliński, R., Stodolak, B., Byczyński, Ł., Poreda, A., Starzyńska-Janiszewska, A., & Żyła, K. (2017). Solid-state fermentation reduces phytic acid level, improves the profile of myo-inositol phosphates and enhances the availability of selected minerals in flaxseed oil cake. *Food Technology and Biotechnology*, *55*(3). https://doi.org/10.17113/ftb.55.03.17.4981

Erkan, S. B., Gürler, H. N., Bilgin, D. G., Germec, M., & Turhan, I. (2020). Production and characterization of tempehs from different sources of legume by Rhizopus oligosporus. *LWT -- Food Science and Technology*, *119*, 108880. https://doi.org/10.1016/j.lwt.2019.108880

Feng, M. X., Ostenfeld Larsen, T., & Schnürer, J. (2007). Production of volatile compounds by Rhizopus oligosporus during soybean and barley tempeh fermentation. *International Journal of Food Microbiology*, *113*(2), 133-141. https://doi.org/10.1016/J.IJFOODMICRO.2006.06.025

Fibri, D. L. N., & Frøst, M. B. (2020). Indonesian millennial consumers' perception of tempe – And how it is affected by product information and consumer psychographic traits. *Food Quality and Preference*, *80*, 103798. https://doi.org/10.1016/J.FOODQUAL.,2019.103798

Gawęcki, J. & Baryłko-Piekielna, N. (2007). Zmysły a jakość żywności i żywienia. Wydawnictwo Akademii Rolniczej im. Augusta Cieszkowskiego w Poznaniu

He, J., Evans, N. M., Liu, H., & Shao, S. (2020). A review of research on plant-based meat alternatives: Driving forces, history, manufacturing, and consumer attitudes. *Comprehensive Reviews in Food Science and Food Safety, 19*(5), 2639-2656. https://doi.org/10.1111/1541-4337.12610

Jeleń, H., Majcher, M., Ginja, A., & Kuligowski, M. (2013). Determination of compounds responsible for tempeh aroma. *Food Chemistry*, *141*(1), 459-465. https://doi.org/10.1016/j.foodchem.2013.03.047

Kuligowski, M., & Nowak, J. (2010). Ocena możliwości adaptacji i zastosowania tradycyjnych azjatyckich technologii w produkcji żywności na rynek polski. *Aparatura Badawcza i Dydaktyczna*, *2*, 63-69.

Kuligowski, M., Sobkowiak, D., Polanowska, K., & Jasińska-Kuligowska, I. (2022). Effect of different processing methods on isoflavone content in soybeans and soy products. *Journal of Food Composition and Analysis*, *110*, 104535. https://doi.org/10.1016/J.JFCA.2022.104535

Lemus-Mondaca, R., Marin, J., Rivas, J., Sanhueza, L., Soto, Y., Vera, N. & Puente-Díaz, L. (2019). Pumpkin seeds (Cucurbita maxima). A review of functional attributes and by-products. *Revista Chilena de Nutrición, 46*(6), 783-791. http://dx.doi.org/10.4067/S0717-75182019000600783

Lestari, B. & Meiyanto, E. (2018). A Review: The Emerging Nutraceutical Potential of Pumpkin Seeds. *Indonesian Journal of Cancer Chemoprevention, 9*(2), 92-101.

Mbow, C., Rosenzweig, C., Barioni, L.G., Benton, T.G., Herrero, M., Krishnapillai, M., Liwenga, E., Pradhan, P., Rivera-Ferre, M.G., Sapkota, T., Tubiello, F.N., Xu, Y., 2019. Food Security, in Chapter 5. In: Shukla, P.R., Skea, J., Calvo Buendia, E., Masson-Delmotte, V., P¨ortner, H.-O., Roberts, D.C., Zhai, P., Slade, R., Connors, S., Diemen, R., Ferrat, M., Haughey, E., Luz, S., Neogi, S., Pathak, M., Petzold, J., Portugal Pereira, J., Vyas, P., Huntley, E., Kissick, K., Belkacemi, M. & Malley, J. (Eds.), Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes interrestrial ecosystems. Retrieved November, 6, p. 2021 (from). https://www.ipcc.ch/srccl/.

Miszkiewicz, H., Okrajni, J., & Bielecki, S. (2008). Zmiany zawartości oraz aktywności przeciwutleniającej polifenoli i albumin grochu podczas fermentacji w bioreaktorze SSSR. *ŻYWNOŚĆ. Nauka. Technologia. Jakość*, *3*(58), 67-79. Retrieved from http://www.pttz.org/zyw/wyd/czas/2008, 3%2858%29/06_Miszkiewicz.pdf

Mugula, J. K., & Lyimo, M. (2000). Evaluation of the nutritional quality and acceptability of sorghum-based tempe as potential weaning foods in Tanzania. *International Journal of Food Sciences and Nutrition*, *51*(4), 269-277. https://doi.org/10.1080/09637480050077158

Nout, M. J. R., & Kiers, J. L. (2005). Tempe fermentation, innovation and functionality: Update into the third millenium. *Journal of Applied Microbiology*, *98*(4), 789-805. https://doi.org/10.1111/j.1365-2672.2004.02471.x

Nowak, J. (1992). Oats tempeh. *Acta Biotechnologica*, *12*(4), 345-348. https://doi.org/10.1002/ABIO.370120418

Nursiwi, A., Pertiwi, F., Ishartani, D., Sari, A. M., & Zaman, M. Z. (2021). Substrates and storage time evaluation for preparing tempeh starter from *Rhizopus oryzae* CBS130145. *IOP Conference Series: Earth and Environmental Science*, *828*(1). https://doi.org/10.1088/1755-1315/828/1/012003

Polanowska, K., Grygier, A., Kuligowski, M., Rudzińska, M., & Nowak, J. (2020). Effect of tempe fermentation by three different strains of *Rhizopus oligosporus* on nutritional characteristics of faba beans. *LWT – Food Science and Technology*, *122*. https://doi.org/10.1016/j.lwt.2020.109024

Puspitasari, D. J., Peuru, F. P., Prismawiryanti, Syamsuddin, Ridhay, A., Mirzan, M., & Nuryanti, S. (2023). Comparison of winged bean (*Psophocarpus tetragonolobus* L.) seeds and moringa (*Moringa oleifera*) seeds on the nutritional value of winged bean tempeh. *AIP Conference Proceedings*, *2642*, 110731. https://doi.org/10.1063/5.0110731

Stodolak, B., Starzyńska-Janiszewska, A., & Mickowska, B. (2013). Effect of flaxseed oil-cake addition on the nutritional value of grass pea tempeh. *Food Science and Technology Research*, *19*(6), 1107-1114. https://doi.org/10.3136/fstr.19.1107

Stone, H. & Sidel, J.L. (2004). Sensory evaluation practices (3rd ed.). Elsevier, Academic Press, London

Surmacka-Szcześniak, A. (2002). Texture is a sensory property. *Food Quality and Preference, 13*(4), 215-225

Rohrmann, S., Overvad, K., Bueno-de-Mesquita, H.B., Jakobsen, M.U., Egeberg, R., Tjønneland, A., Nailler, L., Boutron-Ruault, M.-C., Clavel-Chapelon, F., Krogh, V., Palli, D., Panico, S., Tumino, R., Ricceri, F., Bergmann, M.M., Boeing, H., Li, K., Kaaks, R., Khaw, K.-T., Wareham, N.J., Crowe, F. L., Key, T.J., Naska, A., Trichopoulou, A., Trichopoulos, D., Leenders, M., Peeters, P.H.M., Engeset, D., Parr, C.L., Skeie, G., Jakszyn, P., Sánchez, M.-J., Huerta, J.M., Redondo, M.L., Barricarte, A., Amiano, P., Drake, I., Sonestedt, E., Hallmans, G., Johansson, I., Fedirko, V., Romieux, I., Ferrari, P., Norat, T., Vergnaud, A.C., Riboli, E. & Linseisen, J. (2013). Meat consumption and mortality results from the European Prospective Investigation into Cancer and Nutrition. *BMC Medicne, 11*(1), 63.

The Royal Society. 2019. Future food: health and sustainability – conference report. London, https://royal-society.org/-/media/events/2019/12/tof-future-foods/Future-of-Food-ToFconference-report.pdf?la=en-GB&h-ash=23A54C1F233745C70AFA42545A883422, access 30.06.2021.

Yuliani, S., Juniawati, Ratnaningsih, & Suryana, E. A. (2022). Characteristics of Tempeh Prepared from Several Varieties of Indonesian Soybeans: Correlations between Soybean Size and Tempeh Quality Properties. *IOP Conference Series: Earth and Environmental Science*, *1024*(1). https://doi.org/10.1088/17551315/-024/-1/012051

THE POSSIBILITY OF USING COMPOSITE WASTE TO ASPHALT

Mariola Jastrzębska

Department of Industrial Product Quality and Chemistry, Faculty of Management and Quality Science, Gdynia Maritime University, Gdynia, Poland
**Corresponding Author e-mail:m.jastrzebska@wznj.umg.edu.pl*

DOI: 10.56091/CTQS.Innov-9

Abstract

In Europe there is a high potential for recycling waste in road construction. Various types of waste materials for example glass, plastics, scrap tyres have been successfully used in road pavements. Fibres and polymers are two important examples used to improve the engineering properties of asphalt, so composite waste has potential for re-use in asphalt. Recycling composites represents a techno-logical challenge and little practical experience exists. The research focuses on sustainable recycling of composite waste. Recycled composite waste applied to asphalt can be considered one of solution to overcome such environmental problem by reducing the large quantities of such waste. The paper aimed to demonstrate the possibility of using glass polyester recyclate to bitumen. The influence of adding glass reinforced polyester recyclate on some rheological properties of bitumen have been studied. The dynamic viscosity, penetration and softening points of the obtained modified bitumen were tested.

The addition of glass polyester recylate to bitumen resulted in an increase of dynamic viscosity and softening points of bitumen. It was also observed that after adding glass polyester recyclate there was a decrease of bitumen penetration.

Keywords: composite waste, recycling, bitumen

Introduction

In recent years there has been an increase in the use of composite products, particularly in the automotive, construction and marine industries. The world market for composites showed an increase from 12.1 million tonnes to 12.7 million tonnes last year 2022 despite many negative impacts on the economic climate (Förster, 2023). The overall manufacturing volume of thermoset composites (excluding carbon fibre reinforced) was 1138 kilo tonnes in 2022. Glass fibre reinforced systems still accounted for more than 95% of the total market. The largest part of all composites production flowed into the transport sector, which continued to account for more than 50% of the market volume.

The superior mechanical properties of composite materials provide an existing opportunity to build structures that are lightweight and of high strength, characteristics that have led to many engineering applications for composites. Now the wind energy industry represents one of the fastest growing application sectors of composites, where reinforcement fibres, such as fibreglass or carbon fibres, a polymer, such as polyester or epoxy, and a core material are used to build strong and compliant rotor blades. Composites like glass reinforced polyester have also many advantages in the manufacturing of recreational boats. Composites enable 30-40% reduction in overall weight of boat in contrast to metal., Glass reinforced polymers accounted for more than 80% of overall maritime composites demand while unsaturated polyester and vinyl esters dominated among polymers. Despite their many advantages composites are not recyclable. These materials cannot be heated and shaped once the polyester has cross-linked and cured, and they are termed thermoset.

In Europe, approximately 1 mega tonne of composites are manufactured each year. According to the European Composites Industry Association, 304 kilo tonnes of glass reinforced polymers waste were expected in 2015 (Jacobs, 2011). Existing European waste legislation emphasises the need to develop circular economy and increase recycling rates to deal with unnecessary waste pollution and increase resource efficiency. At national level, Germany, Austria, Finland and the Netherlands forbid composites from being landfilled. EU directive, 199/31/EC, prohibits the landfilling of material with more than 10% organic content. Potential techniques that could be in use for glass reinforced polyester waste include mechanical breakdown, thermal recycling as well as chemical recycling. The main concern is non-reprocessable glass thermosetting waste and it has been described in the literature by Goodship (2010). The following options are potentially available for glass reinforced waste, in decreasing order of preference: waste minimization, reuse, recycling, incineration with energy recovery and landfill or incineration without energy recovery. The possibility of re-using glass reinforced polyester waste in cement was investigated by Tittarelli and coworkers (2010, 2013). Today, the main technology for recycling composite waste is through cement co-processing. Cement co-processing is commercially available for processing large volumes of waste (although not in all geographies yet). In this process the mineral components are reused in cement. However, the glass fibre shape is not maintained during the process, which from a waste hierarchy perspective may be less preferred. The development of alternative recycling technologies gives preference to mechanical recycling which produce higher value recyclates (both in terms of resin and fibre) and enables production of new materials like modified asphalt.

Mechanical recycling involves grounding of glass reinforced polyester waste to a recyclate that can be used as a new material with reinforcing properties in composite part and in other products that need reinforcement. It can also be used as filler.

It does however drastically decrease the value of the recycled materials. Mechanical grinding is a commonly used technology due to its effectiveness, low cost and low energy requirement. The recycled products, short fibres and ground matrix (powder), can be used respectively as reinforcement or fillers. Because of the deterioration of the mechanical properties, the incorporation level of filler material is extremely limited in thermoset composite applications (less than 10%). Glass fibre reinforced polyester partly loses its properties during aging and regrinding. The advantages of mechanical recycling are the most readily available and most cost effective process to start up and run, some proven applications in composite industry, all of which can be considered more friendly to the environment. Although the finer grade particles can be used to replace filler, leading to some modest performance improvement, the challenge still remains to find sufficient markets for the range of mechanically recycled grades. Improvement of mechanical properties has been obtained by using composite waste in base resin systems, concrete and thermoplastics. Asphalt made with recycled composite waste has already been proposed in the litera-ture by Poulikakos et al., (2017).

The use of fibre to modify bitumen has become a much more attractive alternative for the construction of road pavements. Different types of fibres have been used in asphalt binders as an alternative to solve mainly mechanical performance problems. There is a large number of fibre-modified asphalt binders and fibre-modified asphalt mixtures in which fibres have been used to deal with the main flexible pavement problems, such as rutting, fatigue cracking, thermal cracking and ravelling. The use of glass, aramid, steel and waste fibres in asphalt was investigated (Zaltuom et al., 2022, Slebi-Acevedo et al., 2019). Some fibres have high tensile strength relative to bituminous mixtures and it was found that fibres have the potential to improve the cohesive and tensile strength of bituminous mixes. They are believed to impart physical changes to bituminous mixtures by the phenomena of reinforcement and toughening. This high tensile strength reinforcement may increase the amount of strain energy that can be absorbed during the fatigue and fracture process of the mix. Finely divided fibres also provide a high surface area per unit weight and behave much like filler materials. Fibres also tend to bulk the bitumen so it will not run off the aggregates during construction (Mahrez et al., 2003). Utilisation of fibres in asphalt mixtures, such as glass fibre, polyester fibre, polypropylene fibre, carbon fibre, cellulose fibre, etc. results in lower maintenance requirements, longer service life, higher tensile strength, resistance to moisture susceptibility and permanent deformations (Mahrez et al., 2003). Glass fibre modification on asphalt mixtures improves performances at high and low temperatures (Luo et al., 2019). Additionally, glass fibre-modified asphalt mixtures are more resistant against rutting, crack initiation and crack propagation (Luo et al., 2019, Morea & Zerbino, 2018). Glass waste in asphalt can be used in the form of fibres, large or small particles and powder.

In the paving industry researchers have attempted to use almost all available polymers as asphalt modifiers, including thermoplastics and thermosetting resins. Polymer-modified asphalts derive their technological and conceptual origin from the need for enhancing the performance and durability of asphaltic materials as well as their adhesion to mineral aggregates. Polymer-modified asphalts are produced by mixing asphalt and polymer (usually 3-7% by weight); they were developed because conventional flexible pavements had become inadequate in the last few decades because of the dramatic increase in traffic intensity and load, which shortened their in-service life, thereby increasing the frequency of road maintenance and re-paving required. Modification is normally achieved through simple mechanical dispersion of the polymer in molten asphalt under high shear. Approximately 75% of all modifiers are elastomeric, 15% are plastomeric, and the remaining 10% are rubber. The longer life and better quality of polymer-modified asphalt-based pavements usually lead to both economical and safety requirements that overcome the initial investment, which is higher with respect to the use of conventional unmodified binders (Polacco et al., 2015).

This case study was carried out the mechanical recycling of glass reinforced polyester waste. With a ban on the disposal of glass reinforced polyester waste into landfill and the ever-increasing costs of waste disposal, the stabilising of waste in the road paving system has increasing attraction. The paper aimed to demonstrate the possibility of using glass polyester recyclate to bitumen. The recyclate was a mixture of cured polyester resin particles and glass fibre. The influence of the different amounts of glass reinforced polyester recyclate on some rheological properties (e.g., softening point, penetration, viscosity) of bitumen has been tested. The work presented in this paper forms part of a major investigation into the potential for comminuted glass reinforced polyester waste to be recycled in bitumen.

Materials and methods

Materials

Glass reinforced polyester recyclate

To modify bitumen-based material, fine grounded E-glass fibre reinforced polyester recyclate has been used during the cutting of a boat dismantling process. The fibres in the form of layers known as stitched multilayer reinforcements were supplied by Krosglass®. E glass fibre is commonly used for reinforcement in laminates and is based on an alumina-limeborosilicate composition. Matrix material was an orthophthalic polyester produced by Sarzyna Chemical Sp. z o.o., as a general purpose resin which is widely used in small craft building industry.

Hand lay-up was the preferred method since E-glass fibre and polyester are used widely in the boat building industry due to lower cost and the ease of obtaining uniform thickness throughout the lamination. The waste of glass fibre reinforced cold-cured polyester laminates was ground in a shredder manufactured in Kubala Sp. z o.o. The grains of recyclate were of different size smaller than 0.3 mm (14.6%), size 0.3÷3.15 mm (47.9%) and higher than 3.15 mm (37.5%). The recyclate was a mixture of cured polyester resin particles and glass fibre (~40%).

Bitumen

Paving grade bitumen 70/100 intended the use for construction and maintenance of roads, airfields and other paved areas from LOTOS Asfalt Sp.z o.o.

Before adding the glass polyester recyclates, bitumen has been heated up to 180-200°C. During the preparation of the specimens, the mixtures have been mixed in 2000 rpm for 60 min. For each bitumen product, three mixtures in different glass polyester recyclate/bitumen weight ratio (5, 10 and 15 wt.%) have been prepared and three calculations/determinations on samples have been made and averaged for each type of tests to eliminate possible preparation and testing errors. Polymer modified bitumen usually contain from 3% to 8% polymers (by weight). Because in the recyclate there was about 60 wt.% of cured polyester resin 5, 10 and 15 wt.% of glass reinforced polyester recyclate were used in the mixtures.

Methods

In this study three tests have been aimed to investigate the possible effects of glass polyester recyclate on bitumen: viscosity, softening point and penetration of modified bitumen.

VISCOTESTER 2+ company HAAKE rotational viscometer has been utilized for measuring viscosity, or resistance to flow according to the related standard at temperature 150°C.

Softening point test is to determine the softening point of virgin and modified bitumen within the range 30-157°C by means of the Ring-and-Ball apparatus. A high softening point ensures that they will not flow in service. For a bitumen of a given penetration, the higher the softening point the lower the temperature sensitivity. During the test, specimens have been prepared exactly as specified in the related PN-EN 1427:2015-08 standard in precisely dimensioned brass rings and maintained at a temperature of not less than 10°C below the expected softening point for 30 min before the test. The rings and assembly, and two ball bearings, have been placed in a water bath filled to a depth of 105±3 mm and the whole maintained at a temperature of 5±1°C for 15 min.

Then a 9.5 mm steel ball bearing (weighing 3.50±0.05 g) has been centered on each specimen and heat has been then applied to the beaker so as to raise the temperature by 5±0.5°C per minute. The temperature at which each bitumen specimen touches the base plate has been recorded as its softening point.

Penetration test is to examine the consistency of a sample of bitumen by determining the distance in tenths of a millimetre that a standard needle vertically penetrates the bitumen specimen under known conditions of loading, time and temperature. The consistency is a function of the chemical constituents of a bitumen: the relative proportions of asphaltenes (high molecular weight, responsible for strength and stiffness), resins (responsible for adhesion and ductility) and oils (low molecular weight, responsible for viscosity and fluidity). Penetration test in this study has been performed using a penetration apparatus specified in the related standard PN-EN 1426:2015-08. Specimens have been prepared in sample containers and placed in a water bath at 25°C for 1.5 h before the test. The precisely dimensioned needle, loaded to 100±0.05 g, has been brought to the surface of the specimen at right angles, allowed to penetrate the bitumen for 5±0.1 s, while the temperature of the specimen has been maintained at 25±0.1°C. The penetration is measured in tenths of a millimetre (deci-millimetre, d-mm).

Results and discussion

The study determined the impact of glass polyester recyclate on some properties of bitumen. It was expected that the introduction of the recyclate consisting of short glass fibres and polyester resin would improve bitumen performances at high and low temperatures.

The viscosity of bitumen and different amounts of glass polyester recyclate are given in Fig. 1. In this study the sought relationship has been determined in the form of linear functions. Conformity of the relationship to experimental data was evaluated using determination coefficient R^2. The model partially predicts the outcome. The estimated regression function only with a certain approximation reflects the actual relationships between the examined features. Tests of a larger number of samples with glass polyester recyclate will allow for a through statistical analysis.

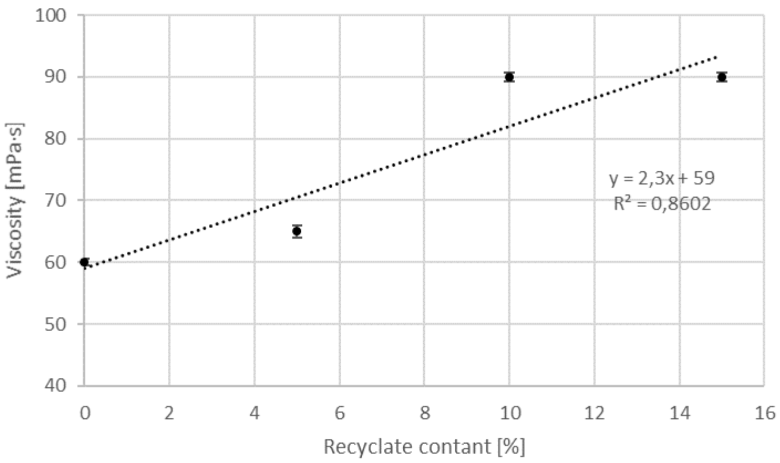


Fig. 1. Viscosity of bitumen depending on the amount of glass polyester recyclate

Source: own study.

Adding 10% and more glass polyester recyclate in a mixture implies high viscosity and low workability in the blending procedure. According to the results obtained, 5% recyclate by weight of mixture is the optimum dosage to improve the rutting behavior and the maximum stress as determined in the bending test.

The softening point and the penetration of bitumen with different amount of glass polyester recyclate are given in Figures 2 and 3. In this study the sought relationships have been determined in the form of 2nd degree polynomials (quadratic functions). Conformity of the relationship to experimental data was evaluated using determination coefficient R^2.

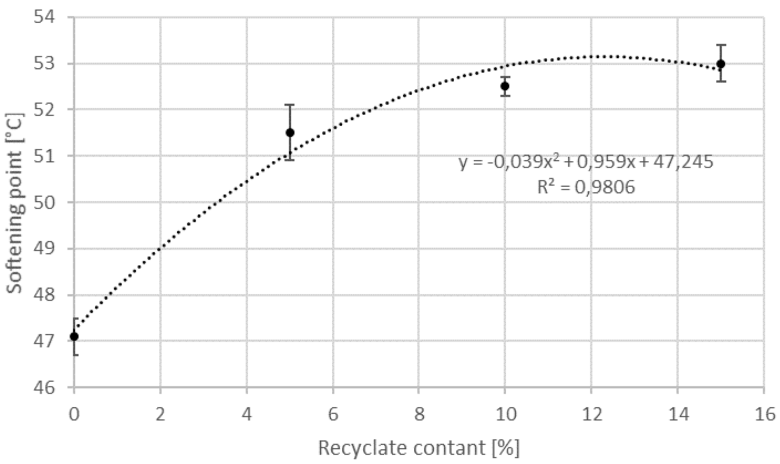


Fig. 2. Softening point of bitumen depending on the amount of glass polyester recyclate

Source: own study.

The application of 5%, 10% and 15% of polyester recyclate containing glass fibre to bitumen resulted in an increase in the softening point. This is a beneficial phenomenon due to the increased resistance of bitumen to high temperatures. The effects include reduced temperature susceptibility of the tested binders.

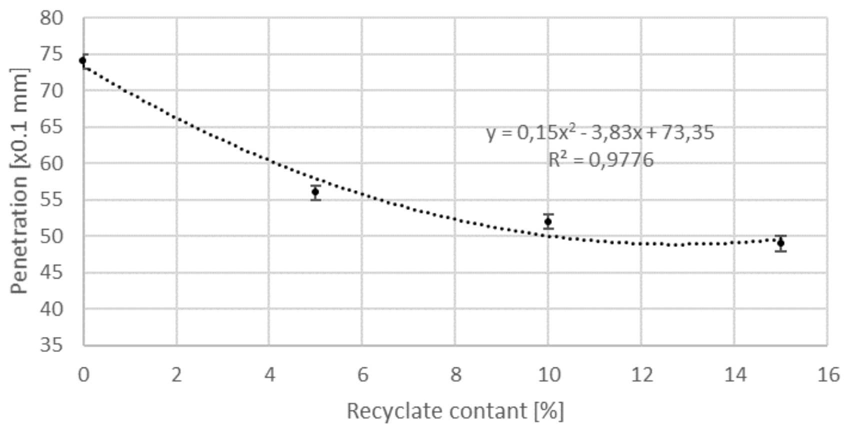


Fig. 3. Penetration of bitumen depending on the amount of glass polyester recyclate

Source: own study.

In the analysed cases glass polyester recyclate addition decreased the penetration index from 74 (bitumen 70/100) to 49x0.1 mm (bitumen 70/100+15% recyclate). The greater the addition of glass polyester recyclate to the bitumen, the lower the penetration value, and thus the increase in hardness.

The adding of glass polyester recyclate changes the properties of bitumen, reducing the penetration and increasing the softening point.

Conclusions

The purpose of this study was to estimate recycling application for finely ground glass reinforced polyester waste to modification of bitumen. The study showed that using glass reinforced recyclate in bitumen increases the viscosity and the softening point and also decreases the penetration. It will improve bitumen life cycle performance including more resistance to permanent deformation at high temperatures (higher resistance to rutting). Taking into account the research results bitumen after adding glass polyester recyclate has been increasing stiffness, it can be assumed that, like 50/70 asphalt, would be suitable for binding layers and highway bases on large areas of Poland.

The use of glass polyester recyclate as a modifier in bitumen can be considered as a potential technique to solve the recycling problem of the industry in a cost-effective way. The possibility of using glass polyester recyclate to modify bitumen may significantly facilitate its use in road construction and gives an opportunity to reduce the number of composite waste. An environmental benefit would result from the conservation of landfill space. The obtained results were promising for a global waste management solution for glass reinforced polyester waste and end-of-life products that will lead to a more sustainable composite materials industry.

References

Förster, B. (2023). The European market for Fibre Reinforced Plastics/Composites in 2022. AVK Industrievereinigung Verstärkte Kunststoffe, Press release 04/2023. https://www.avktv.de/files/20230425-_pr_042023_market_report_2022.pdf

Goodship, V. (2010). *Management recycling and reuse of waste composites.* Woodhead Publishing Limited. https://www.sciencedirect.com/book/9781845694623/management-recycling-and-reuse-of-waste-composites

Jacobs, A. (2011). Composites can be recycled. *Reinforced Plastics*, *55*(3), 45-46. https://doi.org/10.1016/S0034-3617(11)70079-0

Luo, D., Khater, A., Yue, Y., Abdelsalam, M., Zhang, Z., Li, Y., Li, J., & Iseley, D.T. (2019). The performance of asphalt mixtures modified with lignin fiber and glass fiber: A review. *Construction and Building Materials 209*, 377-387. https://doi.org/10.1016/j.conbuildmat.2019.03.126

Mahrez, A., Karim, M.R., & Katman, H.,Y. (2003). Prospect of using fibre reinforced bituminous mixes. *Journal of the Eastern Asia Society for Transportation Studies*, *5*, 704-807.

Morea, F., & Zerbino, R. (2018). Improvement of asphalt mixture performance with glass macro-fibers. *Construction and Building Materials, 164*, 113-120. https://doi.org/10.1016/j.conbuildmat.2017.12.198

Polacco, G., Filippi, S., Merusi, F., & Stastna, G. (2015). A review of the fundamentals of polymer-modified asphalts: Asphalt/polymer interactions and principles of compatibility. *Advances in Colloid and Interface Science*, *224*, 72-112. https://doi.org/10.1016/j.cis.2015.07.010

Poulikakos, L.D., Papadaskalopoulou, C., Hofko, B., Gschösser, F., Cannone, Falchetto, A., Bueno, M., Sousa, J., Ruiz, R., Petit, C., Loizidou, M., & Partl, M.N. (2017). Harvesting the unexplored potential of European waste materials for road construction. *Resources, Conservation and Recycling, 116*, 32-44. http://dx.doi.org/10.1016/-j.resconrec.2016.09.008

Slebi-Acevedo, C.J., Lastra-González, P., Pascula-Muñoz, P., Castro-Fresno, D. (2019). Mechanical performance of fibers in hot mix asphalt: A review. *Construction and Building Materials, 200*, 756-769. -https://doi.org/10.1016/-j.conbuildmat.2018.12.171

Tittarelli, F., Moriconi, G. (2010). Use of GRP industrial by products in cement based composites. *Cement & Concrete Composites*, *32*, 219-225. https://doi.org/10.1016/j.cemconcomp.2009.11.005

Tittarelli, F., Shah, S.P. (2013). Effect of low dosages of waste GRP dust on fresh and hardened properties of mortars: part 1. *Construction and Building Materials*, *47*, 1532-1538. https://doi.org/10.1016/j.conbuildmat-.2013.06.043

Zaltuom, A., Frag, M., Akhmira, A.A. (2022). Comparative study of stabilizing additives effect on bituminous mixture; a review. *Global Scientific Journals, 10*(11), 1287-1291. https://www.globalscientificjournal.com-/researchpaper/Comparative_Study_of_Stabilizing_Additives_Effect_on_Bituminous_Mixture_A_Review.pdf

PN EN 1427:2015-08. Bitumen and bituminous binders. Determination of the softening point. Ring and Ball method.

PN-EN 1426:2015-08. Bitumen and bituminous binders. Determination of needle penetration.

THE EFFECT OF THE MODIFICATION OF A THREE-PLY CORRUGATED BOARD WITH RECYCLED FIBERS ON ITS PROPERTIES

Tomasz Kalak*, Michał Marcinkowski

Department of Industrial Products and Packaging Quality, Institute of Quality Science,
Poznań University of Economics and Business, Poznań, Poland
**Corresponding Author e-mail:tomasz.kalak@ue.poznan.pl*

DOI: 10.56091/CTQS.Innov-10

Abstract

Corrugated cardboard is currently one of the most popular packaging materials in the world. The reason for the ever-growing demand for this material is its many benefits, such as the low cost of products, being a completely biodegradable and environmentally friendly material, the possibility of modifying the composition with recycled fibers, the possibility of repeated use, and good functional and strength properties, which allow for a wide industrial application, especially for the production of packaging. In addition, due to the fact that cardboard is a paper product, it perfectly fits into the current pro-ecological trends, including the assumptions of sustainable development and the circular economy model.

This paper presents research on the effect of modifying three-ply corrugated board with recycled fibers on its physicochemical and strength properties. The aim of the research was to show the differences in selected properties of corrugated board resulting from the use of modified paper in one of the layers, and two layers were identical in the samples. Many experiments have been carried out on property testing, including organoleptic evaluation, determination of moisture content of paper and board, total thickness of board and individual plies, apparent density, grammage, wave height, wave pitch, corrugation coefficient, water absorption using the Cobb method, and strength tests such as bursting strength and edgewise crush strength of cardboard. The research results showed similar values of grammage, thickness, apparent density, corrugation coefficient, and wave pitch. All samples had an acceptable moisture level of 6-9%, so they can be classified as a compliant finished product or semi-finished product for further production, e.g., packaging. In another case, it was shown that the KS/WB/T3 board (containing primary and recycled fibers) achieved a higher linear water absorption of 16.8 g/m^2 than the T3/WB/T3 board (containing only recycled fibers) of 14.7 g/m^2. In tests of edge crushing and bursting strength, higher values were obtained by KS/WB/T3 (4.8 kN/m, 537 kPa) compared to T3/WB/T3 (4.36 kN/m, 440 kPa). Summing up, it was found that the KS/WB/T3 board had better strength properties, which may translate into wider use in many industries, including transport and storage.

Keywords: three-ply corrugated board, primary and recycled fibers, paper, cardboard quality, functional and strength properties

Introduction

Among the many materials used for the production of packaging, cardboard is one of the most popular and commonly used. It is the thickest paper material and is manufactured by gluing together two to several layers of paper pulp. Due to its beneficial properties, corrugated cardboard is one of the highest-rated materials for packaging production. It is characterized by a low specific weight and good mechanical and strength properties, and its price is relatively low. There is the possibility of reprocessing, depreciation, incineration, or composting with energy recovery. Currently, industrial technology allows the production of e.g., packaging, pallets, or even furniture (Jakowski, 2005; Janiga & Michniewicz, 2017).

Corrugated cardboard is a material made of one or more layers of paper in a flat or corrugated form. The layers are glued alternately, most often with starch glue. Each of the layers has its own name, which defines what paper should be used in production. Due to their properties and applications, papers are divided into two groups. The first of them is for flat layers (liners), and the second is for corrugated layers (flutings). Corrugated board is characterized by the number of layers; hence, the following types can be distinguished:

- two-layer corrugated board consisting of one corrugated layer glued to one flat layer (cover),
- three-layer corrugated board consisting of one layer of corrugated paper glued between two flat layers,
- five-layer corrugated board consisting of two corrugated layers glued alternately between three flat layers,
- seven-layer corrugated board consisting of three corrugated layers glued alternately between four flat layers (Fig. 1) (Bielecki et al., 2011).

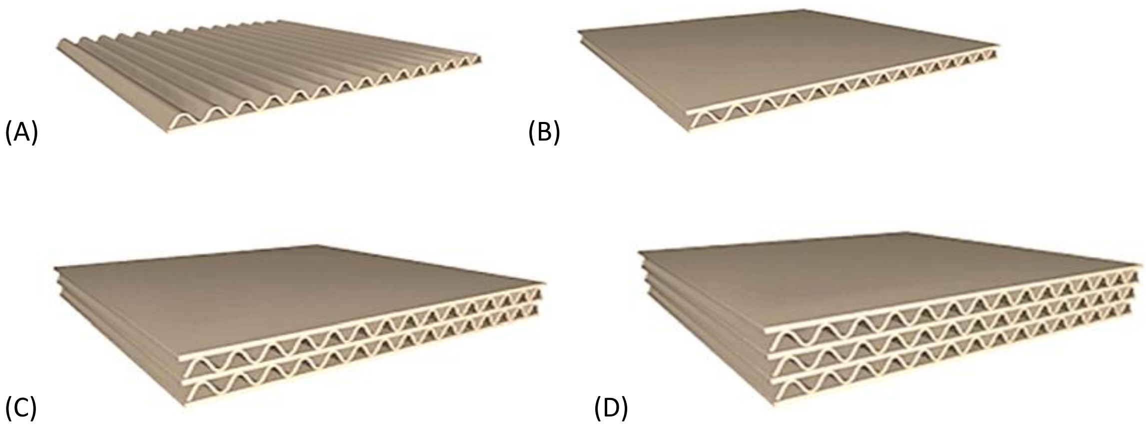


Fig. 1. Multilayer corrugated cardboard: A) two-layer, B) three-layer, C) five-layer, D) seven-layer

Source: own study.

Currently, the industry uses recycled fibers from waste paper for the production of solid and corrugated board. Cardboard consisting only of recycled waste paper as well as an admixture of primary fibers in various proportions is produced at these times. Recycled paper has many advantages. It can be reused in the production of paper and all cardboard packaging. It is estimated that magazines can be recycled at least seven times. Considering the protection of the natural environment, the use of recycled paper reduces greenhouse gas emissions that can contribute to climate change by avoiding methane emissions and reducing the energy consumption of many paper products. There is an increased supply of fiber, which causes carbon sequestration. In addition, there is a significant reduction in the area of landfills, as well as a reduction in water and energy consumption. There is less need for neutralization through thermal transformation or storage, which translates into a reduction of CO_2 emissions into the atmosphere. According to estimates, recycled paper used for photocopiers is about 4-5 times less harmful to the environment, and its lifespan is estimated at over 100 years. It is widely used in the paper industry, construction as an insulating material, and the furniture industry as a substitute for plywood (EPA, 2023; Obradovic & Mishra, 2020). According to the literature report, Germany tops the global recycling list with a recycling rate of 56.1%. Austria ranks second with 53.8%. The next leading countries using recycling are South Korea (53.7%), Switzerland (49.7%), Italy (49.7%), Belgium (49.4%), the Netherlands (46.3%), Slovenia (45.8%), and Singapore (34%) (PGPaper, 2023).

The aim of the research was to determine selected properties of three-ply corrugated board modified with primary and recycled fibers and then compare the test results with cardboard composed only of recycled fibers. As a result of the experiments, the following determinations were carried out: organoleptic evaluation, moisture content of paper and cardboard, thickness of cardboard and individual plies, apparent density, grammage, wave height, wave pitch, wave coefficient, linear water absorption by the Cobb method, bursting strength, and edgewise crush resistance.

Materials and methods

Materials

In this work, corrugated board made of the following types of paper was used for the experiments:

- paper T3 (Testliner 3) with a composition of 100% recycled fibers,
- paper WB: Waste based fluting with a composition of 100% recycled fibers,
- paper KS (Kraftsubstitute, liner) with a composition of 30% (±5%) primary fibers and 70% (±5%) recycled fibers (Fig. 1)

Samples of the three-ply corrugated board were used in the research as follows:

- sample 1: T3/WB/T3 – containing only recycled fibers,
- sa mple 2: KS/WB/T3 – containing primary and recycled fibers (Fig. 2).

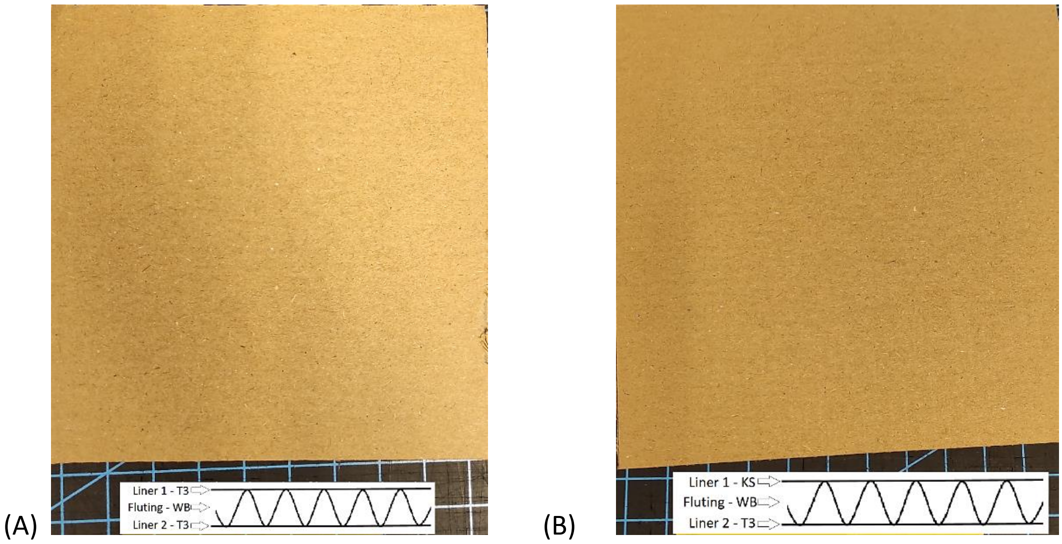


Fig. 2. Three-layer corrugated board samples: A) sample 1: T3/WB/T3; B) sample 2: KS/WB/T3

Source: own study.

Methods

Organoleptic evaluation

The organoleptic assessment tests consisted of using the senses to check the properties of the samples of cardboard or paper. The method is based on the senses of sight, smell, taste, hearing, and touch.

Determination of the moisture content of paper and cardboard

Moisture determination was carried out according to the UNE EN ISO 287:2018 standard. The principle of the method is to calculate the absolute moisture content of paper or cardboard. Absolute humidity is defined as the percentage ratio of the weight of water contained in the cardboard to the dry weight of the product. The moisture content of paper and cardboard is tested in a moisture analyzer or chamber dryer. A 10×10 cm cardboard sample should be placed on the moisture analyzer's forks, and the lid should be closed. After closing, the measurement process will start automatically, ending with a characteristic sound. Then read the displayed value in [%]. The acceptable moisture content for cardboard is 6-9%. The acceptable moisture result for paper is defined by the paper manufacturer's specification.

In the chamber dryer test, a sample of cardboard or paper is weighed under acclimatized conditions and then dried in the chamber dryer to a constant weight. Humidity is calculated using Equation (1):

$$X = \frac{m_1 - m_2}{m_1} \cdot 100\% \tag{1}$$

where:

m_1 – weight of a sample (acclimated) before drying [g],

m_2 – weight of a sample after drying [g] (UNE EN ISO 287:2018).

Determination of the thickness of cardboard and individual pieces

The determination of the thickness of cardboard and its single layers was carried out according to the BS EN ISO 534:2011 standard. The thickness of the cardboard and single layers is measured using a thickness gauge in µm. Before starting the measurement, zero the device with the "ZERO" button. Using a knife, a piece of cardboard is cut out of the sheet or packaging. Use the lever to raise the thickness gauge arms and place the sample between them. The next step is to lower the lever and read the value. For packages or blanks, after passing through the processing machine, a deviation of ±0.3 mm from the initial value is allowed (BS EN ISO 534:2011).

Determination of apparent density

The apparent density of cardboard is the mass of one cubic centimeter of cardboard expressed in g/m^3. It is calculated by dividing the weight of cardboard by its thickness, according to Equation (2). Apparent density is a cardboard property that affects its mechanical, optical, and hydrophilic-hydrophobic properties, e.g., linear absorbency.

$$d = \frac{g}{\delta} \tag{2}$$

where:

d – sample grammage [g/m^2],

δ – average thickness of a single sample sheet [m].

Determination of the grammage of corrugated board and paper

The grammage of corrugated board and flat layers was determined according to the PN-EN ISO 536:2020-08 standard. The principle of the method is to determine the mass of one square meter of material [g/m^2]. A sample from a sheet of cardboard or paper should be cut out using a square die with dimensions of 100 x 100 mm.

A sample of cardboard or paper must be conditioned for at least 3 hours at a temperature of 23°C (±1°C) and humidity of 50% (±2%). The sample should be weighed to three significant figures (0.001), and grammage should be calculated by dividing the weight of the sample by the surface area of the sample and multiplying the whole by 10000 according to Equation (3).

$$G = \frac{m}{A} \cdot 10000 \tag{3}$$

where:

m – weight of the test sample [g],

A – surface of the test sample [cm^2] (PN-EN ISO 536:2020-08).

Determination of wave height, wave pitch, and wave coefficient

Wave height is the distance from the top of the wave to the base, measured with a caliper or thickness gauge with an accuracy of two significant places. The wave pitch is the distance between two adjacent wave crests. For determination, 10 wave crests should be marked on each sample, and then the distance between the first and tenth crests should be measured to two significant places. The wave pitch should be calculated by dividing the obtained dimension by the number of waves. The wave coefficient is the ratio of the length of the paper before corrugation to the length of the web after corrugation. It should be calculated by dividing the length of the straightened sample by its initial length.

Determination of linear water absorption by the Cobb method

The determination of linear water absorption by the Cobb method was performed according to EN ISO 535:2022. The principle of the method is to determine the mass of water that a sample of paper or cardboard with an area of 100 cm^2 and a water surface height of 1 cm absorbs for a certain period of time. A cardboard sample should be cut out of cardboard or paper with a template measuring 125×125 mm. The sample should be even, not ragged, without surface damage, without signs of wetting, and without creases. Before testing, the sample should be conditioned at 23°C (±1°C) and 50% humidity (±2%). The sample should be weighed before testing. The sample is then placed in the Cobb absorption tester. The test sample should be inserted into the gap between the cylinder ring and the rubber base. The cylinder should press down on the sample on all sides. 100 ml of distilled water should be poured into the measuring cylinder while turning on the stopwatch. After 45 seconds, water should be poured into the cuvette and the cardboard or paper removed. The test sample is placed on drain paper. After 60 seconds, a second piece of tissue paper should be placed on the sample. The penultimate step is rolling with a metal roller two times (from top to bottom and from bottom to top of the sample). At the end of the test, the sample should be weighed. Linear water absorption *A* should be calculated according to equation (4):

$$A = \frac{10^4(m_2 - m_1)}{s} \quad (4)$$

where:

m_1 – weight of a sample (acclimated) before wetting [g],

m_2 – weight of a sample after wetting [g],

s – surface wetting of a sample during the test [cm^2] (EN ISO 535:2022).

Determination of bursting strength

The determination of bursting strength was carried out according to the EN ISO 2759:2014 standard. The principle of the method consists of measuring the hydraulic pressure acting unilaterally on the membrane, which, by bulging, causes the product to burst. Before testing, the sample should be conditioned for at least 3 hours at 23°C (±1°C) and 50% humidity (±2%). Cut out two samples, no smaller than 125×125 mm, from cardboard sheets. The sample should be even, not ragged, without creases or mechanical damage. The sample is placed between the clamp and the bulge at the bottom of the base of the burst apparatus. The sample must be centered on the plate so that it covers the silver ring, and then the test proceeds. The result is obtained in kPa (EN ISO 2759:2014).

Determination of cardboard edgewise crush resistance

The determination of edgewise crush resistance was performed according to the EN ISO 3037 standard. Before testing, the samples should be conditioned for at least 3 hours at 23°C (±1°C) and 50% humidity (±2%). Five test pieces of 100×25 mm should be cut from cardboard sheets. Samples should be even, not torn, and without creases. The edgewise crush resistance is measured using a tensile apparatus. The sample is placed vertically between two weights located between the compression plates. The sample must be centered on the plate and flush with the weights. ECT is expressed in kN/m (EN ISO 3037).

Results and discussion

Based on the organoleptic evaluation, it was found that after visual inspection with the unaided eye, the T3/WB/T3 and KS/WB/T3 corrugated board samples are very similar, with no differences on the inner surface. The surfaces on the outer side differ in color. KS/WB/T3 corrugated board is darker in color and gives the impression of a more compact structure than T3/WB/T3. The difference is due to the use of other papers for this layer. Both samples have a characteristic smell, which results from heating the papers to certain temperatures and the use of starch glue.

None of the corrugated board samples showed signs of cracking when they were folded. This may indicate the correct absolute humidity. The surfaces of the samples are flat on each side; however, no roughness can be detected organoleptically.

On T3 papers, there is uneven passing through the surface of the fibers. The papers themselves have no smell. Similar observations apply to the WB corrugated layer. Its fiber composition is identical to that of T3 paper. The difference lies in the degree of sizing, i.e., the addition of different adhesive mixtures to increase the mechanical properties. Organoleptically, it can be stated that WB paper seems to be less mechanically durable; it seems to be of lower quality, with a gray color and wrinkled, fibrous structure.

Absolute humidity tests were carried out, and the results are presented in Table 1. The presented data are average values from the measurements of five samples. Absolute humidity tests were carried out, and the results are shown in Table 1. The presented data are average values from the measurements of three samples. WB paper achieved the greatest average absolute humidity for the corrugated layer (8.9%). Other papers gained values at the level of 8.2-8.4%. The corrugated cardboard had a moisture content of 7.5-7.7%. The obtained results fall within the limits set by the standard of 6-9%; hence, the cardboards can be approved for further production stages. Silveira et al. carried out measurements of the moisture content of waste cardboard and paper packaging bales made in several locations and reported an average moisture content of 10-13% (Silveira et al., 2021). Mahakalkar et al. noted that the best combined qualities for paper, corrugated board, and boxes are obtained at a moisture content of 7-8%; hence, corrugated board sheets used in the corrugated packaging industry may have an ideal moisture content of 7-8% (Mahakalkar et al., 2019).

An exothermal process occurs when moisture adsorbs into the cellulose fibers or when water diffuses into paper. Humidity, on the other hand, tends to increase the moisture content of paper. When testing paperboard at 23°C with varying relative humidity, there is a linear relationship between moisture ratio and mechanical qualities (Marin, 2020). This indicates that as the moisture ratio increases, the strength decreases. If it is wet, paper will gradually degrade into pulp. This is because moisture breaks the bonds formed between the fibers during the paper-making process. It is reported in the literature that moisture reduces the paper's strength, and the optimal moisture rate is 7% (Latka, 2017). According to studies, when the moisture content of paper reaches 14%, which may be reached by curing the paper at 90% relative humidity, the strength reduces by 50%. Other studies confirmed that increasing relative humidity reduces strength properties (Małachowska et al., 2020).

Table 1. Absolute humidity of cardboard and paper samples

Sample	Cardboard		Paper		
Parameter	T3/WB/T3	KS/WB/T3	T3	WB	KS
Average absolute humidity [%]	7.715 ±0.019	7.504 ±0.015	8.234 ±0.019	8.900 ±0.011	8.451 ±0.016

Source: own study.

The thickness of corrugated board and single plies was tested, and the results are shown in Table 2. The results are average values from the measurements of ten samples. Among the tested corrugated board samples, the KS/WB/T3 sample showed a greater average thickness, reaching 1.49 mm. The average thickness of the T3/WB/T3 corrugated board was 1.48 mm. The measurements have a small standard deviation, and the maximum and minimum values are in the range of 1.51-1.47 mm. This proves that the thickness of the entire corrugated board is even. Kalita et al., reported in their research that the thickness of individual layers of corrugated cardboard was 0.253 mm (Kalita et al., 2021). Other researchers showed that the thickness of tested individual cardboard layers ranged from 0.089 to 0.239 mm (Lindberg & Kulachenko, 2022).

Among the tested paper samples, the average thickness was between 0.16 and 0.15 mm. It is worth noting that the standard deviation is small in the range of 0.002-0.003 mm, which proves the repeatability of the measurement results and the equal thickness of the papers.

On the basis of measurements of the weight and specific surface area of the corrugated board and individual flat layers, the grammage was calculated. The results are the average of five measurements and are shown in Table 3. The tested samples of corrugated board showed very similar average grammages of 325.5 and 325.2 g/m^2, with a small standard deviation of 0.04-0.049.

Table 2. Thickness of corrugated cardboard and paper samples

Sample	Cardboard		Paper		
Parameter	T3/WB/T3	KS/WB/T3	T3	WB	KS
Average thickness [mm]	1,480 ±0.007	1.490 ±0.012	0.160 ±0.005	0.150 ±0.005	0.160 ±0.003
Maximum thickness [mm]	1.50	1.51	0.16	0.15	0.16
Minimum thickness [mm]	1.47	1.48	0.15	0.14	0.15

Source: own study.

Based on the results of the thickness of the samples and grammage, the apparent density was calculated. Both cardboards obtained similar values of 0.220 and 0.218 g/cm^3, respectively. T3 paper obtained the highest value, equal to 0.646 g/cm^3, and was higher by 0.017 g/cm^3 than the other paper samples.

Table 3. Grammage and apparent density of cardboard and paper samples

Sample	Cardboard		Paper		
Parameter	T3/WB/T3	KS/WB/T3	T3	WB	KS
Average grammage [g/m^2]	325.5 ±0.049	325.2 ±0.040	101.7 ±0.400	91.14 ±0.150	100 ±0.001
Average thickness [µm]	1480	1490	157	145	159
Average apparent density [g/cm^3]	0.220	0.218	0.646	0.629	0.629

Source: own study.

Measurements of wave height (10 measurements), wave pitch (10 measurements), and corrugation coefficient (5 measurements) were made, and the results are shown in Table 4. For both boards, the measurement results are very similar.

Table 4. Wave height, wave pitch and corrugation coefficient of corrugated board

Sample	Cardboard	
Parameter	**T3/WB/T3**	**KS/WB/T3**
Wave height [mm]	1.48 ± 0.001	1.49 ± 0.001
Wave pitch [mm]	3.20 ± 0.004	3.21 ± 0.005
Corrugation coefficient	1.24 ± 0.001	1.25 ± 0.001

Source: own study.

As can be seen, the KS/WB/T3 cardboard obtained higher values. The wave height was 1.49 mm, 0.01 mm more than T3/WB/T3. The wave pitch was 3.21 mm, and 0.01 mm more than T3/WB/T3. The corrugation coefficient was achieved at a level of 1.24-1.25. The calculated parameters of the T3/WB/T3 and KS/WB/T3 cardboards are very similar and indicate the type E of the wave profile.

Linear water absorption tests were carried out using the Cobb method, and the average results (from 5 measurements) are presented in Table 5. The KS/WB/T3 corrugated board obtained an absorbency of 16.82 g/m^2, which is 2.09 g/m^2 higher compared to the T3/WB/T3 board. Among the tested papers, the highest average linear absorbency was recorded by KS paper (18.05 g/m^2), higher by 3.47 g/m^2 than T3 paper.

The testing of WB paper was difficult due to its low water resistance. Among the tested papers, the highest average linear absorbency was recorded by KS paper, which explains the higher average linear absorbency of corrugated board with this paper in its composition. The admixture of primary fibers (30%) with recycled fibers increased water absorption in the tested samples. In accordance with the literature, the lower the Cobb value, the more resistant the paper and cardboard are to water (Hu et al., 2009). In this study, the Cobb values were low, indicating good water resistance, as also confirmed by Nurul Izzati et al., (2013).

Table 5. Results of Cobb linear water absorption

Sample	Cardboard		Paper		
Parameter	**T3/WB/T3**	**KS/WB/T3**	**T3**	**WB**	**KS**
Average linear water absorption [g/m^2]	14.733 ±0.178	16.819 ±0.124	14.579 ±0.048	—	18.048 ±0.040

Source: own study.

Bursting strength was determined using 10 samples, and the results are shown in Table 6.

Table 6. Bursting strength of corrugated board

Sample	Cardboard	
Parameter	T3/WB/T3	KS/WB/T3
Average bursting strength [kPa]	440±33	537±83
Max. bursting strength [kPa]	483	643
Min. bursting strength [kPa]	400	444
Average burst coefficient [kPa*m^2/g]	1.35±0.103	1.65±0.255
Max. burst coefficient [kPa*m^2/g]	1.49	1.98
Min. burst coefficient [kPa*m^2/g]	1.23	1.37

Source: own study.

The KS/WB/T3 board obtained a higher average burst value of 537 kPa in relation to the T3/WB/T3 board (440 kPa). It also achieved a higher average burst coefficient. This parameter is greatly affected by the type of paper used for the flat layers of the corrugated board. In this study, it was shown that the addition of 30% primary fibers in the liner layer increased the bursting strength as well as the burst coefficient. Similar findings were published in the literature (Manikandan et al., 2017; Sanchez-Salvador et al., 2020; Cho et al., 2008).

The edgewise crush resistance of corrugated cardboard was determined using five samples, and the average results are presented in Table 7. Similarly to bursting strength tests, KS/WB/T3 cardboard also showed higher resistance to edge crushing (F_{max}=480 N, ECT=4.8 KN/M) compared to T3/WB/T3 cardboard (F_{max}=436 n, ECT=4.36 kN/m). In general, it can be said that the mixture of 30% primary fibers and 70% recycled fibers in one liner of the board increases the resistance to edge crushing. Similar results were reported in the literature (Guo et al., 2010; Garbowski et al., 2023; Garbowski et al., 2021).

Table 7. Results of cardboard edgewise crush resistance (ECT)

Sample	Cardboard	
Parameter	T3/WB/T3	KS/WB/T3
Average F_{max} [N]	436±11.7	480±9.24
Max. F_{max} [N]	448	490
Min. F_{max} [N]	422	470
Average ECT [kN/m]	4.36±0.12	4.80±0.09
Max. ECT [kN/m]	4.48	4.90
Min. ECT [kN/m]	4.22	4.70

Source: own study.

Conclusions

This manuscript presents the results of tests on selected properties of three-ply corrugated board in order to demonstrate the effect of modifying one paper with a 70% addition of recycled fibers and a 30% addition of primary fibers. The other two layers of cardboard consisted only of recycled fibers. As a result of the research conducted, the KS/WB/T3 corrugated board achieved similar values to the T3/WB/T3 board in the following tests: grammage, thickness, apparent density, corrugation coefficient, wave height, and wave pitch. The tests in which greater differences can be seen are linear absorbency and absolute humidity. The T3/WB/T3 board shows a higher absolute humidity than the KS/WB/T3 board by 0.211%. Despite this, the values of both boards reached an acceptable level of corrugated board moisture of 6-9%, so they can be classified as a compliant finished product or semi-finished product for further production, e.g., packaging. The linear absorbency of the KS/WB/T3 was 16.82 g/m^2 compared to 14.73 g/m^2 of the T3/WB/T3, which means that corrugated board containing paper with primary fibers is more susceptible to linear deformation under the influence of changes in air humidity. An increase in humidity causes an increase in linear dimensions, and after drying the cardboard, they decrease. Important tests determining the strength of the corrugated board were bursting strength and edgewise crush resistance.

In both tests, the KS/WB/T3 board (537 kPa, ECT 4.8 kN/m) showed better results than the T3/WB/T3 board (440 kPa, ECT 4.36 kN/m).

Summing up, it is shown that the KS/WB/T3 cardboard modified with the addition of primary and recycled fibers is characterized by higher strength, which may translate into use during transport or storage. Greater durability means less chance of damage to the cardboard or packaging and the products packed in it.

Acknowledgments

This research did not receive a specific grant from any a funding agency in the public, commercial or not-for-profit sectors.

References

Bielecki, M., Chmielewska-Wurch, A., Damięcki, T., Patalan, B., Słoma, M. i Ździebło, S. (2011). *Zagadnienia ogólne oraz rekomendowane standardy dotyczące tektury falistej i opakowań z tektury falistej*. Stowarzyszenie Papierników Polskich, Łódź.

BS EN ISO 534:2011. Paper and board. Determination of thickness, density and specific volume.

Cho, B-U., Ryu, J-Y., Song, B-K. (2008). Pilot Study on the Manufacture of Kraft Paper from OCC. *Journal of Korea TAPPI*, 40(5), 27-35.

EN ISO 2759:2014. Board. Determination of bursting strength.

EN ISO 3037. Corrugated fibreboard. Determination of edgewise crush resistance.

EN ISO 535:2022. Paper and board. Determination of water absorptiveness – Cobb method.

EPA. (2023, July 26). *Wastes – Resource Conservation – Common Wastes & Materials – Paper Recycling.* Environmental Protection Agency. https://archive.epa.gov/wastes/conserve/materials/paper/web/html/index-2.html

Garbowski, T. Grabski, J.K. Marek, A. (2021). Full-field Measurements in the Edge Crush Test of a Corrugated Board – Analytical and Numerical Predictive Models. *Materials, 14*, 2840. https://doi.org/10.3390/ma14112840

Garbowski, T., Knitter-Piątkowska, A., Grabski, J.K. (2023). Estimation of the Edge Crush Resistance of Corrugated Board Using Artificial Intelligence. *Materials, 16*, 1631. https://doi.org/10.3390/ma16041631

Guo, Y., Hou, J., Xu, W., Cao, G. (2010). Comparison Studies on Strength Properties of Corrugated and Honeycomb Composite Paperboards. *Proceedings of the 17th IAPRI World Conference on Packaging*, 90-95, ISBN 978-1-935068-36-5.

Hu, Z., Zen, X., Gong. J., and Deng, Y. (2009). Water resistance improvement of paper by superhydrophobic modification with microsized $CaCO_3$ and fatty acid coating. *Colloids and Surfaces A: Physicochemical and Engineering Aspects*, *351(1-3)*, 65-70. https://doi.org/10.1016/j.colsurfa.2009.09.036

Jakowski, S. (2005). Tektura falista. *Opakowanie*, *7*, 6-8.

Janiga, M., Michniewicz, M. (2017). Odpady z produkcji mas włóknistych i papieru – właściwości i sposoby zagospodarowania. *Przegląd Papierniczy, 11*, 759-766.

Kalita, N., Saxena, P., Talha, M. (2021). Influence of Stiffeners forImproving the Compressive Strengthof Ventilated Corrugated PackagesUsing Finite Element Modelling Technique. *Sustainability*, 13, 13926. https://doi.org-/10.3390/su132413926

Latka, J.F. (2017). Paper in architecture: Research by design, engineering and prototyping. *A+BE (Delft.)*, 19,

1-534. https://*doi*.org/10.7480/abe.2017.19

Lindberg, G., Kulachenko, A. (2022). The effect of ply properties in paperboard converting operations: a way to increase formability. *Cellulose* 29, 6865-6887. https://doi.org/10.1007/s10570-022-04673-9

Małachowska, E., Dubowik, M., Boruszewski, P., Łojewska, J., Przybysz, P. (2020). Influence of lignin content in cellulose pulp on paper durability. *Scientific Reports*, *10(1)*, 19998. https://*doi*.org/10.1038/s41598-020-77101-2

Mahakalkar, S.G., Sambare, R., Sunheriya, N. (2019). Effect of Environmental Conditions on Performance of Corrugated Sheet Boxes Manufacturing Process. *International Journal of Recent Technology and Engineering*, 8(2S7), ISSN: 2277-3878.

Manikandan, A.S.P., Nesakumar, D., Deepa Priya, N. (2017). Study of Burst Strength and Deinking Efficiency of Recycled Pulp by using Enzymatic Deinking Method. *International Journal of Engineering Research*, *5(1),* 11-15.

Marin, G. (2020). *On the relation between paperboard properties and packaging performance*. KTH Royal Institute of Technology, Stockholm, Sweden. http://kth.divaportal.,org/smash/record.jsf?pid=diva2%3A1508084&dswid-=6047

Nurul Izzati, M.Z., Ainun, Z.M.A., Abdullah, L.C., Hazwani, H.A., Harun, J., and Jawaid, M. (2013). Water Absorbency and Mechanical Properties of Kenaf Paper Blended via a Disintegration Technique. *BioResources, 8(4)*, 5570-5580. https://doi.org/10.15376/biores.8.4.5570-5580

Obradovic, D., Mishra, L.N. (2020). Mechanical Properties Of Recycled Paper And Cardboard. *The Journal of Engineering and Exact Sciences*, *06*(03), 1-6. http://orcid.org/0000-0001-7774-7290

PGPaper. (2023, July 26). *Recycling rates across the globe*. PGPaper Company Ltd. https://www.pgpaper.com-/global-recycling-rates/

PN-EN ISO 536:2020-08. Paper and cardboard. Determination of grammage.

Sanchez-Salvador, J.L., Balea, A., Monte, M.C., Negro, C., Miller, M., Olson, J., Blanco, A. (2020). Comparison of Mechanical and Chemical Nanocellulose as Additives to Reinforce Recycled Cardboard, *Scientific Reports, 10*, 3778. https://doi.org/10.1038/s41598-020-60507-3

Silveira, A., Cardoso, J., Correia, M.J., Martinho, G. (2021). Moisture Measurement in Paper and Cardboard Packaging Waste Bales for Recycling, *Applied Sciences*, 11, 4586. https://doi.org/10.3390/app11104586

UNE EN ISO 287:2018. Paper and Board – Determination of Moisture Content of a Lot – Oven-Drying Method.

PROCESSING OF PLASTICS WASTE FROM AUTOMOTIVE INDUSTRY: MECHANICAL PROPERTIES-STRUCTURE RELATIONSHIPS

Wiktoria Kanciak[1*], Dorota Czarnecka-Komorowska[1], Mikołaj Popławski[2]

[1] *Faculty of Mechanical Engineering, Poznań University of Technology, Poznań, Poland*
[2] *Faculty of Materials Engineering and Technical Physics, Poznań University of Technology, Poznań, Poland*
**Corresponding Author e-mail:wiktoria.kanciak@doctorate.put.poznan.pl*

DOI: 10.56091/CTQS.Innov-11

Abstract

Nowadays, the increasing number of vehicles is contributing to an increase in the amount of polymer materials in the overall waste stream after the end of their life cycle. Therefore, it is important to appropriately carry out the process of recycling, separation, and reuse of these materials to protect the environment and minimize the utilization of natural resources. These factors are in accordance with the circular economy model and the concept of sustainable development. Implementing these principles enables us to minimize natural resource consumption and reduce our negative environmental impact. By using a circular economy, we can optimize resource utilization and minimize waste generation. The implementation of these factors is essential in achieving a more sustainable and balanced approach to economic growth and environmental protection.

The article presents the possibilities of processing polymer waste from the automotive industry to obtain composites with advantageous mechanical properties and structure. To optimize the technology of producing composites, two versions of technological solutions were used, for which standardized test samples were prepared for evaluating the quality of the produced polymer blends. The mechanical properties of the obtained composites, such as tensile modulus, tensile strength, and tensile at break, were evaluated in a static tensile test. Microscopic analysis of the surface structure of the fractures of the composites was also performed. Based on the obtained research results, it was concluded that the most beneficial mechanical characteristics are attributed to composites produced using the mixing technology with the application of a dispersing system of the roller type.

Keywords: circular economy, polymer waste, recycling, polymer blends

Introduction

An important aspect of the Polish economy is the polymer industry, which is the third largest sector among industrial processing divisions (*Information materials from Stena Recycling*, n.a.; *Plastics industry 2022 A report by the PlasticEurope Poland Foundation*, n.a.). The continuing demand from Polish processors for plastics was about 4.1 million tons in 2020, of which 380,000 tons were post-consumer recyclates (*Plastics industry 2022 A report by the PlasticEurope Poland Foundation*, n.a.). Consumption of polymer materials in Poland in the same year was estimated at 3.4 million tons.

The main areas with the highest consumption of plastics can be cited as packaging production, civil engineering, automotive, electronics and electrical (E&E) industries, among others (*Gospodarka o obiegu zamkniętym*, n.a.). In 2021, it was noted that 56% of polymer waste in Poland's urban waste group comes from packaging, and 9% from the automotive sector (*Plastics industry 2022 A report by the PlasticEurope Poland Foundation*, n.a.).

A significant amount of current scientific research work is focused on developing and exploring opportunities to increase the level of recycling and reuse of plastic waste (Czarnecka-Komorowska, Kanciak et al., 2021; Czarnecka-Komorowska et al., 2021; Czarnecka-Komorowska & Wiszumirska, 2019; Kostecka et al., 2021; Syberg et al., 2021).

Nowadays, each action taken is guided with attention to the protection of the surrounding environment, but also with concern for the well-being of people. A very important aspect to achieve it is the introduction and application of corporate social responsibility (CSR) principles, as well as a circular economy production and consumption model. Both concepts are aimed at reducing humanity's negative impact on the environment and promoting the principles of sustainable development (Gong et al., 2020; Jankowski & Wąsowicz, 2018).

The circular economy model is based on extending the life cycle of products by reusing, renewing, repairing, recycling products and materials as long as possible (Czarnecka-Komorowska & Wiszumirska, 2019). In this way, materials and natural resources are used in an efficient way, due to minimizing waste generation and minimizing the consumption of natural resources. By applying a circular economy model, waste of materials can be eliminated, resulting in increased economic and environmental efficiency (Gong et al., 2020). At the end of the life cycle of products, the products and waste derived from it are recycled to enable their reuse in subsequent production cycles, either as recycled materials or energy for the production of the same or completely different products. The circular economy model assumes that the end of a product's life cycle is also the beginning of a new product's life cycle. This idea is in opposite to the linear economic model, which assumes unreflective consumption of goods (Jankowski & Wąsowicz, 2018).

Corporate Social Responsibility (CSR) is a management strategy in which companies make voluntary actions that take into account environmental, social, as well as ethical aspects, especially to employees. The main areas of activities that companies can introduce in the implementation of CSR can include, for example, protecting the environment, safe working conditions, taking care of the company's good relations with the environment.

These activities, affect the creation of appropriate conditions conducive to sustainable economic development and environmental protection, but also increase the competitiveness of the company in the market. One of several CSR tools are pro-environmental activities aimed at protecting the environment and investments that reduce the negative impact of humans on the environment. Examples of initiatives include, for example, sustainable management of raw materials, implementation of appropriate environmental policies, waste segregation or introduction of green products and new pro-environmental technological processes (*CSR – Społeczna odpowiedzialność biznesu – PARP – Centrum Rozwoju MŚP*, n.a.; *Information materials from Stena Recycling*, n.a.; *Odpady z tworzyw sztucznych i recykling w UE*, 2019; Kiełkowicz, 2016; Krugiełka, 2019; Niyommaneerat et al., 2023; Rodrigues & Borges, 2015)

The processing of plastic waste is one of the aspects of both a circular economy and one of the methods to achieve the sustainable development goals that are the basis of CSR. Energy recovery is one of the methods used to dispose of polymer waste, mainly due to the problems that occur in separating the different types of polymer materials. The second most common way to process waste is recycling (*Odpady z tworzyw sztucznych i recykling w UE*, 2019). This is a process aimed at recovering and reusing waste, which becomes a valuable material for producing new products. As a result, the negative impact on the environment is reduced, and energy savings can be achieved. It becomes necessary to reduce the extraction of non-renewable natural resources, whose global resources are constantly decreasing. Recycling, for both environmental and economic reasons, is becoming a necessity nowadays. The widespread and appropriate use of this process leads to economic benefits by improving the environment and recovering valuable materials (d'Ambrières, 2019; *Information materials from Stena Recycling*, n.a.; *Odpady z tworzyw sztucznych i recykling w UE*, 2019; Shamsuyeva & Endres, 2021; Syberg et al., 2021)Through this, promoting the indicated ideas and activities is important for the purpose of building a more responsible and sustainable economy (*CSR – Społeczna odpowiedzialność biznesu – PARP – Centrum Rozwoju MŚP*, n.a.; *Gospodarka o obiegu zamkniętym*, n.a.).

Recycled automotive waste materials are rarely used for their primary purpose. This is due to the high quality requirements that finished products must comply with. For this purpose, they are used for the production of other products with different applications (Jankowski & Wąsowicz, 2018; Klepka & Białasz, 2017).

In the publication titled Use of polymer plastic recyclates in the automotive industry, the authors point out as examples, among others, the use in the construction of road infrastructure, road safety barriers, sound-absorbing panels with a porous structure containing rubber waste.

Another example of auto-motive plastic waste management is the production of RD panels. These are produced by pressing with heating wood or polymer-wood chips and polymer, which are production waste. There are three variations of this process, i.e., pressing combined with heating to glue fillers, pressing with heating to plasticize and glue polymer with fillers, and pressing with heating to plasticize polymer. The boards are distinguished by a high degree of acoustic and thermal damping, so they can be used as insulating fill (Klepka & Białasz, 2017).

In a subsequent publication entitled Rubber granulate-based composites from waste tires as a sound absorbing and vibration insulating material in the processing industry food processing industry, by Pioś (2019), an example of reuse of polymer waste was indicated. A composite based on rubber granules derived from waste tires was created for use in the food processing industry as a sound-absorbing and vibration-isolating material., The composite contained in its composition rubber granules and other additives especially crosslinking. The following plastics can be distinguished, including polypropylene, polyethylene, poly(ethylene terephthalate), as well as an adhesive in which chloroprene rubber was the binding component. The processing method that was used to make the samples was pressing. Based on the research, it was concluded that the resulting composite containing rubber granules can be successfully used to produce vibration-isolating materials, as well as sound-absorbing ones. The described way to manage rubber waste results in a reduction in the overall amount of rubber waste, which is an ecological aspect in the context of environmental protection, as well as the resulting composite has a protective function against vibrations and noise (Pioś, 2019).

Zawadzka et al., in an article titled Recycled Raw Materials in Composite Products in the Automotive Industry, presented ways to use recycled textile and composite materials from the automotive industry to obtain composites containing a significant proportion of recyclates. The waste raw materials used were polyurethane foam, cotton and multi-component upholstery waste, which were then shredded to obtain recyclate with particle sizes of about 1 cm. The next stage of the work was to incorporate the obtained regranulates into a polyester and epoxy matrix. The most advantageous results were obtained for composites containing an epoxy matrix with a multicomponent and cotton filling (Zawadzka, 2022; Miller et al., 2014).

The aim of the study was to develop a method of managing polymer waste from the automotive industry in accordance with the current circular economy, and to evaluate the mechanical properties and structure of the mixtures obtained.

Materials and methods

The subject of the study was a mixture of polymer waste from the automotive industry (Fig. 1). The mixture included such polymers as poly(butylene terephthalate) (PBT), poly(vinyl chloride) (PVC), polyamide 6 (PA 6), polypropylene (PP), polyamide 66 (PA 66) and other polymers.

Fig. 1. Mixed polymer waste from the automotive industry

Source: own study.

The tests consisted of preparing polymer blends based on automotive polymer waste with the appropriate composition (Table 1). For example, the sample described as M0/10K represents a mixture of polymeric automotive waste not subjected to separation, which was processed using a mixer with cam type rotors for 10 min and then compressed. Standardized shapes were prepared from the resulting mixtures for strength testing and evaluation of mixture morphology.

Table 1. Determination of individual polymer mixtures based on waste from the automotive industry

Sample	Type of polymer mixture
M0	Non-separated mixture
M0/2.5W	Non-separated mixture homogenized for 2.5 min in a Brabender mixer with roller type rotors
M0/5W	Non-separated mixture homogenized for 5 min in a Brabender mixer with roller type rotors
M0/10W	Non-separated mixture homogenized for 10 min in a Brabender mixer with roller type rotors
M0/2.5K	Non-separated mixture homogenized for 2.5 min in a Brabender mixer with cam type rotors
M0/5K	Non-separated mixture homogenized for 5 min in a Brabender mixer with cam type rotors
M0/10K	Non-separated mixture homogenized for 10 min in a Brabender mixer with cam type rotors

Source: own study.

The technology used was direct compression molding using a laboratory press and homogenization in a closed mixer. In order to determine the appropriate processing method and parameter selection, mixers differing in rotor constructions, that is, roller and cam, were used. Mixing times were 2.5, 5, and 10 minutes, accordingly (Table 2). Different mixing times were chosen to determine the appropriate duration of this process to ensure the reproducibility and efficiency of the process and to ensure adequate homogenization of the mixture, while not degrading the individual components.

Table 2. Process parameters for homogenization and pressing of polymer mixtures

Process	Equipment		Processing conditions	
			Parameter	Value
Homogenization	Closed mixer – modular device from Brabender model GMF 106/2 equipped with roller type rotors	Closed mixer – modular device from Brabender model GMF 106/2 equipped with cam type rotors	Compartment temperature [°C].	190
			Mixing time [min]	2.5; 5; 10
			Input weight [g]	30
			Rotor speed [rpm]	120
Compression moulding	Nysa PH-90 press		Compression pressure [MPa]	5
			Compression temperature [°C]	190
			Plasticization time [min]	5
			Forming time [min]	6
			Cooling time [min]	20

Source: own study.

To determine the mechanical properties of the obtained materials, a static tensile test was carried out. The test was conducted in accordance with the current standard PN EN ISO 527-2, at the Department of Plastics of the Faculty of Mechanical Engineering of Poznan University of Technology. The measurement was carried out at a tensile speed of 50 mm/min, at ambient temperature using a Zwick Roel Z010 universal testing machine. The stress-strain curves obtained in the tensile test for the mixtures were the basis for the determination of mechanical characteristics, i.e., tensile modulus, tensile strength, and tensile at break.

Microscopic evaluation of the surface morphology, as well as the structure of the fractures formed in the static tensile test was conducted using a Tescan Mira 3 scanning electron microscope (SEM).

Microscopic images were taken using a secondary electron (SE) detector, applying an accelerating voltage of 20 kV. The study was carried out at the Department of Materials Engineering and Technical Physics, Poznan University of Technology.

Results and discussion

Mechanical properties

Table 3 illustrates the static tensile results of the mixtures obtained. The effect of processing technology (two different rotors) and processing parameters as a function of mixing time on the tensile properties of the blends was evaluated. The measurement results presented in Figures 2-4 represent the average value obtained from five measurements, together with the standard deviation.

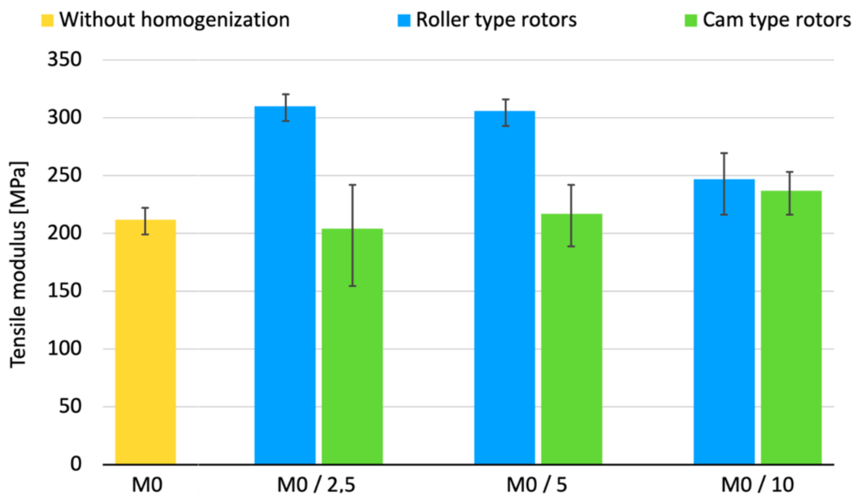


Fig. 2. Comparison of values of tensile modulus of mixtures for different mixing systems (roller/cam)

Source: own study.

Figure 2 shows the values of the tensile modulus of the tested samples depending on the design of the rotors. Mixtures that have been homogenized with roller type rotors show higher values of tensile modulus compared to materials for which cam type rotors have been used. As a result of comparing the values of the tensile modulus of mixtures (that were not homogenized with homogenized mixtures), an increase in stiffness can be observed for materials that were mixed using roller type rotors. The highest value of the tensile modulus of about 300 MPa was obtained for mixtures M0/2.5W and M0/5W, which was homogenized for 2.5-5 min using a roller type mixing system.

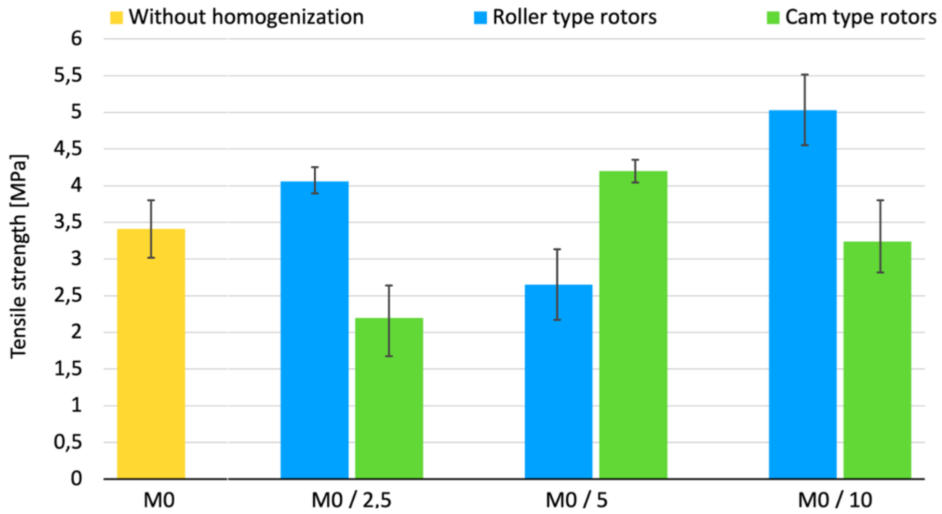


Fig. 3. Comparison of values of tensile strength of mixtures for different mixing systems (roller/cam)

Source: own study.

A comparison of the values of tensile strength for the tested mixtures is shown in Fig. 3. The value of the tensile strength of materials blended using roller type rotors is significantly higher compared to the values obtained for materials that were mixed using cam type rotors. In addition, the mixtures for which roller type rotors were used show smaller values of standard deviation. The highest value of tensile strength (about 4 MPa) was obtained for the M0/5W mixture, for which the mixing time was 5 minutes using the roller type mixing system.

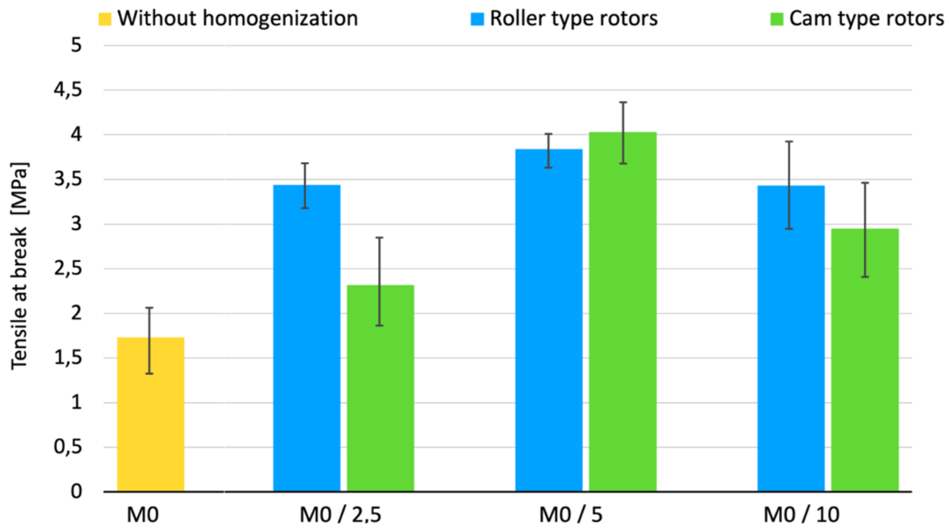


Fig. 4. Comparison of values of tensile at break of mixtures for different mixing systems (roller/cam)

Source: own study.

A comparison of the values of the tensile at break for the tested mixtures for different mixing systems (roller/cam) is illustrated in Figure 4. Mixtures for which the homogenization process was performed show significantly higher values of the tensile at break compared to the mixture without homogenization M0. The highest tensile at break value of 4.03 MPa is shown by the M0/5K mixture. For M0/2.5 mixtures, as well as M0/10, higher tensile at break values are shown by samples mixed with roller type rotors, compared to mixtures for which cam type rotors were used. Also, relatively large values of standard deviation can be observed. The values obtained may be due to the presence of slight differences in the chemical composition of individual mixtures, which may affect the differences in the obtained results.

Results of microscopic examination of mixtures

Figure 5 shows SEM microscopic images of the surface morphology of the tested mixtures obtained under different mixing conditions compared to the mixture not subjected to separation (Fig. 5a – in red box). SEM images were taken using a secondary electron detector (SE) at an accelerating voltage of 20kV. The samples were previously coated with a thin layer of carbon.

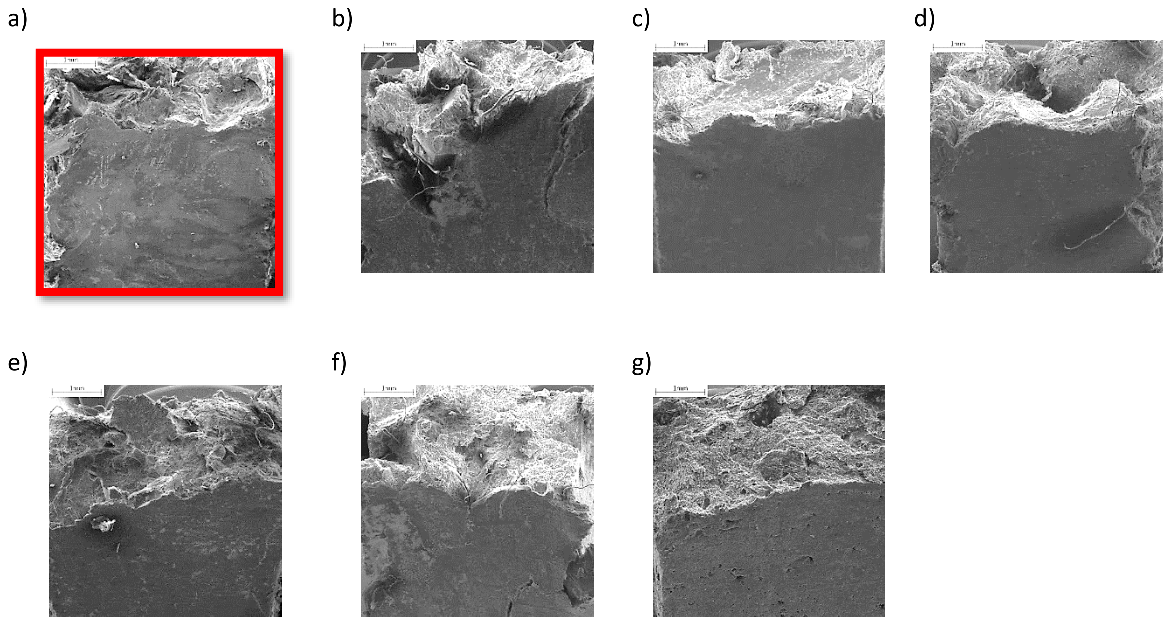


Fig. 5. SEM SE photo of the surface morphology of mixtures: a) M0, b) M0/2,5W, c) M0/5W, d) M0/10W, e) M0/2,5K, f) M0/5 K, g) M0/10K (side view)

Source: own study.

Examining the SEM images shown in Figure 5a-g, it can be concluded that the mixtures for which processing using homogenization combined with compression molding was used show a more homogeneous structure compared to materials that were only compressed.

The M0 mixture (Fig. 5a) is characterized by the presence of many free spaces in the area at the boundaries between the individual components of the mixture. This may indicate a low degree of adhesion between the individual components of the mixture. Samples for which mixing with roller type rotors was used (Fig. 5b-d) have a smaller amount, as well as smaller free spaces compared to materials for which cam type rotors were used (Fig. 5e-g). The length of mixing time significantly affects the resulting structure. From the images shown, it can be seen that a mixing time of 2.5 minutes has a beneficial effect on increasing the adhesion between the components of the mixture compared to the non-homogenized material., However, compared to mixtures for which a time of 5 as well as 10 minutes was used,it can be concluded that homogenization for 2.5 minutes is insufficient. The M0/5W mixture (Fig. 5c) has the most homogeneous structure, due to the low amount of visible discontinuities in the surface structure.

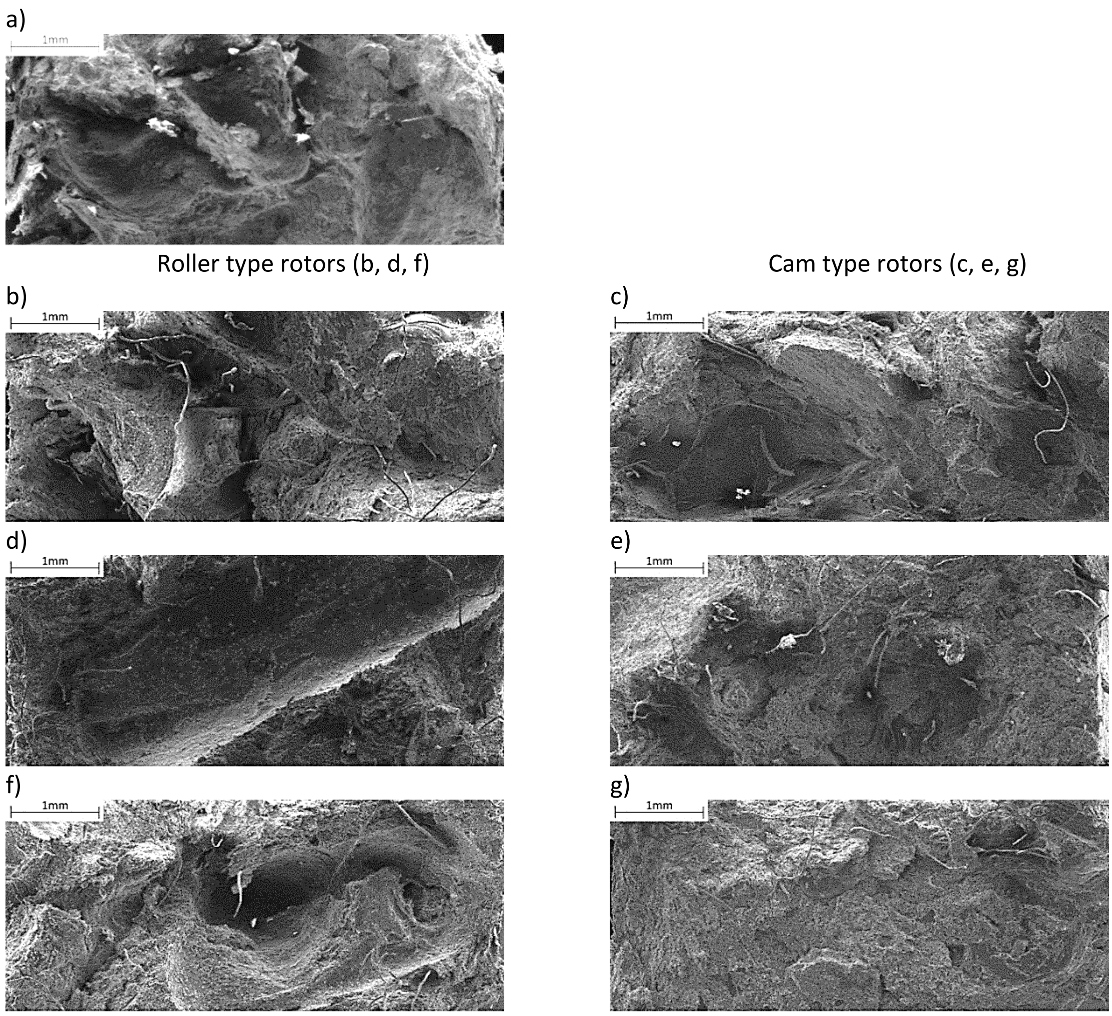


Fig. 6. SEM photo of the surface morphology of mixture fractures a) M0, b) M0/2,5W, c) M0/2,5K, d) M0/5W, e) M0/5K, f) M0/10W, g) M0/10K

Source: own study.

Figure 6a-g shows microscopic images (SEM) of the surface structure of the fractures of the tested mixtures. It can be seen that sample M0 (Fig. 6a), which has not been homogenized, is distinguished by low adhesion between the individual components of the mixture compared to the other samples. Visible boundaries between mixture components can also be observed. It is observed that mixtures for which the mixing time was 2,5 min with both roller (Fig. 6b) and cam (Fig. 6c) type rotors have a higher volume and larger free spaces compared to mixtures that were subjected to mixing for 5 min (Fig. 6d; Fig. 6e) and 10 min (Fig. 6f; Fig. 6g).

Conclusion

In this study, mixtures containing polymer waste from the automotive industry were prepared. In order to select the appropriate processing method, direct pressure molding was used, as well as the material was plasticized in a closed mixer with roller or cam type rotors and different mixing times were used, followed by compression molding. Mechanical properties were determined for the mixtures obtained, and the effects of technology and mixing time on the structure and surface morphology of the mixtures were evaluated.

Based on the research conducted, it can be concluded that the use of plasticization in a closed mixer with both roller and cam type rotors, followed by compression molding, results in an increase in mechanical properties compared to mixtures that were processed using only compression molding technology. Mixtures that have been homogenized using roller type rotors are characterized by higher values of tensile modulus (E_t), as well as tensile strength (σ_m) compared to mixtures that have been prepared using cam type rotors. The highest value of the tensile strength (σ_m) is shown by the M0/5W mixture, which contains mixed polymer wastes that were mixed with roller type rotors for 5 minutes. For most of the samples mixed with roller type rotors, the value of tensile at break (σ_b) is higher compared to the mixtures, formed with cam type rotors. The highest value of tensile at break (σ_b), which was 4.03 MPa, was obtained for the mixture M0/5K.

Based on the mechanical test results obtained, it can be concluded that the optimized method of processing the mixtures is plasticization in a closed mixer using roller type rotors for 5 minutes, followed by compression molding on a hydraulic press. Mixtures made using the described technology are characterized by the most advantageous strength properties, such as tensile modulus, tensile strength, as well as tensile at break.

As a result, from an analysis of the mixture structure, it can be concluded that the use of homogenization results in a more homogeneous structure with significantly reduced free spaces. Mixtures for which roller type rotors were used show higher adhesion between the individual components of the mixture compared to samples for which cam type rotors were used.

Based on the study, it was found that the use of a roller-type mixing system at 5 minutes provides appropriate homogenization, and thus adequate strength characteristics such as stiffness and strength of polymer mixtures prepared from automotive waste. The process used and the material obtained are in line with the current principles of a circular economy. The waste materials were used as inputs for the production of another material with a different purpose, and as a result, their life cycle was extended.

References

CSR – Społeczna odpowiedzialność biznesu — PARP – Centrum Rozwoju MŚP. (b.d.). Access:15.06.2023 https://-www.parp.gov.pl/csr#csr

Czarnecka-Komorowska, D., Kanciak, W., Barczewski, M., Barczewski, R., Regulski, R., Sędziak, D., & Jędryczka, C. (2021). Recycling of Plastics from Cable Waste from Automotive Industry in Poland as an Approach to the Circular Economy. *Polymers*, 13(21), Article 21. https://doi.org/10.3390/polym13213845

Czarnecka-Komorowska, D., Nowak-Grzebyta, J., Gawdzińska, K., Mysiukiewicz, O., & Tomasik, M. (2021). Polyethylene/Polyamide Blends Made of Waste with Compatibilizer: Processing, Morphology, Rheological and Thermo-Mechanical Behavior. *Polymers*, 13(14), Article 14. https://doi.org/10.3390/polym13142385

Czarnecka-Komorowska, D., & Wiszumirska, K. (2019). Zrównoważone projektowanie opakowań z tworzyw sztucznych w gospodarce cyrkularnej Sustainability design of plastic packaging for the Circular Economy. *Polimery* -Warsaw-, 65, 8-17. https://doi.org/10.14314/polimery.2020.1.2

d'Ambrières, W. (2019). Plastics recycling worldwide: Current overview and desirable changes. Field Actions Science Reports. *The Journal of Field Actions*, Special Issue 19, Article Special Issue 19.

Gong, Y., Putnam, E., You, W., & Zhao, C. (2020). Investigation into circular economy of plastics: The case of the UK fast moving consumer goods industry. *Journal of Cleaner Production*, 244, 118941. https://doi.org/10.1016-/j.jclepro.2019.118941

Gospodarka o obiegu zamkniętym: Definicja, znaczenie i korzyści (Wideo). (2023, maj 24). Tematy | Parlament Europejski. https://www.europarl.europa.eu/topics/pl/article/20151201STO05603/gospodarka-o-obieguzamkn-ietym-definicja-znaczenie-i-korzysci-wideo

Jankowski, K., & Wąsowicz, A. (2018). Logistyka w procesie recyklingu okablowania samochodowych instalacji elektrycznych. *Autobusy – Technika, Eksploatacja, Systemy Transportowe*, 218(4), Article 4.

Kiełkowicz, M. (2016). Społeczna odpowiedzialność biznesu wobec środowiska naturalnego w kontekście idei zrównoważonego rozwoju. Analiza podstaw etycznych. *Zarządzanie. Teoria i Praktyka* / Wyższa Szkoła Menedżerska w Warszawie, nr 2 (16), 37-45.

Klepka, T., & Białasz, S. (2017). Wykorzystanie recyklatów tworzyw polimerowych w branży motoryzacyjnej. *Autobusy : technika, eksploatacja, systemy transportowe*, 18(6), 63-68, CD.

Kostecka, E., Tomasik, M., Piesowicz, E., Bryll, K., Czarnecka-Komorowska, D., & Gawdzińska, K. (2021). The composting of PLA/HNT biodegradable composites as an eco-approach to the sustainability. *Bulletin of the Polish Academy of Sciences: Technical Sciences*; 2021; 69; 2; e136720. https://journals.pan.pl/dlibra/publication-/136720/edition/119404

Krugiełka, A. (2019). Modelowanie CSR w odniesieniu do klienta wewnętrznego. Wydawnictwo Politechniki Poznańskiej

Miller, L., Soulliere, K., Sawyer-Beaulieu, S., Tseng, S., & Tam, E. (2014). Challenges and Alternatives to Plastics Recycling in the Automotive Sector. *Materials*, 7(8), Article 8. https://doi.org/10.3390/ma7085883

Niyommaneerat, W., Suwanteep, K., & Chavalparit, O. (2023). Sustainability indicators to achieve a circular economy: A case study of renewable energy and plastic waste recycling corporate social responsibility (CSR) projects in Thailand. *Journal of Cleaner Production*, 391, 136203. https://doi.org/10.1016/j.jclepro.2023.136203

Odpady z tworzyw sztucznych i recykling w UE: Fakty i liczby | Aktualności | Parlament Europejski. (2019, styczeń 15).https://www.europarl.europa.eu/news/pl/headlines/society/20181212STO21610/odpady-z-tworzywsztucz-nych-i-recykling-w-ue-fakty-i-liczby

Pioś, P. (2019). Kompozyt na bazie granulatu gumowego ze zużytych opon jako materiał dźwiękochłonny i wibroizolacyjny w przemyśle przetwórstw a spożywczego®. *Postępy Techniki Przetwórstwa Spożywczego*, 1, 113-116.

Plastics industry 2022 A report by the PlasticEurope Poland Foundation. (2022.). Access:15.06.2023, https://-plasticseurope.org/pl/wp-content/uploads/sites/7/2022/09/Raport-Plastics-Europe-Polska2022_PL.pdf

Rodrigues, P., & Borges, A. (2015). Corporate social responsibility and its impact in consumer decision-making. *Social Responsibility Journal*, 11, 690-701. https://doi.org/10.1108/SRJ-02-2014-0026

Shamsuyeva, M., & Endres, H.-J. (2021). Plastics in the Context of the Circular Economy and Sustainable Plastics Recycling: Comprehensive Review on Research Development, Standardisation and Market.

Syberg, K., Nielsen, M.B., Westergaard Clausen, L.P., van Calster, G., van Wezel, A., Rochman, C., Koelmans, A.A., Cronin, R., Pahl, S., & Hansen, S.F. (2021). Regulation of plastic from a circular economy perspective. *Current Opinion in Green and Sustainable Chemistry*, 29, 100462. https://doi.org/10.1016/j.cogsc.2021.100462

Zawadzka, E. (2022). Surowce wtórne w wyrobach kompozytowych w branży automotive. *Przegląd Elektro-techniczny*, 1(9), 275-278. https://doi.org/10.15199/48.2022.09.64

UPCYCLED FOOD PRODUCTS – SUSTAINABLE SOLUTIONS FOR FOOD WASTE

Małgorzata Krzywonos, Agnieszka Piekara

Department of Process Management, Faculty of Management,
Wroclaw University of Economics and Business, Wroclaw, Poland
**Corresponding Author e-mail:malgorzata.krzywonos@ue.wroc.pl, agnieszka.piekara@ue.wroc.pl*

DOI: 10.56091/CTQS.Innov-12

Abstract

Food wasting is a global crisis that paradoxically accompanies food shortages. Food waste can be generated at any stage of the food product life cycle, increasing the amount of landfilled waste and causing money losses. Upcycling refers to the creation of new value through another stage of recycling. Upcycled food faces several challenges as a new food category, such as the development of a definition, inclusion in the food waste hierarchy and public acceptance.

The purpose of the article was to analyze existing solutions available on the market for upcycling by-products from food processing plants and food wastes. Analysis was performed from the perspective of food producers, food processing companies as well as consumers.

Upcycled food production has recently been introduced as a food waste management option, so it is crucial to include it in the food waste management hierarchy. Upcycled foods are most often present on the market as food and beverages, personal care products, health care products, animal feed as intermediate products or ingredients in food and beverages, pet food and cosmetics. Manufacturers should inform the public about the benefits of using upcycled ingredients. This will also significantly impact future labeling strategies for policymakers, providing valuable information for recycled food producers. When customers are informed about the unique nutritional or environmental advantages of upcycled food, their moral satisfaction with their purchase rises, which is favorably correlated with their willingness to buy upcycled food.

Keywords: upcycled food, by-product, food waste, sustainable solution, upcycling

Introduction

Worldwide food production is continuously growing; however, one question remains how to feed the world today. Food wasting is a global crisis that paradoxically accompanies food shortages. Upcycled food is one solution to the problems of food insecurity and food waste. The FAO has distinguished two kinds of food waste: loss and waste (Table 1).

Table 1. Defined the two ways of food waste by the FAO

Food loss	f**ood that is discarded, incinerated, or otherwise disposed of along the food supply chain from harvest/slaughter/catch up to, but excluding the retail leve**l, and is not used for any other productive use, such as animal feed or seed.
Food waste	**food that is discarded at the level of retailers, food service providers and consumers**, for example: - fresh produce that deviates from what is considered optimal (e.g., size, shape, or color) and is removed during sorting actions, - foods that are discarded by retailers or consumers when it is close to or beyond the best-before date, - unused or leftover food, that is thrown out from households or restaurants.

Source: (FAO, 2013a; Fusions, 2023).

However, other institutions also include food waste, everything generated during the entire process from primary production to consumption, including the pre-harvest stage (Kim, 2023).

It is good to mention that solving the problem of food loss and waste is a defined target of the internationally agreed Sustainable Development Goals (SDGs): "12.3. By 2030, halve per capita global food waste at the retail and consumer levels and reduce food losses along production and supply chains, including post-harvest losses" (United Nations, 2022).

Upcycling refers to the creation of new value through another stage of recycling. Food waste can be generated at any stage of the food product life cycle, increasing the amount of landfilled waste and causing money losses (FAO, 2013b; Moshtaghian et al., 2021). Some of the waste still has nutritional and/or functional value that can be reused, and in this sense, the term "by-product" can be used. Broken down by food groups, roots, stems, and field crops account for 25%, fruits and vegetables for 22%, animal products for 12%, and cereals and legumes for 9%, confirming that by-products from field crops, fruits, and vegetables account for about half of the food losses. The economic value of these food losses is estimated at about $1 trillion, and to achieve the goal of sustainable development (ending poverty, protecting the planet, and ensuring peace and prosperity), ways must be found to actively use food by-products and waste (United Nations Food Systems Coordination Hub, 2023). To date, most by-products have been used as compost or livestock feed. Still, the possibility of their use as high-value products is being explored based on recent scientific and technological developments. Moreover, Whole Foods Market Forecasted upcycled foods among its top ten food trends for 2021 (Ferrer, 2021).

Upcycled food production has been recently introduced as a food waste management option, and food waste definition thus, it is essential to consider upcycled food in the food waste management hierarchy (Fig. 1).

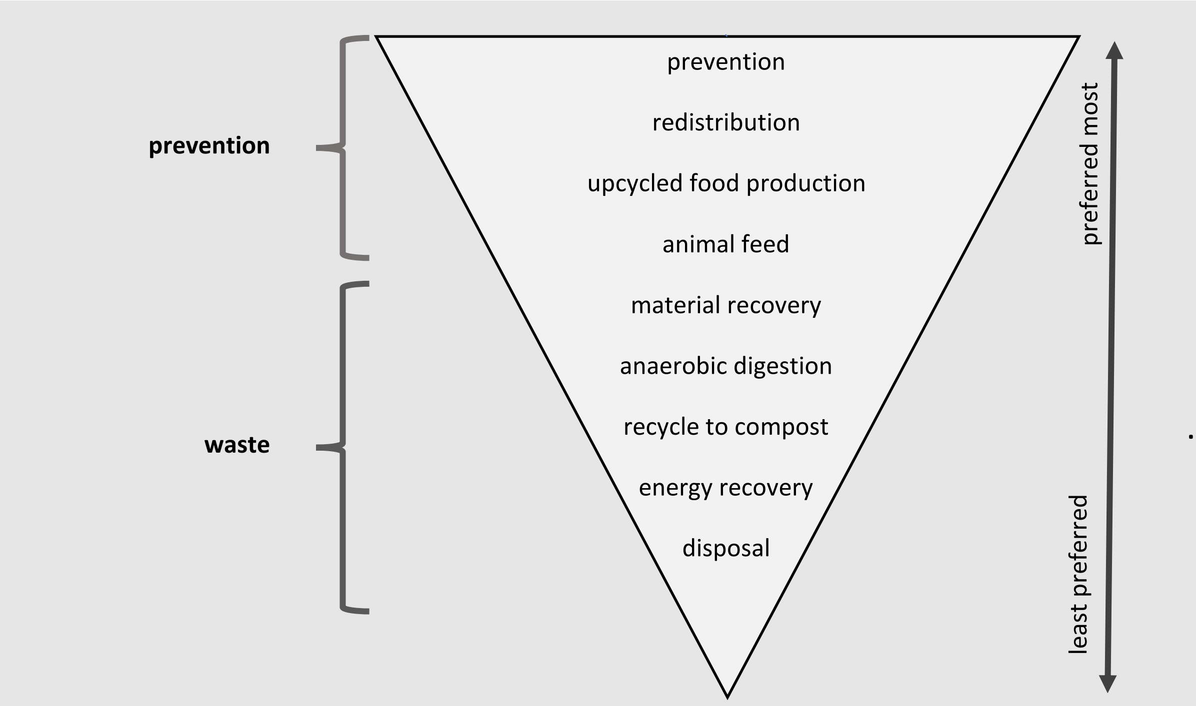


Fig. 1. Food waste management hierarchy. The hierarchy for the management of food surplus, waste, and loss has been modified to include upcycled food production as a management action

Source: Adapted from (UNEP, 2014).

Upcycled food is considered a new food category alongside conventional and organic foods. Since upcycled food is a new concept, it faces several challenges, such as definition development, inclusion in the food waste management hierarchy and public acceptability (Moshtaghian et al., 2021) In 2020, the first definition of upcycled food was announced, and sounds as follows: "**upcycled foods use ingredients that otherwise *would not have gone to human consumption*, are procured and produced using *verifiable supply chains*, and *have a positive impact on the environment".*** The UFA also indicated five attributes of upcycled food to better identify it on the market (Table 2).

The upcycled food sector aims to fully utilize resources rather than extract nutrients and other bioactive compounds, thereby reducing food waste (UFA, 2023a). The extraction of bioactive compounds such as lycopene, beta-carotene, and ferrous sulfate from food by-products is the trend observed worldwide. It leads to the acquisition of valuable ingredients. This approach can be considered as a value-added or waste recovery process. In the literature, the terms “value-added”, “waste recovery”, and “upcycling” are often used interchangeably (Kharel et al., 2021; Madia et al., 2021).

Table 2. Five attributes of upcycled food

Upcycled foods	Are made from ingredients that would otherwise have ended up in any food waste destination
	Are value-added products
	Are an auditable supply chain
	Are for human consumption
	Indicate which ingredients are upcycled on their labels

Source: Adapted from (UFA, 2023a).

The purpose of the article was to analyze existing solutions available on the market for upcycling by-products from food processing plants and food wastes. Special attention was paid to the products and their labeling on the market.

Materials and methods

The authors used the “research onion” by Saunders et al., (2023) to define the methodology for this research. Analysis was performed between 1st June and 15th July 2023. An Internet search using Google website was carried out to identify food products on the market labeled “upcycled food” or claiming that the product consists of valorized ingredients based on upcycled food.

As keywords, combinations (“upcycled food” and “label”) or (“upcycled food” and “claim”) were used. Scientific articles and reports were excluded, and attention was only given to commercial websites and consumer products. After screening the first results, an in-depth analysis was performed on the data-base provided by https://www.upcycledfood.org, https://www.foodingredientsfirst.com/ and https://www.fooddive.com/. Finally, 255 examples of the products labeled as upcycled food were identified. As a result, subjective choices of the products labeled were obtained and presented in the result section.

The analysis of solutions available on the market in the field of upcycling of by-products from food processing plants and food waste carried out from the perspective of food producers, food processing companies and consumers was a “snowballing” method of literature research and narrative style of description.

Results and discussion

The idea of supporting the upcycling trend is spreading worldwide (Holland, 2023; PSZW, 2023; Taylor, 2020; UFA, 2023a). In Table 3, there are presented examples of upcycled food products available on the market with the indication on the label “upcycled”. As can be seen, most of them are available for consumers in the USA, and one in Finland.

Table 3. Examples of upcycled food products available on the market

Products*	By-products used in a production process	Company	Country	Reference
baking mixes (banana bread, pizza crust, carrot cake) puffed snack; pasta; bars	brewery’s spent grain	ReGrained	USA	https://www.regrained.com/pages/product-showcase
Upcycled dried fruit snacks	fruit surplus, fruits peals	RIND	USA	https://www.rindsnacks.com/
Meatless Umami Bouillons	rescued (out of date, side products) vegetables (onions, peas)	The Nordic Umami	Finland	https://nordicumami.fi
Upcycled Cookies	pulp, a by-product of the oat-milk production process	Fancypants Baking Co.	USA	https://www.fancypantsbakery.com/contact-us/
80-proof clear alcoholic beverage	whey in cheese production	Wheyward Spirit’s	USA	https://www.wheywardspirit.com/
Flock Chicken Crisps	chicken skins	Lock foods	USA	https://flockfoods.com/
Hope and Sesame®	protein remaining after sesame seeds pressing for oil production	The Planting Hope Company	USA	https://www.hopeandsesame.com/

*Criterium of selection: products labeled as “upcycled”

Source: own study.

Upcycled products are obtained mainly from grains (brewery spent grain, the by-product of the oat-milk production process); fruits and vegetables (out of date, side products, peals), dairy by-products (whey), seeds pressing cake (pomace, okara) (Fig. 2).

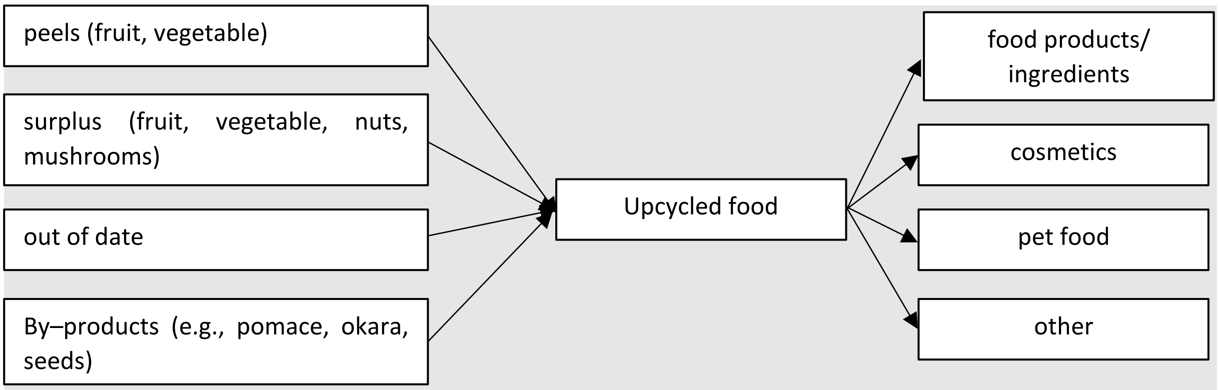


Fig. 2. Typical sources and the final product s based on upcycled food

Source: Adapted from (Holland, 2023; PSZW, 2023; Taylor, 2020; UFA, 2023b,c).

The most important developed standard which helps organizations address food waste and promote sustainable practices in the food industry is ISO 14001 Environmental Management Systems (EMS), which provides a framework for organizations to establish and maintain an EMS. It helps them manage their environmental impact, improve sustainability, and comply with environmental regulations. The second one ISO 22000 focuses on food safety management systems, and its implementation indirectly contributes to reducing food waste by improving processes and minimizing risks that can lead to waste generation. Nevertheless, implemented standards by the producers, any product marketed on an industrial scale, must be accepted by consumers. Food neophobia and technophobia can be an obstacle to this. The solution to this problem is certification, which ensures the quality and safety of such foods. There is no doubt that the most recognized and formalized upcycling initiative is the Upcycled Food Association (UFA). The UFA has introduced the Upcycled certification mark. The certified product must undergo a supply chain audit to verify the sources of upcycled raw materials. The manufacturer must also make available, among other things, details of the upcycled ingredient content in the product and how much food waste is discharged each year in connection with production. Certification is valid for one year and must be renewed annually (UFA, 2021).

By the end of June 2023, the UFA certified many companies that meet the requirements. The approved list consists of products or ingredients retailers. On the first list, 44 food products (bars, soups, baking mixes), one personal care product and 8 pet food can be found (UFA, 2023b). The ingredients category is divided into food and beverage 29 certified brands, cosmetics (one) and pet food (one) (UFA, 2023c)

However, measuring the true impact of described initiatives on food waste upcycling is challenging because accurate data on food waste throughout the supply chain is not collected. This information is important to identify areas for change.

Although the first products labeled as “upcycled food” are available for consumers, according to Grasso and Asioli (2020), most consumers had not heard of upcycled ingredients before. Still, they would consider buying foods with upcycled ingredients. Grasso et al., (2023) studied American and Chinese consumer attitudes to upcycled foods and consumer preferences on new upcycled food combinations. Their research revealed that Chinese participants characterized upcycled foods in terms of quality and health more than the US, while ‘reducing food waste’ and being “good for the environment” were equally associated with upcycled foods in both countries. The public needs to be informed as effectively as possible about the benefits of upcycled ingredients. This will also have important implications for future labeling strategies for policymakers. As pointed Taufik et al., (2023), product communication about concrete environmental or nutritional benefits of upcycled food increases the extent to which consumers experience purchasing upcycled food as morally self-rewarding, which in turn is positively associated with consumers’ intention to purchase upcycled food. As suggested by Coppola et al., (2021), most upcycling activities can therefore be perceived as a reflective and pragmatic form of resistance to consumerism, which, especially the family dimension, dominates more than concern for the environment.

Appropriate management of the logistics process during food production management can help reduce losses and thus increase the amount of material that can be redirected to upcycling (Girotto et al., 2015). Implementing the 6R (or 7R) principles, especially in rethinking and redesigning existing processes, will be a source of better use of raw materials and prevent the transfer of waste to disposals in favor of upcycling products (Alonso-Muñoz et al., 2022). Reduction of food waste can be implemented in various ways, for example:

- education of citizens as well as food producers,
- act as intermediaries to manage the flow of e.g., expiry date food, food losses,
- consultancy to food producers to help them reduce their own food waste,
- collect and manufacture products or ingredients.

Sustainable food management cannot be considered a sufficient point for the modern consumer to be interested in this product. The health and safety of manufactured goods and the importance of pro-environmental action can be regarded as important factors from the consumer’s point of view. Food producers must also keep the following aspects in mind:

- product category,
- low level of processing (consumers prefer not ultra-processed food),
- good nutritional value,
- labelling,
- supply chain (Thorsen et al., 2022).

Consumers must also have a good understanding of what "upcycled food" means. This is especially challenging for countries where English is not the official language. The question is whether to introduce appropriate definitions and terms in other countries or try to get consumers used to the term "upcycled food". This will increase the overall acceptability, positive attitude and desirability of this food group, thus driving further work on new products. Upcycling should be given priority to fruit and vegetable by-products (Thorsen et al., 2022).

Socas-Rodríguez et al., (2021) pointed out that valorizing food by-products is very challenging for food producers who want to use them as secondary raw materials. The main reasons they indicated were the different stability obtained components during processing; the technological problems during large-scale production; the low energy efficiency, and high costs of conventional extraction processes; and the usage of non-food grade solvents.

Food upcycling needs to be evaluated from many aspects, from understanding food to understanding the processes of mass production systems, for example, expertise in nutrition, quality control, sensory analysis, processing, mass production, and legal regulations. It is expected that in the future, an environment for upcycling agricultural food by-products will be established, and farming cooperatives and companies will be able to participate. Ultimately, it is hoped that this process will naturally lead to upcycling through government-led private industrialization (Kim, 2023).

Commercialization of upcycled food is driven by several factors, such as:

- moving towards a circular economy,
- growing consumer interest in a sustainable approach to consumption,
- reducing food waste.

Also, especially in Europe, it introduces Green Deal, "a package of policy initiatives, which aims to set the EU on the path to a **green transition**, with the ultimate goal of reaching climate neutrality by 2050"(*European Green Deal – Consilium*,2023)The first system of assigning the "upcycled food" label was introduced in the USA. It is the only method of labeling this group of products so far. Upcycled food products were obtained mainly from cereals and seeds processing, fruits and vegetables and dairy by-products.

Conclusions

The public needs to be informed as effectively as possible about the benefits of upcycled ingredients. This will also have important implications for future labeling strategies for policymakers. Consumers must also have a good understanding of what "upcycled food" means.

This will increase this food group's overall acceptability, positive attitude and desirability, thus driving further work on new products. Priority for upcycling should be given to fruit and vegetable by-products.

Authors are aware of the limitations of this study, because of the methods used and subjective analysis of the products labeled as "upcycled food". This might potentially impact the generalization and robustness of the study's findings. Future research should consider methodological improvements to address these limitations.

References

Alonso-Muñoz, S., García-Muiña, F.E., Medina-Salgado, M.S., & González-Sánchez, R. (2022). Towards circular economy practices in food waste management: a retrospective overview and a research agenda. *British Food Journal*, *124*(13), 478-500. https://doi.org/10.1108/BFJ-01-2022-0072/FULL/PDF

Coppola, C., Vollero, A., & Siano, A. (2021). Consumer upcycling as emancipated self-production: Understanding motivations and identifying upcycler types. *Journal of Cleaner Production*, *285*, 124812. https://doi.org/10.1016-/J.JCLEPRO.2020.124812

European Green Deal (2023). Retrieved 31st July, 2023, from https://www.consilium.europa.eu/en/-policies/-green-deal/

FAO. (2013a). *Food wastage: Key facts and figures. Summary report*.

FAO. (2013b). *Toolkit: Reducing the Food Wastage Footprint*.

Ferrer, B. (2021) Industry's first upcycling food label targets over 255 product certifications in 2021. Retrieved 31st July, 2023, from https://www.foodingredientsfirst.com/news/industrys-first-upcycling-food-label-targets-over-255-product-certifications-in-2021.html

Fusions. 2023. *Food Waste Definition.* Retrieved 12th May, 2023, from https://www.eufusions.org/index.php/-about-food-waste/280-food-waste-definition

Girotto, F., Alibardi, L., & Cossu, R. (2015). Food waste generation and industrial uses: A review. *Waste Management*, *45*, 32-41. https://doi.org/10.1016/J.WASMAN.2015.06.008

Grasso, S., & Asioli, D. (2020). Consumer preferences for upcycled ingredients: A case study with biscuits. *Food Quality and Preference*, *84*, 103951. https://doi.org/10.1016/j.foodqual.,2020.103951

Grasso, S., Fu, R., Goodman-Smith, F., Lalor, F., & Crofton, E. (2023). Consumer attitudes to upcycled foods in US and China. *Journal of Cleaner Production*, *388*. https://doi.org/10.1016/j.jclepro.2023.135919

Holland, F. (2023). *10 innovative European food waste solutions*. Retrieved 31st July, 2023, from https://food-matterslive.com/article/10-innovative-food-waste-solutions-europe/

Kharel, S., Gautam, A., Mahotra, M., Theniko, N. M., & Loo, S. C. J. (2021). Valorizing okara waste into nutritionally rich polysaccharide/protein-extracts for co-encapsulation of β-carotene and ferrous sulphate as a potential approach to tackle micronutrient malnutrition. *Journal of Functional Foods*, *87*. https://doi.org/10.1016/j.jff.-2021.104749

Kim, S.-O. (2023). Review of food upcycling in South Korea: regulation, limitation, and prospects. *Food Science and Biotechnology*, *32*(1), 1-10. https://doi.org/10.1007/s10068-022-01184-y

Madia, V. N., De Vita, D., Ialongo, D., Tudino, V., De Leo, A., Scipione, L., Di Santo, R., Costi, R., & Messore, A. (2021). Recent Advances in Recovery of Lycopene from Tomato Waste: A Potent Antioxidant with Endless Benefits. *Molecules 2021, 26*(15), 4495. https://doi.org/10.3390/MOLECULES26154495

Moshtaghian, H., Bolton, K., & Rousta, K. (2021). Challenges for upcycled foods: Definition, inclusion in the food waste management hierarchy and public acceptability. *Foods*, *10*(11). https://doi.org/10.3390/foods10112874

PSZW. (2023). *Polskie Stowarzyszenie Zero Waste*. https://zero-waste.pl/

Saunders, M. N. K., Lewis, P., & Thornhill, A. (2023). *Research methods for business students* (9th ed.). Pearson.

Socas-Rodríguez, B., Álvarez-Rivera, G., Valdés, A., Ibáñez, E., & Cifuentes, A. (2021). Food by-products and food wastes: are they safe enough for their valorization? *Trends in Food Science & Technology*, *114*, 133-147. https://doi.org/10.1016/J.TIFS.2021.05.002

Taufik, D., Rood, R., Dagevos, H., Bouwman, E.P., & Reinders, M.J. (2023). Effects of abstract and concrete communication on moral signalling and purchase intention of upcycled food products. *Cleaner and Responsible Consumption*, *8*. https://doi.org/10.1016/j.clrc.2023.100110

Taylor, S. (2020). *These 12 organizations are creating food products from upcycled food waste*. https://www.-greenbiz.com/article/these-12-organizations-are-creating-food-products-upcycled-food-waste

Thorsen, M., Skeaff, S., Goodman-Smith, F., Thong, B., Bremer, P., & Mirosa, M. (2022). Upcycled foods: A nudge toward nutrition. *Frontiers in Nutrition*, *9*. https://doi.org/10.3389/fnut.2022.1071829

UFA. (2021). *Upcycled Food Association, Foundation, and Certification*. Retrieved 31st July, 2023, from https://-www.upcycledfood.org/

UFA. (2023a). *About Upcycled Food — Upcycled Food Association*. Retrieved 31st July, 2023, from https://-www.upcycledfood.org/upcycled-food

UFA (2023b) *Upcycled Certified Ingredients.* Retrieved 31st July, 2023, from https://www.upcycledfood.org/-upcycled-certified-ingredients

UFA (2023c) *Upcycled Certified Products.* Retrieved 2nd August, 2023, from https://www.upcycled-food.org/upcycled-certified-products

UNEP. (2014). *Prevention and reduction of food and drink waste in businesses and households – Guidance for governments, local authorities, businesses and other organisations, Version 1.0. Reducing and preventing food and drink waste in businesses and households:* A guidance document ISBN: 978-92-807-3346-4.

United Nations Food Systems Coordination Hub. (2023) *Chapter 2 Key Inputs from Summit Workstreams Levers Of Change: Policy Brief: The True Value Of Food*. Retrieved 31st July, 2023, from https://www.unfoodsystems-hub.org/fs-summit-legacy/food-systems-summit-compendium/chapter-2-levers-of-change/true-value-of-food/en

United Nations. (2022) *SDG Indicators. Global indicator framework for the Sustainable Development Goals and targets of the 2030 Agenda for Sustainable Development*. Retrieved 23rd November, 2022, from https://unstats.-un.org/sdgs/indicators/indicators-list/

THE USE OF DISPOSABLE PACKAGING IN THE ASPECT OF ENVIRONMENTAL PROTECTION IN THE ASSESSMENT OF CONSUMERS OPINIONS

Klaudia Młoda-Brylewska, Krzysztof Melski*

Department of Natural Science and Quality Assurance, Institute of Quality Science,
Poznań University of Economics and Business, Poznań, Poland,
**Corresponding Author e-mail:k.melski@ue.poznan.pl*

DOI: 10.56091/CTQS.Innov-13

Abstract

The article discusses the challenges associated with reducing the amount of disposable packaging. These include, i.a. the lack of effective waste management mechanisms, the lack of innovation in environmentally friendly packaging, the difficulty of changing consumer behaviour and resistance from producers and consumers.

A consumer survey was carried out to identify the most important problems related to the use and management of disposable packaging by their users. Actions are proposed at various levels, such as consumer education and awareness-raising, investment in research and development of alternative packaging, development of recycling infrastructure and regulation.

The conclusions underline the importance of long-term strategies and action plans that take into account both consumer needs and environmental objectives. Attention was paid to the need to monitor and evaluate the effectiveness of the actions taken and the need for further scientific research towards improving the strategy and pro-environmental approach in the field of packaging and environmental protection.

Keywords: SUP, sustainable development, consumer opinions, waste, packaging

Introduction

The modern world faces serious challenges related to environmental pollution. One of the important areas of risk is single-use packaging, which, on the one hand, is one of the least efficient ways of using natural resources, and on the other hand, poses serious problems in the management of packaging waste (Dey at all, 2021). Among the potentially effective tools to minimize the environmental impact of plastic packaging is the EU Single-use Plastics Directive (SUP). Adopted in 2019, the Directive introduces a number of changes aimed at promoting sustainable alternatives, banning the sale of certain plastic products, and increasing producer responsibility. This article discusses key aspects of the SUP Directive and its implications for industry, society, and the environment.

In 2021, the consumption of packaging by a statistical Pole was about 160 kg (PIE), of which about 40% was plastic packaging. In this category, we deal in equal proportions with flexible packaging, such as pouches and films, and rigid packaging, represented by bottles, boxes, and others. Paper-based packaging covers about 37% of the market, with metals accounting for 12%. Glass packaging closes this list by cover about 10%. It is worth noting that the main buyers of packaging are food manufacturers, responsible for over 60% of total consumption. The pharmaceutical and cosmetics industries occupy 7% and 6% of the share, respectively. The remaining part of the demand for packaging is supplied by manufacturers of household chemicals and other industrial goods (Samsonowska & Kaszuba, 2022).

The analysis of available data indicates that although Poland has lower packaging consumption compared to the most developed EU countries, the growing consumption trend is worrying from the point of view of sustainable resource management. The composition of packaging, where plastics play a significant role, highlights the need to look for alternative, greener solutions. Action to reduce the use of packaging and promote its recycling and other treatment methods is key to achieving a more sustainable economic model and environmental protection.

Key changes in the field of single-use plastic products were introduced by the amendment to the Act on the obligations of entrepreneurs in the management of certain waste and on the product fee, coexisting with the Single-use Plastics Directive (SUP), which entered into force on 24 May 2023. This complex and rigorous legal initiative aims to significantly reduce the negative impact of these products on the environment while introducing a new paradigm towards the sustainable use of raw materials and the protection of ecosystems. One of the requirements of the introduced law is the obligation of permanent attachment of plastic caps to bottles and cartons with liquids, which is an important step in reducing the spread of plastic waste.

Another important element of regulation is the labeling of single-use plastic products. The Implementing Regulation contains four annexes which include harmonized labeling specifications in the following categories:

- sanitary napkins, tampons and tampon applicators,
- wet wipes,
- filters used with tobacco products,
- cups for beverages.

The regulation also introduces a new requirement to report on the plastic content of single-use products. This information will have to be given in the official language of the country where the product is placed on the market. In the case of the Polish language, the expression "contains plastic" will be an appropriate label (Fig. 1) (Journal of Law 2023, item 877). Failure to provide the required labeling is subject to administrative penalties to guarantee transparency and educate consumers, introducing them to a new reality in which the choice of ecological alternatives is crucial.,

Fig. 1. Marking "product contains plastic"

Source: https://www.teraz-srodowisko.pl/aktualnosci/jednorazowe-produkty-plastikowe-nowe-oznakowania-2021-9722.html

Another objective of the Act is to prohibit the marketing of certain single-use products made of plastic, including, among others, cotton buds, cutlery, plates, straws, stirrers, balloon sticks, and food and beverage containers made of expanded polystyrene. In the face of these restrictions, entrepreneurs must adapt their business models, investing in innovation and creating environmentally friendly alternatives. Traders operating in the retail, wholesale, and catering sectors are obliged to collect charges from end-users purchasing regulated products. This is to encourage consumers to make more informed choices, while at the same time introducing into their awareness the fact that their actions have an impact on the state of the environment.

The law also focuses on beverage cups with lids, lids, and food containers, especially those used for meals. The regulations impose, from 1/1/2024, the obligation to charge a fee of 0.20 PLN for each disposable cup (e.g., at a petrol station, in restaurants). The introduction of economic incentives in the form of additional charges for disposable products becomes the dominant mechanism provided for in these provisions. The answer to this regulation has already appeared in practice – many catering outlets have introduced reduced prices for customers using their packaging, intended to promote reusable products. Now the European Union is trying to apply a similar mechanism globally by introducing fees for single-use plastic packaging (Swinarew, 2023).

One of the key objectives of this approach is to discourage consumers from using plastic packaging in favour of greener alternatives. According to the promoted model, the choice of plastic packaging entails an additional cost. This effect is intended to encourage consumers to rethink their choice and choose an option more in line with the idea of sustainable development. Thus, the SUP Directive has a clear impact on shaping consumer habits and introducing changes in the way packaging is perceived.

The current legislation also places a strong emphasis on the sustainable use of packaging and stimulates the development of a circular economy in which packaging is designed to be recyclable and reusable. This perspective is driving manufacturers towards the search for innovative solutions that can replace traditional plastic packaging. This approach is expected to contribute to reducing plastic waste from single-use packaging.

The new regulations, although challenging for entrepreneurs and consumers, also open up space for positive changes. The shift from single-use to reusable packaging has the potential to bring benefits for both the environment and the economy. However, the final impact assessment of the SUP Directive requires time and observation to assess whether the achieved objectives of reducing single-use plastic packaging and promoting green alternatives will be achieved.

To sum up, the Single-Use Plastics Directive (SUP) introduced into Polish law sets a new paradigm in the field of single-use plastic products. It includes a number of strict regulations, including marketing bans, labeling, restrictions on use, and recording obligations. These activities are aimed at protecting the natural environment and changing consumer habits. Entrepreneurs need to adapt their business strategies to these new requirements, which will undoubtedly contribute to profound changes in the single-use plastic sector aimed at achieving greater environmental sustainability. The introduction of these regulations is another step towards achieving the global Sustainable Development Goals and minimizing the impact of plastic packaging on our planet.

Materials and methods

The presented study aimed to obtain deeper insights and quantitative data on the impact of the introduction of the Single-Use Plastics Directive (SUP) on consumer awareness and behavior regarding single-use plastic products. The survey was conducted using the CAWI (Computer-Assisted Web Interviewing) method, in the period from 1 to 30 June 2023.

The CAWI method, or Computer-Assisted Web Interviewing, has become an integral part of modern social and consumer research. It allows for the efficient collection of data from respondents through online platforms, while ensuring control over the quality and precision of the gathered information.

For the presented study, the choice of this method was justified by its availability, scalability, and ability to gather information from a wide group of respondents (Bartłomowicz & Bak, 2022).

The study was conducted on a sample of 206 people who agreed to participate and complete the on-line questionnaire. The sample of respondents was carefully selected in terms of demographic diversity – an age, to obtain a representative picture of society regarding knowledge about issues related to single-use plastic products and the introduction of the new regulation. The questionnaire was completed by 51.5% of women and 40.8% of men (7.7% of respondents did not specify gender). Additionally, respondents in different age categories participated in the survey, with the percentage distribution as follows:

- under 18 years – 4.4%
- 18-24 years – 22.9%
- 25-34 years – 22.5%
- 35-44 years – 22.9%
- 45-54 years – 12.2%
- 55-64 years – 8.1%
- over 65 years – 7.0%

The research questionnaire was developed with care to comprehensively cover important aspects related to the introduction of the SUP Directive. The questions concerned respondents' knowledge of the ban on the marketing of certain products, their perception of changes in the market offer, and their readiness to accept ecological alternatives. In addition, the degree of awareness of labeling on products and packaging containing plastics and the propensity to use reusable products were also examined.

The results of the study, collected using the CAWI method, were subjected to a careful process of statistical analysis and interpretation. The obtained data allowed for a deeper understanding of the impact of the SUP Directive on consumer perception and the predicted directions of changes in their consumer behavior.

Results and discussion

The results of the survey indicate different consumer habits in the use of disposable packaging, such as cutlery, plates, or cups. The subjects were asked to express the frequency with which they use this type of packaging. The responses revealed that the majority of respondents (53.8%) declare the use of single-use packaging sporadically – several times a year. It is worth noting that a small percentage of respondents (7.7%) expressed that they use them once a week or more often.

On the other hand, the group constituting 38.5% of respondents uses disposable packaging several times a month.

These results clearly illustrate that the use of single-use packaging is present in the consumer habits of respondents to varying degrees. The tendency to use them "several times a year" may result from special circumstances, such as celebrations or events, where the convenience and practicality of this type of packaging are often put above ecological considerations. On the other hand, the group of respondents using disposable packaging "several times a month" may indicate permanent needs, where the convenience of disposable packaging is an important factor, although the frequency of their use is controlled.

Another set of questions concerned consumer awareness of the solutions introduced under the SUP Directive. Consumer responses are summarized in Table 1.

Table 1. Respondents' awareness of solutions introduced by the SUP

Type of change	Respondents' responses [%]	
	Yes	No
ban on the sale of disposable plastic packaging (cutlery, plates, cups)	84.6	15.4
ban on the use of polystyrene containers for food	23.1	76.9
fee of 0.20 PLN for each disposable cup (e.g., at a petrol station, in restaurants) (from 1/01/2024)	7.7	92.3
obligation to attach caps to bottles (from mid-2024)	30.8	69.2
deposit system in Poland for disposable plastic bottles up to 3 liters, reusable glass bottles up to 1.5 l and metal cans up to 1 l (from 2025)	23.1	76.9

Source: own study.

An analysis of the survey results shows that while the majority of respondents seem to be aware of the changes made to the Single-use Plastics (SUP) Directive, there are areas where better education and communication are needed. The responses suggest that most people are aware of the ban on the sale of single-use plastic packaging, but fewer people are aware of the ban on Styrofoam containers for food and the applicable fee for single-use cups. A small percentage of respondents are also familiar with the rules on the attachment of bottle caps and the introduction of a deposit system for bottles. The conclusions of the study indicate the need for further information activities to ensure full awareness and understanding of the SUP solutions introduced.

Respondents were then asked whether they thought these changes were a good option. The respondents' responses are summarized in Table 2.

Table 2. Respondents' opinion on the SUP solutions introduced

Type of change	Respondents' responses [%]				
	Definitely yes	Probably yes	Hard to say	Rather not	Definitely not
prohibition of sale of disposable packaging (cutlery, plates, cups) with plastics	7.7	23.1	23.1	15.4	30.8
ban on the use of polystyrene containers for food	15.4	20.8	33.8	15.0	15.,8
fee of 0,2 PLN for each disposable cup (e.g., at a petrol station, in restaurants) (from 1/01/2024)	13.4	7.7	9.7	30.8	38.5
obligation to attach caps to bottles (from mid-2024)	22.1	15.5	30.7	23.1	7.7
deposit system in Poland for disposable plastic bottles up to 3 liters, reusable glass bottles up to 1.5 l and metal cans up to 1 l (from 2025)	24.1	45.1	15.5	5.7	9.7

Source: own study.

The results presented in Table 2 show the differing positions of respondents towards the changes introduced under the Single-use Plastics Directive (SUP). There are differences of opinion on each measure proposed. In the case of a ban on the sale of single-use plastic packaging, a group (30.8%) is against this solution, while 30.8% are strongly in support. There are also differences in the ban on the use of polystyrene containers for food, where the majority (36.2%) assess it positively, but there is also a group (15.8%) expressing opposition. The fee for disposable cups was criticized by 38.5% of respondents, and the obligation to fasten nuts won acceptance of 37.6%. The deposit system for plastic bottles found the greatest support (69.2%), which may result from the visible ecological and social benefit of this solution.

Consumers were also asked whether the above projects will contribute to the improvement of the environment. The results presented in the table 3 reflect the differing opinions of respondents on the impact of the introduced changes on the improvement of the environment. For most of the measures proposed under the Single-Use Plastics (SUP) Directive, there is a fairly large group of people who are convinced of the positive impact of these measures on ecology. For example, 34.9% of respondents are convinced that a ban on single-use plastic packaging will improve the environment, while 32.1% take the opposite view.

Table 3. Opinion of respondents on the effectiveness of SUP solutions in improving the environment

Type of change	Respondents' responses [%]				
	Definitely yes	**Probably yes**	**Hard to say**	**Rather not**	**Definitely not**
prohibition of sale of disposable packaging (cutlery, plates, cups) with plastisc	22.2	12.8	17.4	32.1	15.5
ban on the use of polystyrene containers for food	11.1	6.4	33.3	37.1	12.1
fee of 0,2 PLN for each disposable cup (e.g., at a petrol station, in restaurants) (from 1/1/2024)	7.1	8.2	20.3	23.1	41.3
obligation to attach caps to bottles (from mid-2024)	6.9	10.2	24.1	22.1	36.7
deposit system in Poland for disposable plastic bottles up to 3 litres, reusable glass bottles up to 1.5 l and metal cans up to 1 l (from 2025)	27.1	44.1	14.7	12.4	1.7

Source: own study.

The results obtained show differences in the assessment of the impact of individual measures. The deposit system for plastic bottles won the most support as a measure to improve the environment, with 71.2% of respondents believing that it will have a positive impact. In the case of other measures, such as the ban on polystyrene containers or the fee for disposable cups, a significant percentage of respondents seem to be sceptical about their real impact on improving the ecological situation.

The last question concerned the knowledge of the graphic symbol "the product contains plastic". Only 17.3% of respondents encountered this label. Out of this pool of people, every second respondent was able to correctly indicate the groups of products on which it is placed.

Summary

The SUP Directive, implemented in May 2023, will bring significant changes in the scope of limiting the use of single-use plastic packaging. SUP aims to reduce the negative impact of plastics on the environment. The article presents the diverse sources of plastic pollution, especially packaging, which accounts for a significant part of waste. The changes include a ban on the placing on the market of certain single-use products and an obligation to label products containing plastic.

The survey shed light on consumers' perception of these changes. The results indicate that the majority of respondents are aware of the bans and changes introduced, which indicates a certain level of information on environmental risks in society. The analysis of answers to questions related to the assessment of the introduced changes shows different positions of the respondents.

Some people are positive about the changes, considering them a step in the right direction, and the deposit system for plastic bottles enjoys the greatest support. The results of the survey also indicate scepticism and doubts about the effectiveness of some of the measures introduced. They are most likely due to insufficient education and the lack of an effective information campaign.

The results of the survey shed light on the current state of action of legislators in the field of combating plastic packaging waste pollution and on the diverse attitudes and beliefs of consumers towards these changes. The introduction of the SUP Directive is an important step towards environmental protection, but in order to achieve the expected results, it is necessary to step up education and awareness-raising activities.

References

Bartłomowicz, T., Bąk, A. (2022). *Badania preferencji i zachowań konsumentów z wykorzystaniem metod mikroekonometrii i programu R*. Wydawnictwo Uniwersytetu Ekonomicznego we Wrocławiu.

Dey, A., Dhumal, C. V., Sengupta, P., Kumar, A., Pramanik, N. K., & Alam, T. (2021). Challenges and possible solutions to mitigate the problems of single-use plastics used for packaging food items: A review. *Journal of Food Science and Technology*, *58*(9), 3251-3269. https://doi.org/10.1007/s13197-020-04885-6

Kuna, P., Nowakowski, K. (2023). Uzupełnienie rozszerzonej odpowiedzialności producenta. *Energia i Recykling*, 63(3).

Samsonowska, K., Kaszuba, A. (2022). Mikroplastik w środowisku naturalnym *Polimery*, *67*(1), 28-33.

Swinarew, B. (2023). Projekt ustawy o zmianie ustawy o gospodarce opakowaniami i odpadami opakowaniowymi oraz ustawy o odpadach. *Polimery dla Biznesu*, 2(5), 14-18

Ustawa z dnia 14 kwietnia 2023 r. o zmianie ustawy o obowiązkach przedsiębiorców w zakresie gospodarowania niektórymi odpadami oraz o opłacie produktowej oraz niektórych innych ustaw, Dz. U. 2023, poz. 877.

https://www.teraz-srodowisko.pl/aktualnosci/jednorazowe-produkty-plastikowe-nowe-oznakowania-202197-22.html.

MANAGING CIRCULARITY OF PACKAGING FOR FOOD PRODUCTS – CARBON FOOTPRINT ASSESSMENT OF INNOVATIVE COATED PAPER PACKAGING

Tomasz Nitkiewicz *[1], Karolina Wiszumirska [2] , Artur Jachimowski [3] and Marcin Rychwalski [3]

[1] Life Cycle Modelling Centre, Faculty of Management Częstochowa,
University of Technology, Częstochowa, Poland
[2] Department of Industrial Products and Packaging Quality, Institute of Quality Science,
Poznań University of Economics and Business, Poznań, Poland
[3]Department of Products Technology and Ecology, Institute of Quality Sciences and Product
Management, Cracow University of Economics, Cracow, Poland
**Corresponding Author e-mail: tomasz.nitkiewicz@pcz.pl*

DOI: 10.56091/CTQS.Innov-14

Abstract

Food products pose a big challenge from the perspective of circular economy not only by its manufacturing processes but also by its packaging needs and requirements. The paper presents the innovative coated paper (CP) materials for food product packaging from the perspective of its circularity potential., The objective of the paper is to assess six coated paper packaging with the use of Carbon Footprint (CF) method in order to check the circularity potential and its relation to environmental impacts. The circularity potential is assessed through the following aspects: the recycling of CP and the use of recycled paper for CP packaging manufacturing. The assessment is made on the life cycles of the product within CP packaging. Sensitivity analysis for the assessment is focused on impact of recycling improvement scenario and recycled content involvement scenario on overall CF. The results of the assessment show relatively small contribution of CP packaging to the CF. The recycling and recycled content scenarios bring significant and positive effect on CF in every investigated case. The recommendation from the study is to introduce both scenarios simultaneously and focus on eco-management strategies in order to get the biggest progress towards circularity.

Keywords: food packaging materials, coated paper, carbon footprint, sustainability, circularity

Introduction

Food packaging is one of the most important actors in the food supply chain as it protects and preserves the quality and safety of food products and extends the shelf-life. As a consequence, the food packaging has a share in the material and energy consumption within food life cycle, as well as contribution to its emissions, waste generation and related environmental impacts.

Packaging has the contribution to the impacts that occur in the end-of-life phase when product has been already consumed. Therefore, challenge for assessing the sustainability of food products is the availability of widespread recycling of packaging waste.

In this paper, we follow one of possible solution of food packaging challenge that was settled by REPAC[2] project consortium and is currently being faced by its research and industrial partners. The solution proposed within the project is based on investigation of coated paper use as a substitute for traditional packaging materials for food products. The possible advantages of coated paper packaging include the following: use of paper as biobased raw material for packaging, big capacity of using recycled material in manufacturing, well developed and efficient recycling process and facilities. The challenge is to prepare environmentally safe and technically functional coatings and coated papers, and this is the major objective of REPAC[2] project. The paper presents the partial results of REPAC[2] project. The approach is focused on paper/cardboard materials for food packaging that are one of the key solutions in the food sector.

Circular economy (CE) concept has been introduced a about decade ago (EC, 2015; EllenMacArthur Foundation, 2013) and is a currently streamlined policy in European Union that could be defined as "a regenerative system in which resource input and waste, emission, and energy leakage are minimized by slowing, closing and narrowing material and energy loops"(Geissdoerfer et al., 2017) (Geissdoerfer et al., 2017 p. 759). Consumer demand and emerging guidelines of the European commission are driving packages towards circularity by aiming at 100% reusable and/or recyclable packages in 2030 (European Commission, 2019). The actions introducing CE could be defined as narrowing loops through reducing resource use (i.e., increasing efficiency); slowing loops by prolonging the use of components, parts, and materials by extending lifespans and introducing multiple cycles; closing loops through the recycling of materials from End-of-life (EoL) back to production (Bocken et al., 2016). Packaging is one of the key targets of CE-oriented actions since it is a part of almost every industrial supply chain (Niero & Hauschild, 2017). For paper-based packaging the following principles should be applied: preserve and enhance natural capital, optimize resource yields, and foster system effectiveness (WEF, 2016). Figure 1 presents the paper product life cycle with focus on possible circular strategies of eco-design and eco-management. The eco-design strategy is focused on packaging material and achievement of food product requirements by new, more eco-friendly materials. Eco-management strategy is focused on the optimization of product, by-product and waste flows and is oriented on increasing the efficiency of end-of-life processing and the rate of waste packaging that are processed.

As for the CP solutions, the eco-design strategy is focused on achieving technical and barrier parameters that are at least equal to the parameters of currently used packaging for food products. Eco-management strategy is oriented on CP recycling and getting the efficiency of end-of-life processing on the level of regular paper at least.

Fig. 1. Inputs and outputs in the paper product life cycle

Source: WEF, 2016.

The use of LCA-based methods for assessment of circular solutions impacts on environment is commonly recognized in the literature (Ingrao & Wojnarowska, 2023; Nitkiewicz & Cappelletti, 2022; van Stijn et al., 2021). In our paper, we select Carbon Footprint method out of the LCA-based toolbox. The reason for that selection is related to the limited access to the primary data and screening only orientation of the assessment. The objective of the paper is to assess six coated paper packaging with the use of Carbon Footprint (CF) method in order to check the circularity potential and its relation to environmental impacts. The circularity potential is assessed through the following aspects: the recycling of CP and the use of recycled paper for CP packaging manufacturing. The assessment is made on the life cycles of the product within CP packaging. Sensitivity analysis for the assessment is focused on impact of recycling improvement scenario and recycled content involvement scenario on overall CF.

Materials and methods

The goal of the paper is to compare environmental impacts of different innovative packaging for food products with their currently used alternatives. The innovation is based on developing packaging material from coated paper and achieve the properties that meet the requirements of different food products.

The goal is to check how technological choices would influence the environmental performance of a food product and packaging itself by assessment of types of paper and coatings used, its manufacturing and application methods, its impact on food product, its weight, transport and storing conditions, and end-of-life processing of used packaging.

The subsequent goals of the study are to track the influence of recycling processes on overall carbon footprint and the potential of decreasing the footprint with recycled paper use.

The environmental assessment is made with Carbon Footprint method – namely Global Warming Potential (GWP) that was developed by International Panel on Climate Change (IPCC) in 2013 and later updated in 2021. The method used for the assessment is denoted as IPCC 2021 GWP100 v. 1.01. The method takes the time horizon of 100 years as a point of reference. The method is based on characterization of impacts, which are expressed in single unit of emitted kg of CO_2-eq. Impact factors within GWP100 are referring to the source of generated carbon footprint and include such categories as fossil, biogenic and land transformation sources (PRé Sustainability, 2022). The assessment is made in form of CF screening (European Commission DG Environment, 2010; Fields & Simmons, 2014; ISO, 2018).

Functional unit for the assessment is a final food product within specific coated paper packaging. The following life cycle phases are included in the study: supply of resources for manufacturing, transportation from suppliers, manufacturing, and end of life processing. The phases of distribution itself and use are excluded from the assessment. This is due to the potential lack of any environmental impacts in use phase (consumption of the food product) and lack of data to allocate consumer related transport or waste collection transport to the packaging itself. Each functional unit is different in a sense of size, volume, or weight of food product and therefore the results are presented either for 1 kg of food product within the packaging or for 1 kg of packaging CP material itself. Also, the best way to present the results is to focus on the comparison of structure of impacts and its relative shares.

The reference flow is covering all the material, energy, emission, and waste flows related to the functional unit. The data for reference flow is calculated or estimated on the basis of primary data from manufacturing units (as for the food product and its packaging) and complemented with secondary data whenever necessary. Any allocation issues within the assessment are solved by estimating the volume of specific flow that is prescribed to the specific functional unit. Figure 2 sets the borders of life cycle of a food products within CP packaging.

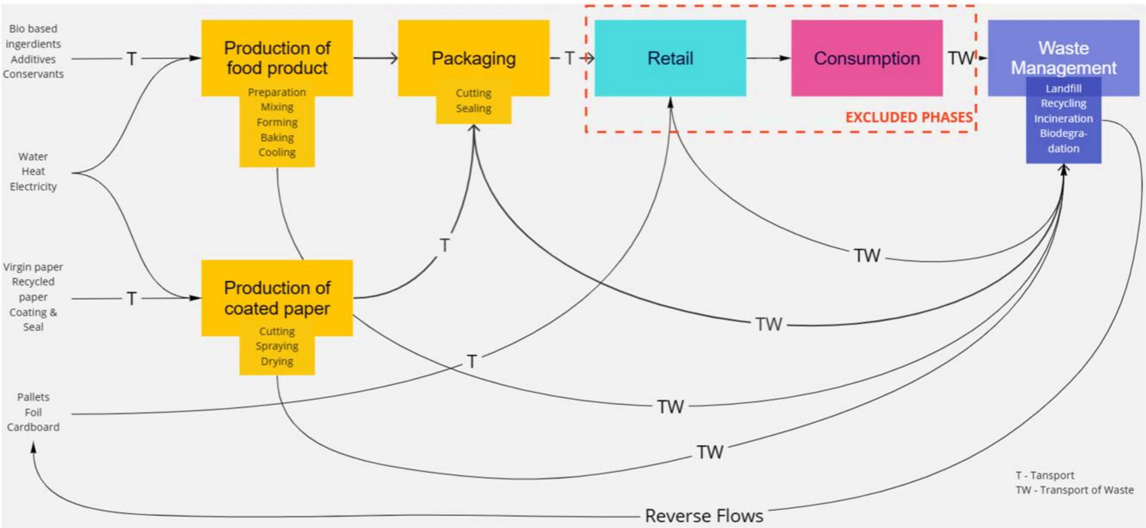


Fig. 2. Schematic presentation of food product and its CP packaging life cycle

Source: own study.

Table 1 presents the research cases and featured functional units, consisting of the food product and its coated paper packaging. In cases no. 1-3 and 6, the coated paper is the only material used for packaging the products. For the case no. 4 and 5 the carton box is used additionally.

Table 1. The list of featured products and coated paper packaging

No.	Food product	Investigated Coated Paper packaging	Type of packaging
CS1	sliced salami	vacuum metallized paper	vertical-form-fill sealed package with 2 horizontal seals and 1 vertical seal
CS2	fruit rolls	acrylic- and vinyl copolymer CP	horizontal-form-fill sealed package with 2 horizontal seals and 1 vertical seal
CS3	oil based crackers	extrusion coated Polyolefin	vertical-form-fill sealed package with two horizontal seals and one vertical seal
CS4	chocolate truffles	PVOH CP	vertical-form-fill sealed package
CS5	box of dried herbs for tea in teabags	extrusion EVOH coated paper	teabag envelope
CS6	chocolate tablet	coated paper with cold seal	3-sided sealed pouch with horizontal form-fill-sealer

Source: own study.

For the sake of clarity, the following section analyses the functional unit impact (product within CP packaging LC) or the CP packaging only.

Results and discussion

The results are presented for basic life cycle impact assessment with Carbon Footprint indicator. Additionally, since the assessment is a screening type of research, the results are analyzed for sensitivity on recycling of CP paper issue and recycled paper content in CP packaging manufacturing. These two issues of sensitivity analysis would certainly highlight the capacity of CP packaging with regard to its circularity potential., Note that the level of recycled paper use or share of CP in recycling are not covering circularity issue in a complex way but present the basic capacity of this type of packaging for improving the circularity of food product packaging.

Figure 3 presents the share of CP packaging footprint within the overall footprint for product life cycle. The lowest share of CP packaging within whole life cycle could be observed for CS1 salami and accounts for 2.8%. The second lowest contribution is observed for CS1 Teabag box and accounts for 3.5%. It is important to notice, that in case of Teabag box the CP is used for teabag envelopes and not the box itself. Next three cases 2-4 have significantly higher share of CP in overall impact that accounts for 8.5-9.7%. The highest share is observed for case no. 6 where the contribution of CP packaging is equal to 12.5%.

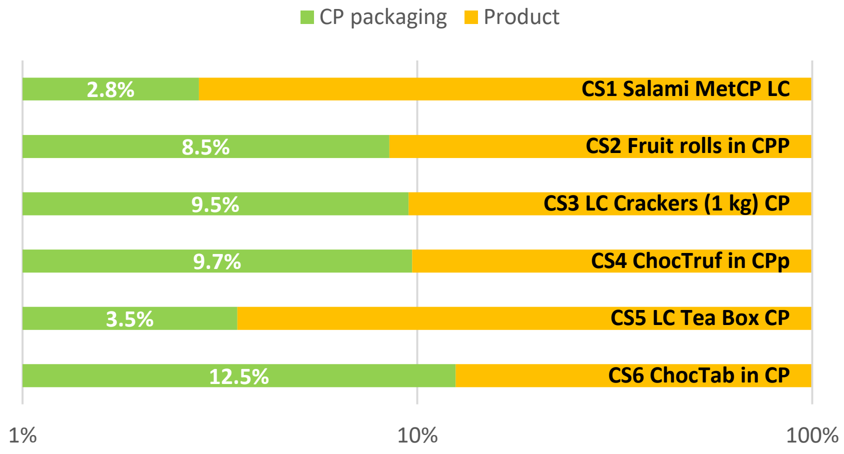


Fig. 3. Comparison of CP packaging share in overall CF

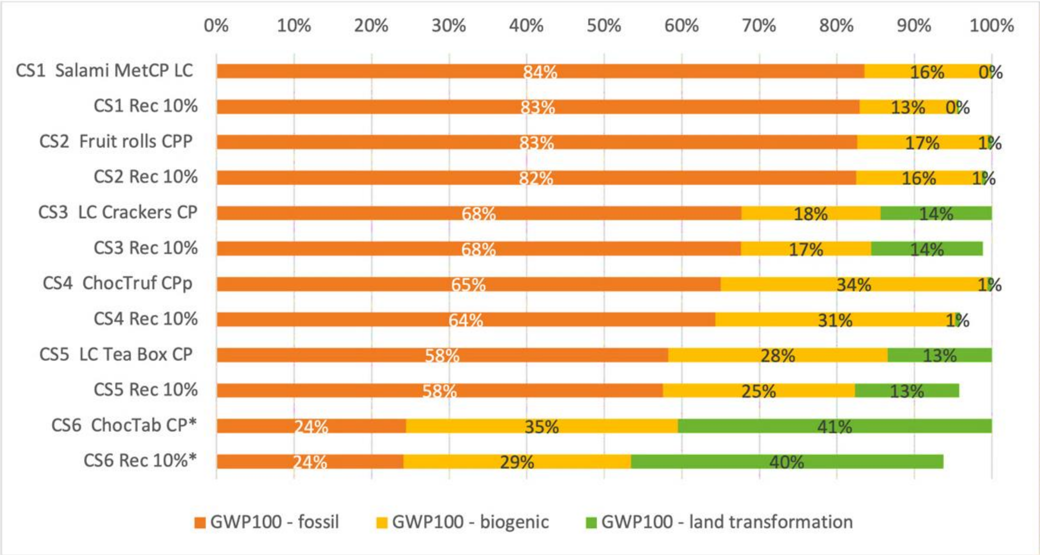
Source: own study.

It seems that the share of CP packaging in overall contribution is rather moderate. On the other hand, these results show also the potential to decrease the impacts that is contributed to packaging.

Since CF assessment has a form of screening only, it is not focused on bringing out detailed structure of impacts but rather on possible drivers responsible for its overall outcome. In this paper, we focus on the circularity issue, which could be attributed to the closed loop flow of packaging materials. In case of CP packaging, we bring out the two issues that shed some light on its circularity: recycling and recycled paper content contributions to the overall CF. It has a form of sensitivity analysis of CF assessment results and is presented below.

This part of sensitivity analysis is devoted to investigation of the possibility of improvement of recycling scenario if CP packaging could possibly get a status of "recycled like paper". It seems that CP recycling could be a vital point of its market campaign. Therefore, the scenario of recycling improvement is considered in order to check how significant it could be while overall CF is concerned. Just to get noticeable results the recycling improvement scenario is assuming 10% higher recycling ratio for coated paper packaging as collected from consumers. The assumed level of paper recycling is 81.5%.

The results of sensitivity analysis are presented at Figure 4. The results are presented for all GWP impact categories. The results for each one of the cases are presented for original case with regular recycling and potential case with recycling level increase by 10% (denoted by “Rec 10%” on the Fig. 4).



* Calculated for packaging only (and not for whole life cycle)

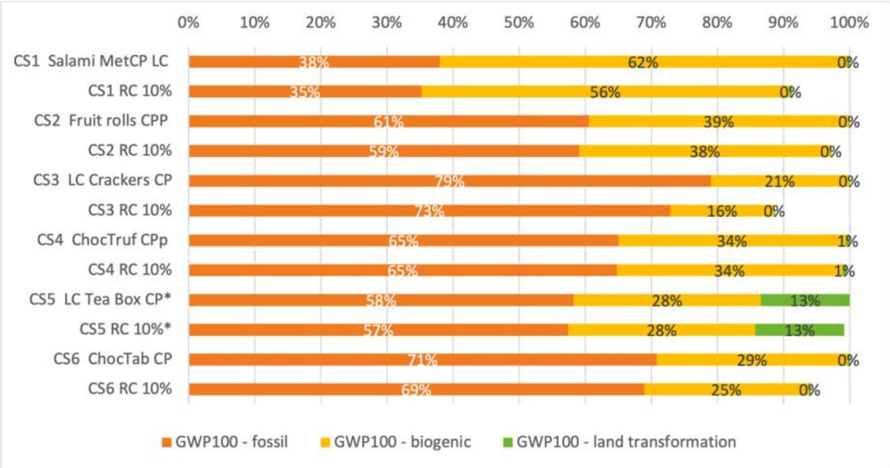
Fig. 4. Comparison of Recycling scenario +10% effect on CF impact categories

Source: own study.

As we could observe on Figure 4 the changes are rather slight in impact category indicators. The highest relative change is observed for biogenic related impacts and accounts for 3% decrease in whole LC impact for cases of salami, chocolate truffles and teabag box. A noticeable decrease of 6% is also observed for chocolate tablet but the change is measured for the packaging life cycle only. The category with the highest shares (in 5 out of 6 cases) is not significantly influenced by the improvement of recycling scenario and its contribution is decreasing by 1% (in case of salami, fruit rolls and chocolate truffles) or is not decreasing at all (crackers, teabag box and chocolate tablet). The category of land transformation related impact has regularly the smallest, and in most cases almost negligible, share and the impact of recycling scenario improvement is not visible. The only exception is for CP packaging for chocolate tablet, but it is again calculated for the packaging LC only, and the scale of the change is rather small (1%).

The following part of sensitivity analysis is devoted to investigation of the effect of recycled paper use in CP packaging manufacturing. The recycled paper content could play an important role in achieving circularity status for the packaging. While it is already commonly recognized for regular paper or plastics, it is not yet well covered for CP packaging. The data used to model life cycle impacts of products within CP packaging does not assume the use of recycled paper at all. The recycled content scenario assumes the 10% share of recycled paper in manufacturing of CP packaging.

The results of sensitivity analysis are presented at Figure 5. The results are presented for all GWP impact categories. The results for each one of the cases are presented for original case without any recycled paper content and potential case with 10% share of recycled paper use in CP packaging manufacturing (denoted by “Rec 10%” on the Fig. ***5***). Note that in order to get clearer overview of recycled content impact the assessment is made for the packaging life cycle only. The only exception for this rule is research case no. 5 with teabag box – the results of recycled content scenario are calculated for whole LC of a product within packaging.



* Calculated for whole life cycle (and not for packaging only)

Fig. 5. Comparison of recycled content +10% scenario effect on CF impact categories

Source: own study.

Conclusions

It seems that the use of circular solutions in the life cycle of food products within CP packaging is in line with the policy of decreasing environmental impact. The two investigated solutions, namely increasing the recycling ratio and introducing recycled paper in manufacturing process, bring some improvements while overall CF is concerned.

presents the comparison of potential contributions of recycling and recycled content scenarios to overall CF. The impact is always positive and leads to the mitigation of some CO_2 eq. emissions. The range of impacts is significantly higher for recycled content scenario that spans from 0.8% to 11.3% decrease. The range of impacts for recycling scenario spans from 0,8% to 6,3%. It seems that the potential of introducing recycled content scenario is comparable with the results obtained for plastic packaging, like PET bottles (Ingrao & Wojnarowska, 2023).

Table 2. Comparison of overall impact of recycling and recycled content scenarios on overall CF

Specification	Impact of potential scenarios on overall CF	
	Recycling +10%	**Recycled content +10%**
CS1 Salami MetCP LC	-4.3%	-8.7%
CS2 Fruit rolls in CPP	-0.8%	-2.7%
CS3 LC Crackers CP	-1.2%	-11.3%
CS4 ChocTruf in CPp	-4.1%	-0.5%
CS5 LC Tea Box CP	-4.2%	-0.8%*
CS6 ChocTab in CP	-6.3%**	-5.9%

* Measured for whole life cycle impact (not for packaging only)
** Measured for packaging impact only (not for whole life cycle)

Source: own study.

In order to achieve the objectives of the recycling scenario the more complex scenario is required. It should certainly involve more stakeholders, including consumers, waste management and recycling companies, and waste logistics organizations. In case of recycled content scenario, the focus is more on the manufacturer and recycling industry. It seems that the decision-making power belongs to the manufacturing company in recycled content scenario, while it is more public oriented in recycling scenario.

The packaging industry is struggling to achieve significant reduction of plastic packaging use, especially in a context of single use packaging, and is taking the potential of coated paper packaging development as its serious alternative. Achieving required technical parameters and barrier properties would be a first step only, while achieving improved sustainability and circularity characteristics should be a final goal., It is important to mention, that currently presented results should contribute to shed some light on the coated paper packaging for food industry use and is not definite argument for its introduction. In fact, the true challenge is related to commercialization of most promising solutions and working on its further development within joint ventures of industrial partnership between packaging manufacturers and food producers and different stakeholders, including such groups as R&D units, financing institution or market research units.

Since the major issue in assessing the effectiveness of circular economy strategies is to avoid focusing on one part of the value chain (Niero & Hauschild, 2017) the recommended solution from the investigated cases should include introduction of both scenarios simultaneously. Recycling scenario could provide secondary resources for recycled content scenario. Such an approach could also result in building the bridge and market relationship between key stakeholders involved. As a result, it could also contribute to opening new sources of market advantage and competitiveness.

Acknowledgements

The paper presents partial results from the project titled *Functional and recyclable coated paper packaging for food products (REPAC²)* that is co-financed by Polish National Centre for Research and Development (NCBR) within CORNET initiative.

References

Bocken, N. M. P., de Pauw, I., Bakker, C., & van der Grinten, B. (2016). Product design and business model strategies for a circular economy. *Journal of Industrial and Production Engineering*, *33*(5), 308-320. https://doi.org/-10.1080/21681015.2016.1172124

EC. (2015). *Closing the Loop – an EU Action Plan for the Circular Economy*. https://eurlex.europa.eu/-resource.html?uri=cella%0Ar:8a8ef5e8-99a0-11e5-b3b7-01aa75ed71a1.0012.02/DOC_1&format=PDF

EllenMacArthur Foundation. (2013). *Towards the circular economy: Economic and business rationale for an accelerated transition*.

European Commission. (2019). *The green deal: sustainable industry*. Https://Ec.Europa.Eu/Commission/Presscorner/Api/Files/Attachment/859389/Sustainable_industry_nl.Pdf.

European Commission DG Environment. (2010). *Product Carbon Footprinting – a study on methodologies and initiatives. Final report*.

Fields, & Simmons. (2014). *Product Carbon Footprinting for Beginners Guidance for smaller businesses on tackling the carbon footprinting challenge*. https://www.bsigroup.com/LocalFiles/en-GB/standards/BSI-sustainability-guide-product-carbon-footprinting-for-beginners-UK-EN.pdf

Geissdoerfer, M., Savaget, P., Bocken, N.M.P., & Hultink, E. J. (2017). The Circular Economy – A new sustainability paradigm? *Journal of Cleaner Production*, *143*, 757-768. https://doi.org/10.1016/j.jclepro.2016.12.048

Ingrao, C., & Wojnarowska, M. (2023). Findings from a streamlined life cycle assessment of PET-bottles for beverage-packaging applications, in the context of circular economy. *Science of The Total Environment*, *892*, 164805. https://doi.org/10.1016/j.scitotenv.2023.164805

ISO. (2018). *ISO 14067:2018 – Gazy cieplarniane -- Ślad węglowy wyrobów -- Wymagania i wytyczne dotyczące kwantyfikacji*.

Niero, M., & Hauschild, M.Z. (2017). Closing the Loop for Packaging: Finding a Framework to Operationalize Circular Economy Strategies. *Procedia CIRP*, *61*, 685-690. https://doi.org/10.1016/j.procir.2016.11.209

PRé Sustainability. (2022). *SimaPro database manual – Methods library*. Https://Support.Simapro.Com/s/-Article/SimaPro-Methods-Manual.,

Tomasz Nitkiewicz, & Cappelletti, G.M. (2022). Verification of Circular Economy solutions and sustainability of products with Life Cycle Assessment. In M. Wojnarowska, M. Ćwiklicki, & C. Ingrao (Eds.), *Sustainable Products in the Circular Economy* (1sr Edition). Routledge.

van Stijn, A., Malabi Eberhardt, L.C., Wouterszoon Jansen, B., & Meijer, A. (2021). A Circular Economy Life Cycle Assessment (CE-LCA) model for building components. *Resources, Conservation and Recycling*, *174*, 105683. https://doi.org/10.1016/j.resconrec.2021.105683

WEF. (2016). *White Paper: Design and Management for Circularity – the Case of Paper*. www.weforum.org

CONDITIONS FOR THE MANAGEMENT OF BY – PRODUCTS OF CHOKEBERRY FRUIT PROCESSING IN THE OPINION OF POLISH FOOD PRODUCERS

Agnieszka Piekara*[1], Małgorzata Krzywonos[1], Bogdan Pachołek[2], Sylwia Sady[3], Alfred Błaszczyk[3], Stanisław Popek[4], Justyna Syguła-Cholewińska[5], Tomasz Sawoszczuk[5]

[1]Department of Process Management, Faculty of Management,
Wroclaw University of Economics and Business, Wroclaw, 53-345 Poland
[2]Department of Product Marketing, Institute of Marketing,
Poznan University of Economics and Business, Poznan 61-875 Poland
[3]Department of Natural Science and Quality Assurance, Institute of Quality Science,
Poznan University of Economics and Business, Poznan, Poland
[4]Department of Food Product Quality, Institute of Quality Sciences and Product Management,
Cracow University of Economics, Cracow, Poland
[5]Department of Microbiology, Institute of Quality Sciences and Product Management,
Krakow University of Economics, Cracow, Poland
**Corresponding Author e-mail: agnieszka.piekara@ue.wroc.pl*

DOI: 10.56091/CTQS.Innov-15

Abstract

For many years, research and work have been carried out on the possibilities of managing agricultural and food industry waste. Such direction is the production of high-quality food products with the use of such by-products. The approach used in the study to introduce a new product or group of products was design thinking. The first stage of such an approach is getting to know the user thoroughly (emphathisation). As part of empathizing, the focus was also on getting to know the opinion and experiences of industry representatives on chokeberry pomace.

The research aimed to determine key opportunities and problems related to the use of by-products of chokeberry fruit processing in the development of food products with additional functional features in relation to the examined industries.

The Individual In-Depth-Interview (IDI) method and the categorised interview questionnaire research tool were chosen. The study was conducted among experts on fruit, including chokeberry processing and food processing waste management (N=10, targeted sampling) in Poland.

The identified problems are related to the lack of repeatability of raw material parameters, including the amount of antioxidants and the need for proper storage conditions, and the possible impurities. The opportunities identified include, among others, a large amount of raw material, availability of domestic pomace, and potentially high material value (high in polyphenols).

Keywords: chokeberry, chokeberry by-products, chokeberry pomace, IDI, new products upcycling

Introduction

Food producers focus their efforts on meeting the current expectations of the modern consumer, oriented, among others, on the pro-health effects associated with food consumption. Biologically active substances derived from fruit and vegetable processing by-products, especially by-products of berry fruit processing, arouse great interest. The main groups of waste from fruit and vegetable processing are pomace from the production of juices and concentrates, residues from peeling vegetables and sorting residues (Amaya-Cruz et al., 2015; Padayachee et al., 2017).

In Poland, over 400,000 tons of waste are generated annually in the fruit and vegetable processing industry. A significant part of them is irrationally stored and underutilized, posing potential environmental hazards and contributing to waste. Activities to minimize the waste of raw materials and by-products of food production, in particular towards the valorization of by-products, correspond to the ideas of sustainable development and consumption, sustainable diet and corporate social responsibility, as well as the circular economy promoted at the EU level and the implementation of commitments adopted under the Union of Innovation (Pacholek, 2020). Sustainable Development Goal 12.3 advocates for reducing food waste and food losses in supply chains to achieve sustainability by 2030, especially at the retail and consumption levels (SDG goals). Therefore, the secondary use of by-products can bring economic and ecological benefits.

The food sector is one of the most important and fastest-growing branches of the Polish economy. Poland is a significant producer of berries in the EU, including strawberries, blueberries, raspberries and chokeberries. Poland is one of the world leaders in producing chokeberries and an exporter of its semi-finished products (Łakomiak & Zhichkin, 2020). In 2021, the value of chokeberry exports in the world amounted to USD 4.14 billion. The export leader was Canada, with a share of 10.59%, worth USD 443.57 million, followed by Thailand, with a share of 9.03% and a value of USD 378.17 million, and Poland, with a share of 6.39% and a value of USD 267.77 million USD (TRIDGE, 2021). The chokeberry cultivation area in Poland has increased from 4.5 (2018) to 14.2 thousand ha (2022); at the same time, fruit production increased from 50.2 to 55.0 thousand tons. The production of concentrated chokeberry juices in 2020/21 and 2021/22 amounted to 6 and 7.8 thousand tones, respectively (IERiGŻ-PIB, 2022).

Chokeberry fruit waste is generated at each processing stage, including sorting and pressing the juice. At this last stage of the juice production process, pomace is produced in the amount of about 15% of the total amount of fruit, consisting of skins, seeds and tails. Fruit pomace contains a high content of bioactive substances (Jurendić, 2021).

Therefore, chokeberry pomace is one of the richest source of natural bioactive substances such as anthocyanins, polyphenols or proanthocyanidins, which can be used in the food, pharmaceutical and cosmetic industries (Strucks 2016; Jurendić, 2021). In addition, chokeberry pomace, due to the content of simple and complex carbohydrates, can be a raw material for producing biofuels such as bioethanol, biohydrogen or biogas.

Due to the high water content (70-80%) and the high drying costs, the majority of the chokeberry pomace in Poland is sent to composting plants or as a raw material for biogas production. Only a small amount undergoes the drying process or is used as a raw material for wine in the production of natural dyes (anthocyanins), fruit teas, dietary fiber preparations and for the production of dietary supplements (Łaba, 2012). A few research is being conducted to increase the use of chokeberry fruit pomace in various applications, such as:

- production of breakfast cereals (Schmid et al., 2020),
- addition to meat products (Tamkute et al., 2021; Babaoğlu et al., 2022),
- feed additive (Sosnówka-Czajka & Skomorucha 2021),
- a component of coatings and intelligent packaging that increases the durability of food products (Wang et al., 2023; Oun, Shin, & Kim 2022; Sady et al., 2021).

The main goal of the study was to assess the management of by-products from chokeberry fruit processing according to the Polish food producers. Based on the previous literature review on the by-products of berry fruit processing (including chokeberry) and possible scenarios for their utilization, two specific objectives of the study were planned. The first specific objective included identifying functioning solutions for managing by-products of chokeberry fruit processing in the examined industries. The second objective was to identify key opportunities and challenges related to using by-products of chokeberry fruit processing to develop food products with additional functional features concerning the examined industries. An essential aspect of the work was the inclusion of the most important stakeholders in the research, who determine the pace and when it will be possible to increase the use of by-products in food processing.

Methods

Ten experts representing food industry enterprises (study including the management of by-products of berry fruit processing) participated in the survey. The selection of respondents was intentional., Individuals were deemed eligible to participate based on the following criteria:

- dynamic development of product categories within industries,
- diversity in terms of the size of market entities offering or using similar products,
- high innovativeness of processes and products within the surveyed industries.

The study was conducted using the method of in-depth individual interviews (IDI) among technologists and managers co-responsible for product and process management representing the surveyed enterprises. The interviews were conducted according to a designed questionnaire – an interview scenario that allowed the respondents to express themselves freely in terms of the desired topics. The research timeframe covered the period from December 2022 to March 2023. The interviews were recorded and then transcribed.

The first area of the study was to diagnose the functioning solutions for managing by-products of chokeberry fruit processing in the surveyed industries. The second area of the study was identifying key opportunities and problems related to using by-products of chokeberry fruit processing in developing food products with additional functional features concerning the examined industries.

The conducted research provided highly interesting results regarding the diagnosis of functioning solutions for managing by-products of chokeberry fruit processing and identifying key opportunities and problems in using chokeberry pomace in developing food products with additional functional features.

Results and discussion

Pomace utilization is one of the main concerns of the agro-fruit industry (Iqbal et al., 2021). Therefore, the first area of the study was to diagnose the functioning solutions for managing by-products of chokeberry fruit processing. According to the representatives of the entities participating in the IDI, the directions of development are primarily influenced by the quality of pomace, as well as the current situation in the food market. Among the surveyed entities, the vast majority of entities replied that they use chokeberry pomace in the form of dried powder as a food additive and as an ingredient of animal feed (Fig. 1).

The multidirectional positive influence of chokeberry, confirmed by scientific research, makes products derived from it successfully used for health purposes and as an auxiliary treatment for many civilizational diseases. The investigated entities emphasized that processing chokeberry fruits produces a large amount of pomace rich in bioactive compounds, which can be further used as secondary raw material., Approximately 800 tons of pomace are produced annually during juice pressing, from which 300-500 tons of dried pomace are obtained yearly. Attempts are being made to extract chokeberry seeds from the pomace, but technologically, this is a difficult process; about 700 kg of seeds can be obtained from 100 tons of pomace. According to companies' representatives, adding chokeberry pomace also enhances the dietary value of feed mixtures by increasing the amount of anthocyanin monomers and sorption capabilities.

The reprocessing of pomace by using them, among others, as a component of functional food for humans and animals, medical food, dietary supplements, and cosmetics, aligns with the goal of combating food waste within the framework of a circular economy strategy and also contributes to the growth of economic and ecological benefits for companies (European Commission, 2020; Venskutonis, 2020; May & Guenther, 2020).

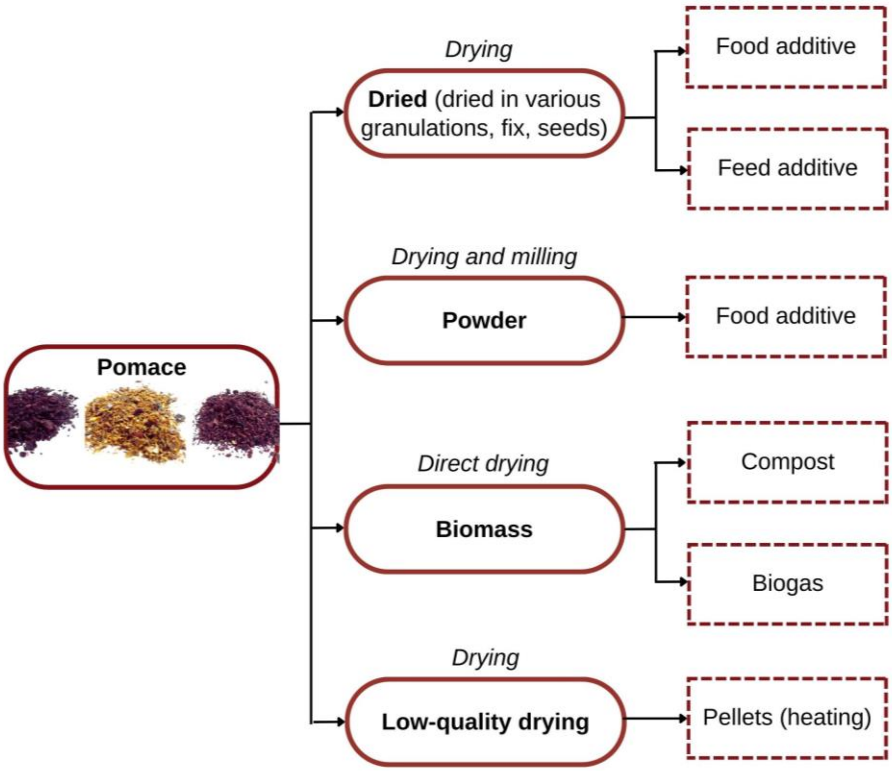


Fig. 1. Declared directions of use of chokeberry pomace by Polish food producers

Source: own study.

The half of the entities indicated the utilization of fruit processing waste for biogas production (Fig. 1). Regarding the utilization of fruit processing waste for biogas production, it was also found that they play an essential role in producing so-called "green energy," promoted worldwide in response to growing concerns related to climate change and the demand for electricity. Thanks to their decentralized nature and regional investment structure, they can significantly contribute to the sustainable development of rural areas and create new financial prospects for farmers and processors. This was particularly emphasized by two representatives. On the other hand, the acquisition of fruit processing waste is characterized by seasonality and diverse quality of waste, which significantly hinders sustainable development towards biogas. Due to the high water content in fresh pomace, this direction is problematic as it poses a high risk of biological contamination. Therefore, waste must often undergo preservation treatments (e.g., drying, lyophilization).

It was found that two surveyed companies exclusively utilize chokeberry pomace for energy purposes. They used it to produce fuel pellets or as a component of fuel pellets mixed with sorted grain and oak sawdust or oat bran (Fig. 1). It was also found that chokeberry pomace pellets are an efficient and environmentally friendly heating solution. The raw material has good calorific value, especially when dried and combined with wood sawdust. This fuel type aligns with the principles of a sustainable economy, where every waste should be treated as a potential resource as much as possible.

During the interviews, the participating companies were also asked to propose possible innovative solutions for using chokeberry pomace. One attractive solution would be to obtain concentrated extracts that can serve as an alternative to synthetic antioxidants, effectively protecting the digestive tract and tissues from the harmful effects of oxidation processes. During pressing, most of the coloring compounds remain in chokeberry pomace, making them an excellent raw material for producing anthocyanin dyes. Therefore, it would be worthwhile to focus on developing innovative vegetarian/vegan products or nutritious fruit puree beverages. The surveyed companies considered the above solution promising, with high market potential.

The quality of berry fruits (as well as other plants), expressed by the content of vitamins, minerals, and polyphenols, including anthocyanins, depends closely on climatic conditions, fertilization, and irrigation during cultivation (Di Vittori et al, 2018; Zheng, 2019). In the case of chokeberry, the presence of a high amount of polyphenolic compounds, which influence the antioxidant properties of the derived products, is crucial., This variability of raw material parameters, i.e., pomace obtained from juice production plants, was indicated as a fundamental problem (Table 1). Meeting the minimum requirements specified by the recipient is crucial when planning production using pomace as a raw material.

Table 1. Challenges and opportunities expressed by industry experts

Challenges	Opportunities
The high price of frozen raw material	A large amount of raw materials on the market
Sugar content	Sugar content
High drying costs	Many possible directions of use
The need to quickly protect pomace after fruit processing against the development of microflora	The durability of frozen raw material
Low quality of dried raw material (reduced content of polyphenols as a result of drying at elevated temperature)Unstable market situation	

Source: own study.

The high carbohydrate content in chokeberry pomace has been indicated as a disadvantage and an advantage. It benefits when used in brewing or winemaking as a carbon source for yeast. However, sugars hinder the production of dry extract. For products rich in dietary fiber prepared with chokeberry pomace, the low sugar content allows for safe use by people suffering from or at risk of diabetes (Jurendić & Ščetar, 2021; Yamane, 2017).

Drying the pomace is one of the primary methods of preserving the material (Struck et al., 2026). However, the drying process has drawbacks, as was pointed out by the experts participating in the study. Firstly, there are high drying costs (Fakhreddin, 2021). When using a drum dryer with a capacity of 1000 kg/h and a power of about 2500 kW, approximately 260-280 m^3 of natural gas per hour or 240-250 litres of fuel oil are consumed, significantly impacting the cost of the dried pomace. Another problem is the thermal conditions during drying, as high temperatures can degrade bioactive compounds, which are valuable components often determining the further use of dried pomace. As was expressed by study participants, freezing the pomace is another option for preserving the material from microbial contamination and biomass degradation. However, it poses challenges for entrepreneurs, including the cost of transportation (maintaining refrigeration conditions) and the need for immediate use in production or expensive storage. Nevertheless, freezing ensures the preservation of the quality characteristics of the pomace for a longer period, thus reducing potential losses of this raw material.

Experts also pointed to the problem of an unstable market situation. It results, among others, the unprecedented increases in imports of berries (and frozen berries) from Ukraine in the 2022/2023 season. This hinders the functioning of enterprises and affects the profitability of production.

The high availability and quantity of chokeberry pomace can be a reason to look for new solutions for using this raw material in food production. For several years, the fashion for sustainable consumption has been noticeable among consumers (Trudel, 2019). Observing other current trends, including the increasing number of vegetarians and vegans (Onwenzen, 2020), it can be assumed that the drive to use by-products will find buyers.

Summary

The results of the qualitative study on the assessment of the management of by-products of chokeberry fruit processing in the opinion of Polish food producers clearly indicated that, according to the surveyed enterprises, it is necessary to take specific horizontal measures that will allow minimizing chokeberry pomace by implementing full recovery and reuse of these by-products, in particular treating them as a potential source of secondary raw materials.

Despite the high pro-health value of chokeberry pomace, a significant part of them is used as a food additive, an ingredient of animal feed or is treated as waste (biogas production or composted). The industry can articulate the challenges it sees but, at the same time, declares its willingness to manage by-products. In this way, both possible economic and environmental benefits are recognized. This awareness can be perceived as an excellent opportunity to implement new solutions towards the circular economy through the use of fruit pomace.

Acknowledgements

"Publikacja została sfinansowana ze środków Uniwersytetu Ekonomicznego w Poznaniu, Uniwersytetu Ekonomicznego w Krakowie, Uniwersytetu Ekonomicznego we Wrocławiu – umowa ramowa o współpracy CRU-6414/2021”.

"The publication has been financed by the Poznań University of Economics nad Business, Krakow University of Economics, Wroclaw University of Economics and Business – framework cooperation agreement CRU-6414/2021"

References

Amaya-Cruz, D.M., Rodríguez-González, S., Pérez-Ramírez, I.F., Loarca-Piña, G., Amaya-Llano, S., Gallegos-Corona, M.A. i Reynoso-Camacho, R. (2015). Juice by-products as a source of dietary fibre and antioxidants and their effect on hepatic steatosis. *Journal of Functional Foods*, *17*, 93-102. doi:10.1016/j.jff.2015.04.051

Babaoğlu, A.S., Unal, K., Dilek, N.M., Poçan, H.B., Karakaya, M. (2022). Antioxidant and antimicrobial effects of blackberry, black chokeberry, blueberry, and red currant pomace extracts on beef patties subject to refrigerated storage. *Meat Science*, 187, 108765, https://doi.org/10.1016/j.meatsci.2022.108765.

Di Vittori, L., Mazzoni, L., Battino, M., & Mezzetti, B. (2018). Pre-harvest factors influencing the quality of berries. *Scientia Horticulturae*, 233, 310-322. https://doi.org/10.1016/j.scienta.2018.01.058

European Commission. (2020). New Circular Economy Action Plan for a cleaner and more competitive Europe. European Commission, Brussels. Retrieved March 16, 2023. https://eur-lex.europa.eu/legalcontent/EN/TXT/?-qid=1583933814386&uri=COM:2020:98:FIN

Fakhreddin Salehi (2021) Recent Applications of Heat Pump Dryer for Drying of Fruit Crops: A Review, *International Journal of Fruit Science*, 21:1, 546-555, DOI: 10.1080/15538362.2021.1911746

Institute of Agricultural and Food Economics – National Research Institute. (2022). *Fruit and vegetable market – state and prospects.* December 2022. Warsaw

Iqbal, A., Schulz, P. i Rizvi, S. S. H. (2021). Valorization of bioactive compounds in fruit pomace from agro-fruit industries: Present Insights and future challenges. *Food Bioscience* 44, 101384. https://doi.org/10.1016/j.fbio.-2021.101384

Jurendić, T., & Ščetar, M. (2021). Aronia melanocarpa Products and By-Products for Health and Nutrition: A Review. *Antioxidants*, 10(7), 1052. https://doi.org/10.3390/antiox10071052

Łaba, S. (2012). Proekologiczne działania w zakresie zagospodarowania odpadów w przemyśle owocowo-warzywnym. *Roczniki Naukowe Stowarzyszenia Ekonomistów Rolnictwa i Agrobiznesu*, 14(5), 133-138.

Łakomiak, A., & Zhichkin, K.A. (2020). Economic aspects of fruit production: A case study in Poland. *BIO Web of Conferences*, *17*, 00236. https://doi.org/10.1051/bioconf/20201700236

May, N. & Guenther, E. (2020). Shared benefit by Material Flow Cost Accounting in the food supply chain – The case of berry pomace as upcycled by-product of a black currant juice production. *Journal of Cleaner Production*, 245. https://doi.org/10.1016/j.jclepro.2019.118946

Onwezen, M.C., Kunz, M.C., Dagevos, H., & Verain, M.C.D. (2020). Consumers more inclined to eat 'alter-native'proteins compared to 2015. Wageningen University & Research.

Oun, A.A., Shin, G.H., Kim, J.T. (2022). Antimicrobial, antioxidant, and pH-sensitive polyvinyl alcohol/chitosan-based composite films with aronia extract, cellulose nanocrystals, and grapefruit seed extract. *International Journal of Biological Macromolecules*, 213, 381-393, https://doi.org/10.1016/j.ijbiomac.2022.05.180.

Pachołek, B. (2020). Development Directions for Food Design Research Using by-Products in the Perspective of Innovative European Economy. [in:] *Innovations in food quality development*, ed. P. Dmowski, 105-116

Padayachee, A., Day, L., Howella, K. i Gidley, M.J. (2017). Complexity and health functionality of plant cell wall fibers from fruits and vegetables. *Critical Reviews in Food Science and Nutrition*, *57*(1), 59-81. doi:10.1080-/10408398.2013.850652

Schmid, V., Steck, J., Mayer-Miebach, E., Behsnilian, D., Briviba, K., Bunzel, M., Karbstein, H.P., Emin, M.A. (2020). Impact of defined thermomechanical treatment on the structure and content of dietary fiber and the stability and bioaccessibility of polyphenols of chokeberry (Aronia melanocarpa) pomace. *Food Research International*, 134, 109232, https://doi.org/10.1016/j.foodres.2020.109232.

Sady, S., Błaszczyk, A., Kozak, W., Boryło, P., Szindler, M. (2021). Quality assessment of innovative chitosan-based biopolymers for edible food packaging applications. *Food Packaging and Shelf Life*, 30, 100756, https://doi.org/-10.1016/j.fpsl.2021.100756.

Sosnówka-Czajka, E., Skomorucha, I. (2021). Effect of supplementation with dried fruit pomace on the performance, egg quality, white blood cells, and lymphatic organs in laying hens. *Poultry Science*, 100(9), 101278, https://doi.org/10.1016/j.psj.2021.101278.

Struck, S., Plaza, M., Turner, C., & Rohm, H. (2016). Berry pomace – a review of processing and chemical analysis of its polyphenols. *International Journal of Food Science & Technology*, 51(6), 1305-1318. https://doi.org/-10.1111/ijfs.13112

Tamkutė, L., Vaicekauskaitė, R., Melero, B., Jaime, I., Rovira, J., Venskutonis, P. R. (2021). Effects of chokeberry extract isolated with pressurized ethanol from defatted pomace on oxidative stability, quality and sensory characteristics of pork meat products. LWT, 150, 111943, https://doi.org/10.1016/j.lwt.2021.111943.

TRIDGE (2021). Overview of Global Aronia Market. Pobrano 9 lipca 2023 z: https://www.tridge.com-/intelli-gences/aronia-chokeberry

Trudel, R. (2019). Sustainable consumer behavior. *Consumer Psychology Review*, 2(1), 85-96. https://doi.org/-10.1002/arcp.1045

UN Sustainable Development Goals Knowledge Platform (2021), Sustainable Development Goals (12.05.2023)

Venskutonis, P.R. (2020). Berries. W: Ch.M. Galanakis (red.), *Valorization of Fruit Processing By-Products*. (s. 95-125). Academic Press. https://doi.org/10.1016/b978-0-12-817106-6.00005-8

Wang, C., Cao, J., Liu, T., Jin, L., Hang, C., Zhang, C., Qian, X., Jiang, D., Jiang, C. (2023). Preparation and characterization of antioxidant and pH-sensitive films based on arrowhead (*Sagittaria sagittifolia*) starch, κ-carrageenan and black chokeberry (*Aronia melanocarpa*) extract for monitoring spoilage of chicken wings. *International Journal of Biological Macromolecules*, 224, 544-555, https://doi.org/10.1016/j.ijbiomac-.2022.10.143.

Yamane, T., Kozuka, M., Wada-Yoneta, M., Sakamoto, T., Nakagaki, T., Nakano, Y., & Ohkubo, I. (2017). Aronia juice suppresses the elevation of postprandial blood glucose levels in adult healthy Japanese. *Clinical Nutrition Experimental*, 12, 20-26.

Zheng, J., Huang, C., Yang, B., Kallio, H., Liu, P., & Ou, S. (2019). Regulation of phytochemicals in fruits and berries by environmental variation – Sugars and organic acids. *Journal of Food Biochemistry*, 43(6), e12642. https://-doi.org/10.1111/jfbc.12642

ATTITUDES AND BEHAVIOR OF POLISH CONSUMERS ON THE NANOPRODUCTS MARKET

Piotr Przybyłowski*, Natalia Żak, Milena Magdziarczyk

Department of Quality Management, Faculty of Management and Quality Science,
Gdynia Maritime University, Gdynia 81-225, Poland
**Corresponding Author e-mail: p.przybylowski@wznj.umg.edu.pl*

DOI: 10.56091/CTQS.Innov-16

Abstract

The subject of the study was a group of 260 respondents diverse in terms of gender, age and education. The aim of the study was to examine the extent to which Polish society uses nanoproducts in everyday life, in what spheres of life and with what awareness. The opinion of consumers was examined using a survey questionnaire, which contained 16 questions.

Consumers rarely use food-related nano-products. 31% of respondents are not interested in food packaging containing nanoparticles. On the other hand, consumers are eager to use nano-products used in medicine and household. A large percentage of consumers feel anxious about the harmful effects of nano-products. A high percentage of respondents stated that nano-products have not been sufficiently tested in terms of safety. The information that the product contains nanoparticles generates a sense of insecurity in them. They also believe that such goods can have a detrimental effect on health and the environment. However, consumers are interested in a new group of products manufactured with the use of nanotechnology, and they place a lot of hope in them, mainly in the field of pharmacotherapy and cosmetology.

Keywords: consumer, nanoproducts, attitudes, behaviors

Introduction

Over the last decade, there has been a significant development of a new science – nanotechnology. Nanotechnologies are no longer associated only with the object of scientific research, but are becoming more and more often noticed on the market and are addressed to a wide range of consumers. The intensive development of nanotechnology and nanomaterials may revolutionize all aspects of production and production of goods and services in the world. The market for nano-products is relatively young and it is not entirely clear how many nano-products we deal with as consumers and how the number and types of products have evolved over time.

Nano-products are a relatively new group of products and do not yet have a unified definition. The term consists of the noun product with the prefix nano-. Nano is derived from the Greek word nanos, meaning dwarf, and in terms of the SI system, it is one billionth of a size. Nano-products contain structures whose one dimension does not exceed 100 nm, i.e., 10^{-9} m, so such a structure is 500 times smaller than the thickness of a human hair. The popularity of nanostructures is primarily associated with different properties compared to classical materials, which may be due to the relatively larger surface area of nanomaterials in relation to the same mass of material produced in a larger form. It may affect:

- chemical reactivity,
- resilience,
- electrical properties.

Secondly, it may be caused by the dominance of quantum effects in the behavior of matter at the nanoscale, shaping the optical, electrical and magnetic behavior of these types of materials.

In everyday life, nanomaterials provide new functions for many products. For example, they increase the performance of batteries and many electronic products, such as touch screens. Their properties depend on the type of nanomaterials. Various nanomaterials have been used for a long time in cosmetics, sunscreens, disinfectants, dyes and fillers. Among the nanomaterials characterized by the greatest universality, the following stand out: nanosilver, nanocarbon, carbon nanotubes and nanogold (EUON, 2023).

Nano-products are present in almost all many spheres of our lives and sectors of economic activity, they can be found:

- in medicine are used (to improve the physicochemical properties of the active substance) (EUON, 2023; Pattekari et al., 2011).
- in cosmetics used nanoparticles have the possibility of prolonged release and protection of unstable groups against their degradation, and can penetrate biological barriers (Cevc, 1996; Durán, Teixeira & Marcato, 2011; Santana & Zanchetta, 2011).
- in industrial chemistry and construction, they are used to improve durability and provide new properties, e.g., resistance to water and dirt – "easy to clean" coatings, resistance to microbes and scratch resistance. Currently, the most important nanomaterials for the paints and coatings industry are titanium dioxide and silicon dioxide at the nanoscale.) (Kaiser, Zuin & Wick, 2013; EUON, 2023).

- in agriculture, nanoparticles are used to nanoformulate fertilizers, breaking barriers of efficiency and nutritional quality through bionanotechnology. They are used in surveillance and pest and disease control.

Knowledge in the field of nanotechnology allows us to understand the mechanism of host-parasite interaction on a molecular scale. Nanoparticles are used to develop new generations of pesticides and safe carriers, preservation and packaging of food, production of food additives. Nanoparticles also help to strengthen natural fiber, remove pollutants from soil and water reservoirs, and improve the durability of vegetables and flowers. They are used to improve soil fertility, reclaim saline soils, control the acidification of irrigated land and stabilize surfaces prone to erosion (Diamond, 2004; Ditta, 2012).

The application of nanotechnology in the discipline of food science and nutrition concerns: nanosensors and biosensors (food quality and safety control), food processing (nanofiltration, nanocapsules), new products (packaging, transport, formulation, DNA recombination) (Rashidi & Khosravi-Darani, 2011).

On the other hand, environmental research on the impact of nanotechnology on the environment follows two separate paths. The first takes the view that nanotechnology has environmental benefits: innovative repair alternatives, improved catalysts (using green chemistry), better sensors to detect pollutants. The second takes a precautionary approach, bearing in mind the intended use, potential toxicity, risks and health effects of nano-products (Hara et al., 2004; Choudhary et. al, 2005; Adams, Lyon & Alvarez, 2006).

Nanotechnologies can cause many changes in living organisms, people are exposed to nanoparticles because they are produced by natural processes. The production, use, disposal and processing of waste products containing nano-products are the main causes of the release of nanoparticles in the original or modified form into the environment (Buzea, Pacheco & Robbie, 2007).

A wide range of research on the safe use of nanoproducts, along with the assessment of consumer opinions, is conducted worldwide (Lo et al., 2012; Cinelli et. al, 2016; Foss Hansen et al., 2016; Mallakpour et al., 2022) and in Poland (Jasiczak, 2009; Jasiczak, 2010; Chomaniuk & Przybyłowski, 2014; Przybyłowski et.al., 2016). Scientific articles cover the issue in various aspects. Starting with the history and development of nanomaterials and nanoproducts (Baya et al., 2020; Saritha et al., 2022; Malik et al., 2023). After safety research (Talebian et al., 2021), commercialization of these products (Lo et al., 2022) and ecological aspects (Som et al., 2010; Zahra et al., 2022).

The possibilities of using nanomaterials and nanoproducts are practically unlimited (He et al., 2019; Mohammad et al., 2022; Haleem et al., 2023), which makes many authors interested in the topic of nanoproducts and the social aspect of their reception by consumers. However, technology and the product market are changing very quickly. Similarly, new generations, often with different preferences, are becoming consumers. For example, Jasiczak's research conducted in 2007-2008 showed that consumers are essentially favourably disposed towards nanotechnology. The majority of study participants were for the development of nanotechnology as long as it served the needs of humans and the environment. The responders valued potential benefits of nanotechnology very highly, mainly in medicine, computer science, environmental conservation, and also in products of everyday use which are not in direct contact with the body (Jasiczak, 2009).

In the light of the above literature knowledge, the aim of this work was to investigate, to what extent Polish society uses nano-products in everyday life, in what spheres of life and with what awareness.

Materials and methods

In the survey, an original questionnaire was used, which contained 16 questions, both single and multiple choice. The form of research was an online questionnaire.

The surveyed group consisted of 302 people living in the Tri-City and its vicinity, in the Pomeranian Voivodeship. These people were randomly selected for the study. Among the group of 362 people, 102 people had never heard of the definition of nanoproducts (41% of women, 34% of men). Therefore, these people were excluded from further analysis.

The exact characteristics of the surveyed population are presented in Table 1. The survey was conducted in the last quarter of 2021 and in the first quarter of 2022. The results were statistically analyzed using Statistica 13 (Stat-Soft).

Table 1. Characteristics of the study population

N = 260 person	%	N = 260 person	%	N = 260 person	%	N = 260 person	%
sex		age		place of residence		education	
woman	80%	under 25	60%	village	26%	basic	3%
man	20%	25-40 years old	34%	city up to 50,000	19%	gymnasium	2%
		41-65 years	5%	city of 50-100 thousand	7%	high school	39%
		66 years and over	1%	city over 100,000	48%	university studies	56%

Source: own study.

Results and discussion

Almost 38% of respondents aged over 41 had not come across the term "nano-product" before. Almost half of the respondents – 48.5% believe that nano-products contain structures whose one of the dimensions does not exceed 100 nm, i.e., 10^{-9} m. A large group of respondents, as many as 36.9%, admitted that they did not know the answer to the question of what size structures should be in nanoproducts.

More than half of the respondents (60.8%) indicated that they were unable to determine whether nano-products had been sufficiently tested in terms of their safety. On the other hand, 22.3% of the respondents declared that nano-products were not sufficiently tested. Only 16.9% of respondents claim that nano-products are sufficiently tested.

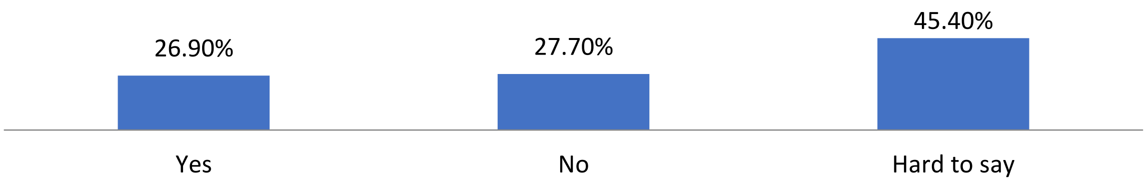


Fig. 1. The willingness of consumers to buy nano products more expensive than classic products

Source: Own study.

Only 26.9% of the survey participants declared that they are willing to pay more for a nano-product compared to a classic equivalent. This claim was supported by as many as 75% of women and it may be due to the growing popularity of nano-cosmetics as "products of the future". According to 27.7% of respondents, goods manufactured with the use of nanotechnology are not attractive enough to pay more for them. On the other hand, 45.5% of the respondents did not clearly specify their answer (Fig. 1).

More than half of the respondents (56.2%) admitted that the information that the product contains nanoparticles arouses their interest. Only 14.6% of consumers are not interested in such information. 30% of the respondents agreed with the statement that the information that the product contains nanoparticles translates into an increase in the attractiveness of the product (23.1% agree and 6.9% strongly agree). 39.2% of consumers were unable to clearly decide whether the product in their eyes becomes more attractive with nanoparticles in its composition. For 30.8% of the respondents, such information does not translate into an increase in the attractiveness of the product. The message that the product contains nanoparticles evokes a sense of security in only 10.78% of consumers. On the other hand, for 40.8% of the respondents, such information does not evoke a sense of security.

In 33.1% of the respondents, the manufacturer's declaration that the product contains nanoparticles generates fear that the product may be dangerous to health. The manufacturer's message that the product contains nanoparticles was indifferent to 21.6% of the respondents, the answer "yes and no" was given by 34.6% of the respondents (Fig. 2).

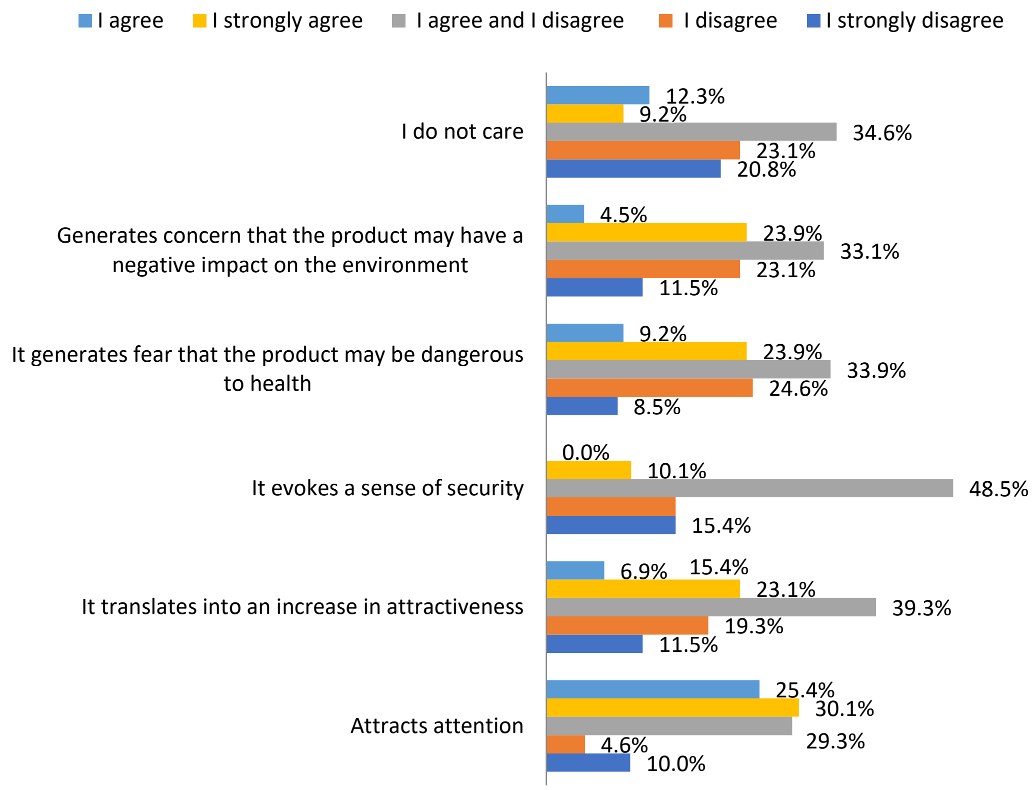


Fig. 2. Consumer feelings generated by information that a product contains nanoparticles

Source: own study.

The vast majority of respondents (66.9%) believe that the product packaging should contain information that the product contains nanomaterials. On the other hand, 29.2% had no opinion on this subject. Only 3.9% of respondents gave a negative answer. 66.3% of women and 70.4% of men declared that the information that the product contains nanoparticles should be included on the product packaging. The expectations of most consumers translate into EU restrictions, because the first mentions in EU law on the appropriate labeling of products containing materials with dimensions smaller than 100 nm appeared in 2009 and concerned cosmetic products, currently such arrangements also apply to food products and biocides.

Over 85% of consumers declared that they pay attention to the chemical composition of food products (yes, always – 39.2% and rather yes – 46.1%). Such a high result may be influenced by the popular promotion of a healthy lifestyle in recent years and the increasingly emphasized consumer awareness, focusing on the analysis of the composition of consumed products. Only 7.7% (rather not – 3.1% and never – 4.6%) of the respondents do not pay attention to the chemical composition of food products. 69.2% of respondents pay attention to the chemical composition of products for children (yes, always – 43.9% and rather yes – 25.4%). On the other hand, 20% of respondents declared that the chemical composition of products intended for children was not important to them, for 10.8% of respondents it is difficult to say. Another group of products for which the chemical composition was clearly important are cosmetics. For this group of products, 78.5% of respondents declared that they always check the composition of the cosmetic (Fig. 2).

The study shows that women check the chemical composition of food products for children and cosmetics more often than men and are more conscious consumers. This may affect the way some products are presented and the targeting of advertisements and promotions to a given group of recipients.

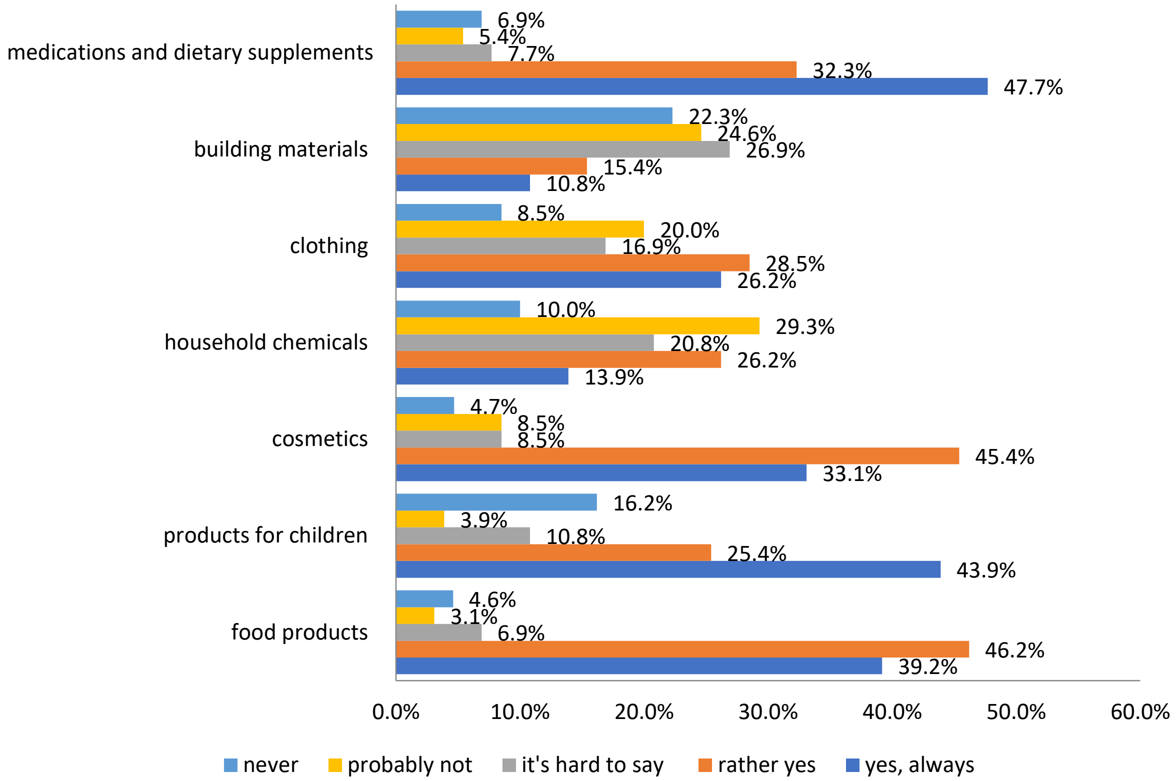


Fig. 3. The essence of the composition of products by product groups

Source: own study.

Another group of products analyzed was household chemicals. Significantly fewer people declared a systematic analysis of their composition – 13.6% of respondents. As many as 20.8% of respondents were unable to determine whether they pay attention to the composition of these products. On the other hand, 54.6% of people who took part in the survey declared that they check the composition of clothes (yes, always – 26.2% and rather yes – 28.5%). For 28.5% of respondents, the quality and type of material was not important. It can be assumed that the price, brand or appearance of selected products are more important for such buyers. 46.9% of buyers did not pay attention to the chemical composition of building materials. On the other hand, only 26.2% of the respondents declare that they pay attention to the chemical composition of the purchased building materials, of which the vast majority – 82.3% – are men.

The last group of analyzed products are drugs and dietary supplements. For 80% of the respondents, their composition was important and they tried to pay attention to it when shopping. This is true for both men and women, regardless of age group. The data is shown in Fig. 3.

When asked about the field in which nano-products are encountered, the respondents replied that they are most often found in medicine (56.2%) and the cosmetics industry (47.7%). The next indicated industry was the food industry (25.4%), followed by the electronics industry (21.5%). On the other hand, the energy industry was clearly the least popular (2.3%). The data is shown in Fig.4.

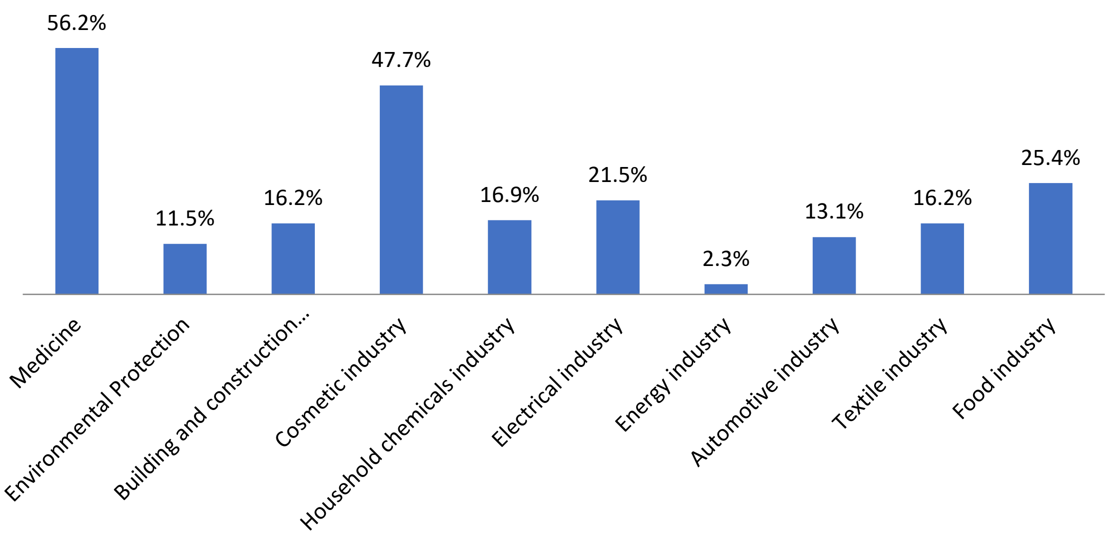


Fig. 4. Popularity of nanoproducts among consumers in different types of products

Source: Own study.

The vast majority of people (66.9%) were interested in or declared the use of pharmaceutical products. These were dressings made of nanofibers that rebuild tissues, dressings with nanosilver for hard-to-heal wounds and nanomedicines (drugs with a carrier facilitating the target transport of the drug). Among these people, 5.4% of users were dissatisfied with these products. Another group of articles evaluated by respondents was functional clothing and underwear with nanosilver and carbon nanotubes. Fabrics in which carbon nanotubes have been embedded are characterized by high electrical conductivity, tensile strength and are very good insulators. On the other hand, functional clothing with nanosilver has bactericidal properties, because silver ions are a natural agent that slows down the growth of bacteria, which translates into reducing the formation of unpleasant odors. 42.3% of respondents were interested in or had such articles. Only 4.6% of users would not buy them again. One third of the respondents declared that they were not interested in clothing produced with the use of nanotechnology.

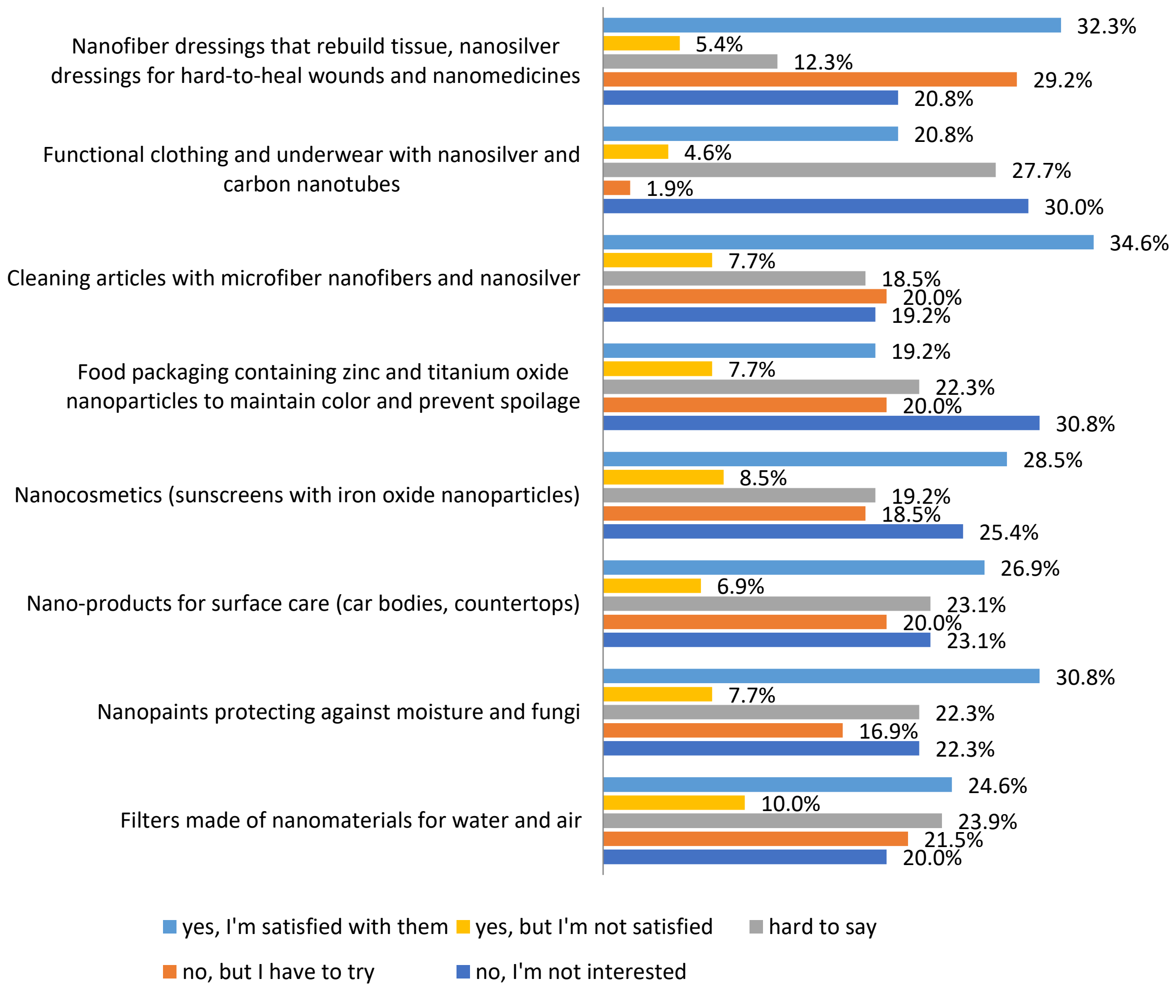


Fig. 5. Consumer interest in nano-products

Source: own study.

The next group of products assessed by the respondents were household products – intended for cleaning with microfiber nanofibers and nanosilver. According to the manufacturers' declarations, such products perfectly absorb dirt and water, are more durable than commonly available substitutes and are exceptionally soft and delicate. Moreover, articles with nanorebre, like clothing, have bactericidal properties. Among the respondents, 62.3% declared interest in such products. Only 7.7% of users were not satisfied with these products and would not buy them again. 19.2% of respondents showed no interest in household products manufactured with the use of nanotechnology.

Food packaging containing zinc and titanium oxide nanoparticles to maintain color and prevent spoilage is another group of goods that respondents were asked about. Interest in these products was shown by 20% of respondents, but among them 7.7% were not satisfied. One third of the respondents indicated no interest in these products. The next group of articles that the respondents were asked about were such nanocosmetics as: sunscreens with nanoparticles of iron oxide and titanium dioxide, nanoemulsions and nanocapsules. 55.4% of respondents were interested in such articles or their holders, among them 8.5% were dissatisfied. Lack of interest was declared by 25.4% of the respondents. Among the users and those interested in nanocosmetics, the overwhelming majority were women – 82.3%.

Nano-products for surface care (car bodies, countertops) constituted another group of products – 20.0% of the respondents were interested in them. 30.8% of the respondents were satisfied with the nanopaints protecting against moisture and fungi, and 38.5% were interested in their further use. Filters made of nanomaterials for water and air were the last group of products whose opinion the respondents were asked about. 56.2% of respondents were interested in nanofilters or their users, of which 20% of respondents showed no interest in nanocoatings. The data is shown in Fig. 5.

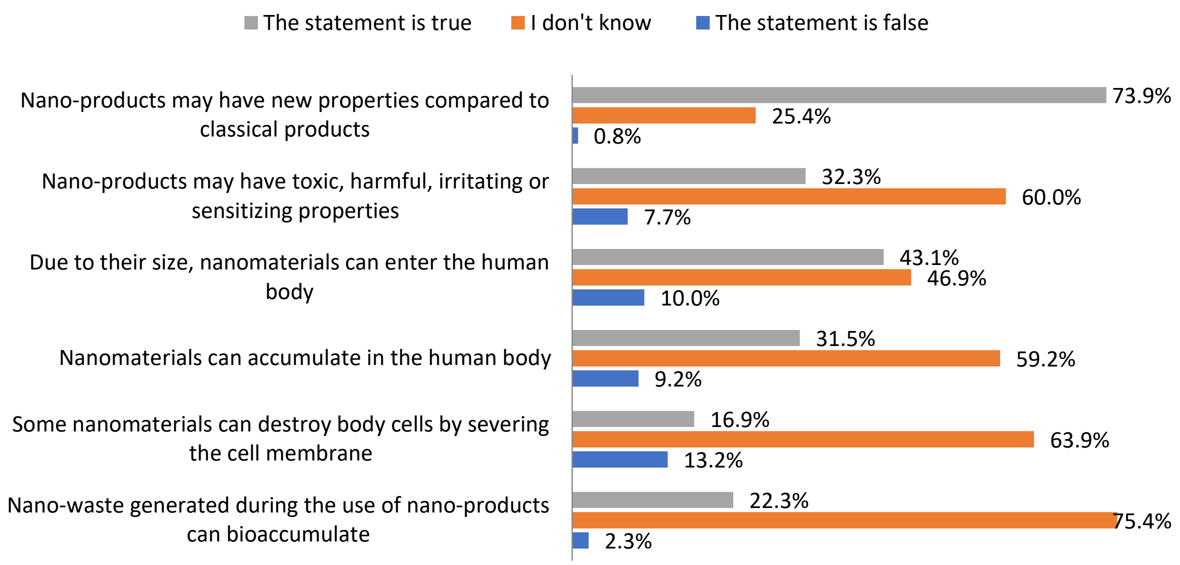


Fig. 6. Consumer knowledge about nano-products

Source: own study.

The vast majority of respondents, i.e., 73.8%, declared that nanoproducts may have new properties compared to classic products. It is surprising, however, that as many as 60% of people from the same group could not indicate the answer to the question whether nano-products may have toxic, harmful, irritating or sensitizing properties. Only 32.3% of the respondents stated that nano-products may have such an effect.

Almost half of the respondents (43.08%) stated that due to their size, nanomaterials can get into the human body through the respiratory system, digestive system and skin. On the other hand, 31.5% of people believe that nanomaterials can accumulate

in the human body. A small percentage of respondents believe (16.9%) that some nanomaterials can destroy body cells by cutting the cell membrane. The vast majority of people participating in the study (75.4%) do not know that nanowaste generated in the process of using nanoproducts can bioaccumulate. The data is shown in Fig. 6.

According to 37.7% of the respondents, nanowaste should be segregated separately. However, as many as 23.1% declared that nanowaste does not pose a threat to the environment (the statement is false). According to 13.3% of people, nanowaste can be collected together with plastic waste, and according to 20.8% of respondents, there are no such recommendations. The data is presented in Fig. 7.

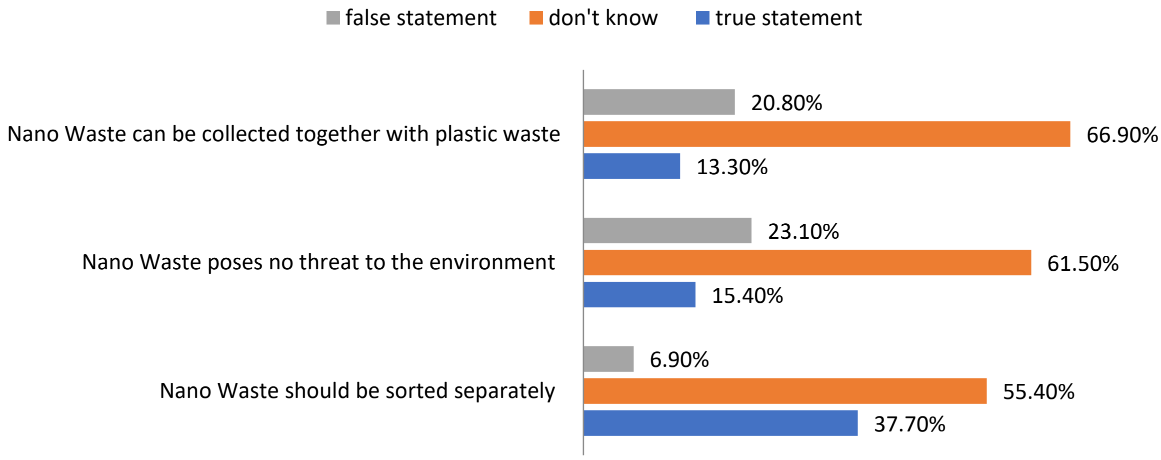


Fig. 7. Consumer knowledge about nanowaste

Source: own study.

The most popular source of knowledge about nanoproducts indicated by the respondents was the Internet – 48.5%, followed by school and university. Conversations with friends are in third place. The fewest respondents declared that they get their knowledge from the radio and at work – 1.5%. The data is shown in Fig. 8.

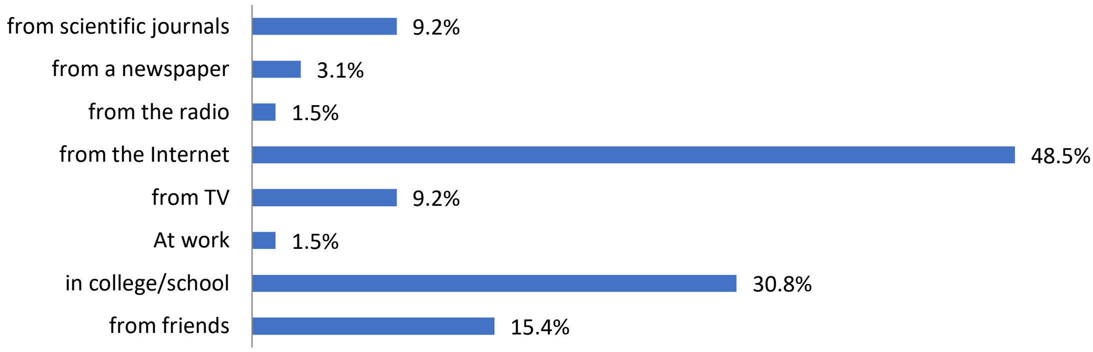


Fig. 8. Sources of acquiring knowledge among consumers

Source: own study.

Unfortunately, due to the form of the study – an online questionnaire – it was not possible to reach representatives of the age group over 66 years of age. Therefore, the results of the research cannot directly relate to the opinion of the whole society on the nano-products market.

Similar conclusions were obtained by the team of Przybyłowski et al., in 2016, namely the respondents indicated a positive attitude to the use and development of nanotechnology achievements in the food industry, medicine and packaging. In addition, this study showed that despite the positive attitude of respondents to nano-products, information about nano-ingredients in the product also triggered some concerns in them. In addition, the respondents showed a varied level of knowledge about the impact of nanoproducts on the natural environment (Przybyłowski, Chomaniuk & Reszka, 2016).

Conclusions

1. The Internet is the largest source of information on nano-products. Almost half of the respondents indicated the Internet as a key source of information.
2. Consumers rarely use food-related nano-products, but prefer nano-products used in medicine and household.
3. A large percentage of respondents are concerned about the harmful effects of nano-products.
4. Consumers declared their interest in a new group of products manufactured with the use of nano-technology and indicate that they have high hopes for them. Mainly in the area of pharmacotherapy and cosmetology. In addition, they declared that they are willing to pay more for innovative products than for their classic counterparts.

References

Adams, L.K., Lyon, D.Y., Alvarez, P.J.J. (2006). Comparative eco-toxicity of nanoscale TiO2,SiO2, and ZnO water suspensions. *Water Research*, 40, 3527-3532.

Bayda, S., Adeel, M., Tuccinardi, T., Cordani, M., & Rizzolio, F. (2020). The history of nanoscience and nano-technology: From chemical-physical applications to nanomedicine. *Molecules*, 25, 1). https://doi.org/10.3390/-molecules25010112

Buzea, C., Pacheco, I.I., Robbie, K. (2007). Nanomaterials and nanoparticles: Sources and toxicity. *Biointerphases*, 2, 17-71.

Cevc, G. (1996). Transfersomes, liposomes and other lipid suspensions on the skin: permeation enhancement, vesicle penetration, and transdermal drug delivery. *Critical reviews in therapeutic drug carrier systems,* 13, 3-4.

Chomaniuk, N., Przybylowski, P. (2014). *Nanoprodukty-co wiedzą o nich studenci*. *Przemysł Spożywczy*, 7(68).

Choudhary, V.R., Dhar, A., Jana, P., Jha, R., Uphade, B.S. (2005). A green process for chlorine-freebenzaldehyde from the solvent-free oxidation ofbenzyl alcohol with molecular oxygen over a sup-ported nano-size gold catalyst. *Green Chemistry*, 7, 768-770.

Cinelli, M., Coles, S.R., Sadik, O., Karn, B., & Kirwan, K. (2016). A framework of criteria for the sustainability assessment of nanoproducts. *Journal of Cleaner Production*, 126. https://doi.org/10.1016/j.jclepro.2016.02.118

Diamond, J. (2012). The wealth of nations. *Nature*, 429, 616-617.

Ditta, A. (2012). How helpful is nanotechnology in agriculture*? Advances in Natural Sciences: Nanoscience and Nanotechnology*, 3, 2-10.

Durán, N., Teixeira, Z., Marcato, P.D. (2011). Topical Application of Nanostructures: Solid Lipid, Polymeric and Metallic Nanoparticles. *Nanocosmetics and Nanomedicines,* 69-99.

Foss Hansen, S., Heggelund, L. R., Revilla Besora, P., Mackevica, A., Boldrin, A., & Baun, A. (2016). Nanoproducts – What is actually available to European consumers? *Environmental Science: Nano*, 3(1). https://doi.org-/10.1039/c5en00182j

Haleem, A., Javaid, M., Singh, R.P., Rab, S., & Suman, R. (2023). Applications of nanotechnology in medical field: a brief review. *In Global Health Journal* (Vol. 7, Issue 2). https://doi.org/10.1016/j.glohj.2023.02.008

Hara, T., Mori, K., Oshiba, M., Mizugaki, T., Ebitani, K., Kaneda K. (2004). Highly efficient dehalo-genation using hydroxyapatite-supported palla-dium nanocluster catalyst with molecular hydro-gen. *Green Chemistry*, 6, 507-509.

He, X., Deng, H., & Hwang, H. (2019). The current application of nanotechnology in food and agriculture. *In Journal of Food and Drug Analysis* (Vol. 27, Issue 1). https://doi.org/10.1016/j.jfda.2018.12.002

Home – Echa. (2023.). Pobrano 29 June 2023, from *https://euon.echa.europa.eu/url*

Jasiczak, J. (2009). Postawy konsumentów wobec nanotechnologii jako determinanta jej rozwoju rynkowego, Thesis,Poznan University of Economics, Poznań.

Jasiczak, J. (2010). Konsumenci wobec wschodzących technologii (przykład nanotechnologii). *Problemy Zarządzania*, *Finansów i Marketingu, Zeszyty Naukowe Uniwersytetu Szczecińskiego,* (15), 173-180.

Kaiser, J.P., Zuin, S., Wick, P. (2013). Is nanotechnology revolutionizing the paint and lacquer industry? A critical opinion*. Science of The Total Environment*, 442, 282-289.

Lo, C.C., Wang, C. H., Chien, P.Y., & Hung, C.W. (2012). An empirical study of commercialization performance on nanoproducts. *Technovation*, 32(3-4). https://doi.org/10.1016/j.technovation.2011.08.005

Malik, S., Muhammad, K., & Waheed, Y. (2023). Nanotechnology: A Revolution in Modern Industry. *Molecules* (Vol. 28, Issue 2). https://doi.org/10.3390/molecules28020661

Mallakpour, S., & Hussain, C.M. (2022). Handbook of Consumer Nanoproducts. Handbook of Consumer Nano-products. https://doi.org/10.1007/978-981-16-8698-6

Mohammad, Z.H., Ahmad, F., Ibrahim, S.A., & Zaidi, S. (2022). Application of nanotechnology in different aspects of the food industry. *Discover Food* (Vol. 2, Issue 1). https://doi.org/10.1007/s44187-022-00013-9

Nowack, B., Bucheli, D. (2007). Occurrence, behavior and effects of nanoparticles in the environment. *Environmental Pollution*, 150, 5-22.

Pattekari , P., Zheng, Z., Zhang, X., Levchenko, T., Torchilin, V., Lvov, Y. (2011). Top-down and bottom-up approaches in production of aqueous nanocolloids of low solubility drug paclitaxel. *Physical Chemistry Chemical Physics*, 13, 9014-9019.

Przybyłowski, P., Chomaniuk, N., Reszka, M.M. (2016). Postrzeganie przez konsumentów jakości i bezpieczeństwa nanomateriałów. *Zeszyty Naukowe Akademii Morskiej w Gdyni*, 93, 227-235.

Santana, M.H.A., Zanchetta, B. (2011). Elastic Liposomes. *Nanocosmetics and Nanomedicines*, 139-162.

Saritha, G.N.G., Anju, T., & Kumar, A. (2022). Nanotechnology – Big impact: How nanotechnology is changing the future of agriculture? *Journal of Agriculture and Food Research*, 10. https://doi.org/10.1016/j.jafr.2022.100457

Som, C., Berges, M., Chaudhry, Q., Dusinska, M., Fernandes, T.F., Olsen, S.I., & Nowack, B. (2010). The importance of life cycle concepts for the development of safe nanoproducts. *Toxicology*, 269(2-3). https://doi.org/-10.1016/j.tox.2009.12.012

Talebian, S., Rodrigues, T., Das Neves, J., Sarmento, B., Langer, R., & Conde, J. (2021). Facts and Figures on Materials Science and Nanotechnology Progress and Investment. ACS Nano, 15(10). https://doi.org/10.1021/-acsnano.1c03992

Zahra, Z., Habib, Z., Hyun, S., & Sajid, M. (2022). Nanowaste: Another future waste, its sources, release mechanism, and removal strategies in the environment. *Sustainability*, *14*(4), 2041. https://doi.org/10.3390/-su14042041

TASTE THE SWEET REVOLUTION: URBAN STUDY ON CONSUMER BEHAVIOR TOWARDS FLAVOURED HONEY AMONG THE IGENERATION

Peter Šedík*[1], Kristína Predanócyová[2], Erik Janšto[1], Elena Horská[1]

[1]Institute of marketing, trade and social studies, Faculty of Economics and Management, Slovak University of Agriculture in Nitra, Nitra, Slovakia
[2]AgroBioTech Research Centre, Slovak University of Agriculture in Nitra, Nitra, Slovakia
**Corresponding Author: peter.sedik@uniag.sk*

DOI: 10.56091/CTQS.Innov-17

Abstract

The aim of the study was to identify consumer behaviour and attitudes of iGeneration in the market of flavoured honey. The presented study is based on primary data obtained by implementing consumer research in 2023. In total, 40 urban honey consumers participated. The research including both questionnaire survey and sensory testing where respondents evaluated 5 different types of flavoured honey (cocoa and hazelnuts, cinnamon, raspberry, grapes and ginger). The results showed that urban consumers representing iGenerations mostly consume honey occasionally (40%) with annual consumption 1-2 kilograms (50%) or less than 1 kilogram (30%). Most respondents indicated the preference for the following honey flavours: ingredient rich in health promoting substances, traditional fruits, exotics fruits and herbs. The least preferred were the edible insects. Furthermore, the most importance motives for consumption were indicated as follows: taste, immunity booster, vitamin content and health benefits. The sensory research revealed that the highest evaluation was obtained by honey with cinnamon in nearly all examined sensory attributes followed by honey with cacao and hazelnut in taste attribute and honey with raspberry in colour. The results provide interesting insights for honey producers for extending their product portfolio by producing honey enhanced by various ingredients and flavours.

Keywords: iGenerations, consumer preferences, flavoured honey, Slovakia

Introduction

The food market faces development challenges, which include economic factors, lifestyle changes, climate changes, changes in food consumption, shrinkage of Earth's resources, but also the production and consumption of food regarding sustainable development (Gazdecki et al., 2021). Based on the above, the food market is constantly changing and the changes result from consumer demands for the consumption of tasty, healthy, sustainable and authentic food and from the choice of food with regard to the convenience trend (Hudecová et al., 2021; Grunert, 2017b; Brohm & Domurath, 2017; Petz & Haas, 2017; Nagyová & Košičiarová, 2017).

Recently, also due to the impact of Covid-19, the importance of healthy and rational eating is growing and the choice of food is determined by the health of consumers, and therefore it is possible to consider the aspect of health and a healthy lifestyle as a key driving force of the food market (Huang et al., 2022; Irene Goetzke & Spiller, 2014; Karpyn et al., 2020; Predanócyová et al., 2022). An important part of a healthy diet is the consumption of functional foods (Horská et al., 2022; John & Singla, 2021; Jurek, 2022). The market for functional foods is growing due to the rapid sharing of information in the media, increasing consumer awareness of the consumption of healthy and nutritious foods, as well as consumer demand for new foods with a beneficial effect on health (Guldas et al., 2022). Changes in consumer behaviour and changing consumer needs create demand for innovation (Gazdecki & Goryńska-Goldmann, 2018; Stubbs, 2019), and functional foods represent a significant opportunity for innovation and growth for the food industry (Bigliardi & Galati, 2013). Functional foods are suitable for the implementation of food innovations and allow the consumer to lead a healthier life without changing eating habits (Oraman, 2019). Producers reflect on consumer requirements and produce new foods that meet consumer needs (Grabek-Lejko et al., 2022). In this context, Grunert (2017a) points out that new developments in agriculture, food processing and retailing open up new opportunities in the development of food products. The honey market is no exception.

Honey is an important, rare and increasingly popular food among consumers (Šedík et al., 2023a). Honey is a nutritionally and energy-rich product that contains a spectrum of minerals, vitamins, amino acids, organic acids, phenolic compounds, flavonoids, essential oils and other (Bogdanov et al., 2008; Pita-Calvo & Vázquez, 2017; de Oliveira, 2018; Keskin et al., 2021; Gündoğdu et al., 2019). In the context of honey market trends, Sparacino et al., (2022) identified different types of consumers according to their preferences, namely healthy people, sustainable people, organic people and quality-sensitive people. Thus, the world honey market is changing depending on the current consumption trends, the dynamics of consumer behaviour, consumer demands for rational eating, a healthy lifestyle based on the consumption of unprocessed and natural foods, as well as the need to consume food with the intention of treating diseases with natural products (Ribeiro et al., 2019; Pocol & Teselios, 2012). In connection with the mentioned Ketwaropaskul et al., (2017) emphasizes that the honey market has an increasing trend since consumers are more health conscious. In order to meet the demands of consumers for the consumption of healthy and functional foods, honey, which has a natural and nutritious content, is enriched with other functional components, thereby increasing its functional composition and the health benefits resulting from its consumption (Guldas et al., 2022).

Understanding consumer preferences can have a positive effect on increasing consumer awareness of flavoured honeys and their consumption, and therefore the aim of the study was to identify consumer behaviour and attitudes of iGeneration in the Slovak market of flavoured honey. The following research questions were established:

RQ1: Are there any statistically differences in respondent´s evaluation of selected honey flavours?

RQ2: Are there any statistically differences in sensory evaluation of 5 different samples of flavoured honey?

Materials and methods

The study is based on consumer research conducted on 40 university students from urban areas of Slovakia. The design of consumer research combined traditional questionnaire survey and sensory testing. The research was implemented in April 2023. The research sample can be characterized as follows: 72.5% were females and average age was 23.4 years.

The questionnaire included closed-ended questions regarding consumer behaviour as well as 7-point scaling questions where 7 indicated the highest preference and 1 represented no preference towards ingredients for flavoured honey and key motives for consumption. The sensory testing included 6-point scales, where 1 represented the lowest preference while number 6 indicated the highest preference. The above mentioned scale represents a scale format with no midpoint in marketing research (Weijters et al., 2010). Consumers tested 5 different samples of flavoured honey (cinnamon, cacao with hazelnut, raspberry, ginger, and grape-resveratrol). Respondents evaluated colour, taste, aroma, consistency, and overall acceptance. The samples were distributed in small transparent cups and all samples were introduced to each participants.

Statistical analysis was carried out by applying statistical software XLSTAT 2022.4.1 (Addinsoft, NY, USA) with the significance level $\alpha=0.05$. The following non-parametric tests were applied: Friedman's test and Multiple pairwise comparisons using Nemenyi's procedure.

Results and Discussion

The results showed that iGeneration of university students tend to consume honey 1-2 times per month or less (65.12%) with annual consumption 1-2 kilograms (41.86%) or less than 1 kilogram (40.7%). This segment tends to prefer liquid polyfloral honey of Slovak origin purchased directly from beekeeper. Moreover, Friedman test and multiple pairwise comparisons (Nemenyi's procedure) revealed statistically significant differences in respondents’ evaluations (p-value=<0.0001).

Based on acquired results (Fig. 1), it can be concluded that the most preferred ingredients for flavoured honey were as follows: ingredient rich in antioxidants or other health promoting substances, traditional fruits, exotic fruits, mixture of different tastes and herbs. The RQ 1 was confirmed.

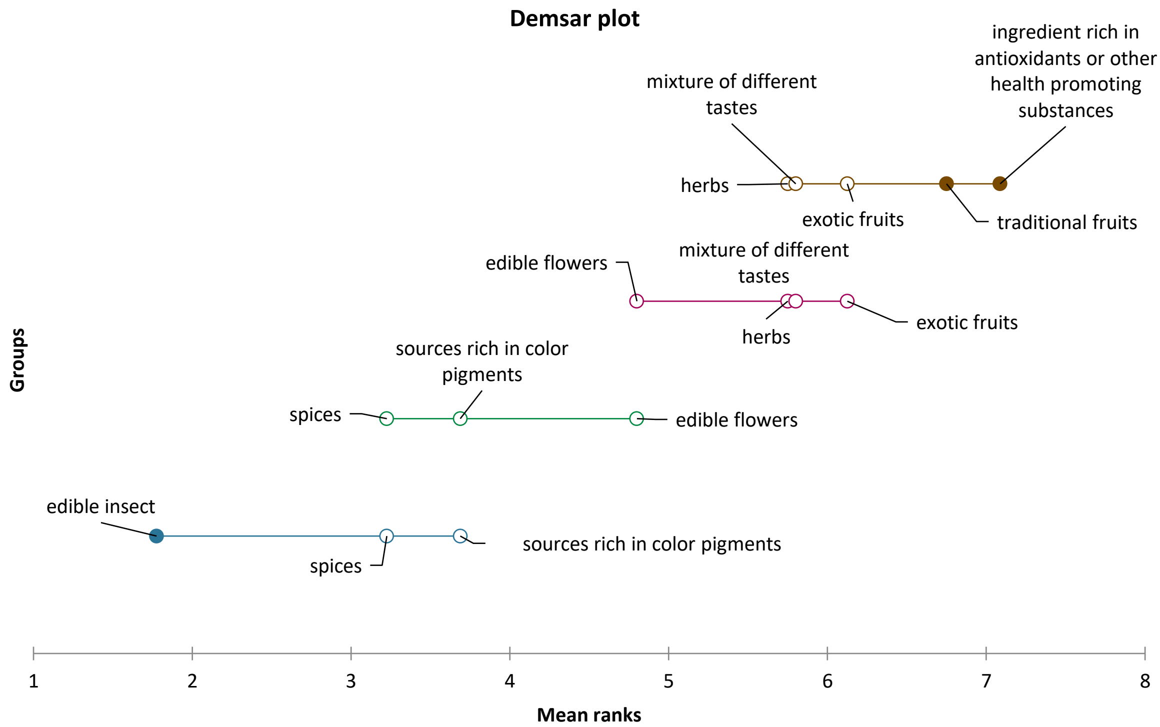


Fig. 1. Preferred ingredients for flavoured honey

Source: own study.

In addition, respondents evaluated the motives for consumption of flavoured honey. By applying Friedman test and Nemenyi's procedure identified statistically significant differences (p-value=<0.0001). Results showed that the key motives for consumption are taste, capability to boost immune system, source of vitamins as well as health benefits. The least important motives were recommendations from nutritionist (Table 1).

Table 1. Key motives for consumption of flavoured honey

Sample	Mean of ranks	Groups				
recommendations from nutritionist	4.213	A				
habit of consuming honey since childhood	5.913	A	B			
nutritional values	6.338	A	B			
supporting good sleep	6.463	A	B	C		
an alternative to other foods	6.788	A	B	C	D	
lifestyle	6.875	A	B	C	D	
source of sacharides	6.950	A	B	C	D	
antioxidant effect	7.950		B	C	D	
source of energy	8.475		B	C	D	
source of minerals	8.513		B	C	D	
curiosity/ try something new	8.588		B	C	D	
health benefits	9.813			C	D	E
source of vitamins	10.163				D	E
immunity booster	10.213				D	E
taste	12.750					E

Source: own study.

The sensory research showed that university students belonging to iGeneration indicated preference for certain types of flavoured honey (Fig. 2). Statistically significant differences were acquired by applying Friedman test and multiple pairwise comparisons implemented via Nemenyi's procedure (p-value = <0.0001). The highest evaluation was acquired by honey with cinnamon in nearly all examined sensory attributes (taste – 4.6; aroma – 5.1; consistency – 4.1 and overall acceptance – 4.7) followed by honey with cacao & hazelnut (taste – 4.6). The best evaluation of colour was obtained by honey with raspberry. The lowest evaluation acquired honey with grapes (resveratrol) in nearly all examined attributes (overall acceptance, taste, colour and consistency). Honey with ginger obtained nearly the best evaluation in consistency together with cinnamon flavour. All in all, the preferences based on overall acceptance were as follows: cinnamon, raspberry, cacao & hazelnut, ginger and grapes. It can be concluded that RQ 2 was confirmed.

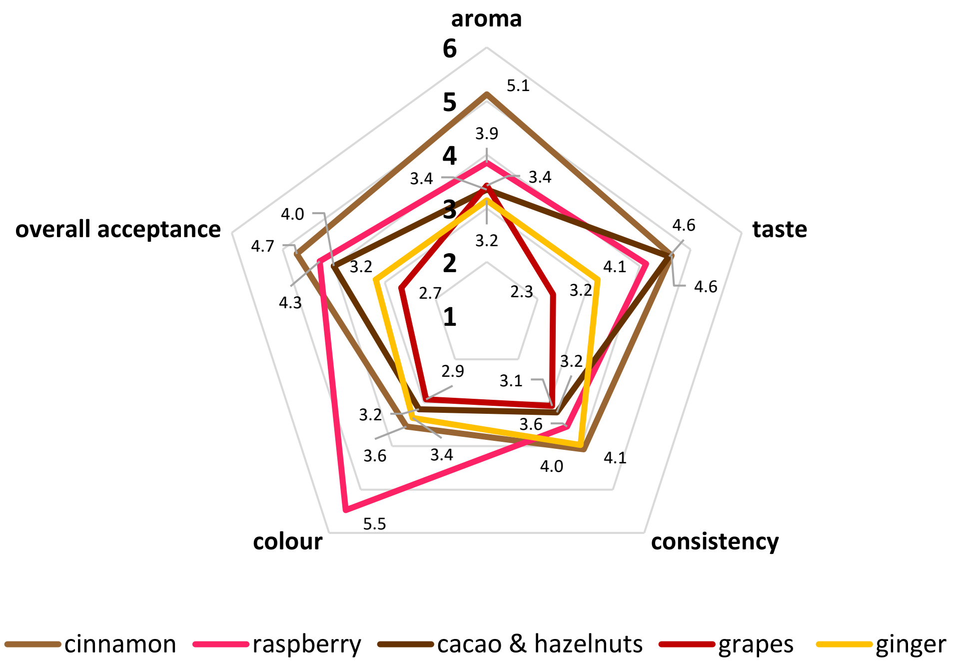


Fig. 2. Sensory evaluation of different samples of flavoured honey

Source: own study.

Honey can be enriched with other bee products, such as bee pollen, bee bread, royal jelly and propolis (Adam Florkiewicz et al., 2019; Sánchez-Martín et al., 2022; Osés et al., 2016). The presence of bee pollen and bee bread significantly affects the content of potassium, calcium, magnesium, iron, zinc and manganese (Adam Florkiewicz et al., 2019). Habryka et al., (2020) add that their addition to honey significantly increases the ability of enriched honey to cover the daily need for macro and micro-elements. Other functional ingredients that can be added to honey are herbs, vegetables and fruits (Grabek-Lejko et al., 2022; Socha et al., 2009). Šedík et al., (2023b) further state that it is attractive to add spices, herbs, dried fruits, nuts, turmeric, ginger, or cinnamon to honey, but also pollen, propolis, royal jelly and various other health-promoting ingredients and thus create new, innovative products. Honey with other additions such as chocolate or fruits can be interesting for children's consumers as a suitable alternative to sweet spreads or jams (Šedík et al., 2023a; Šedík et al., 2020; Miłek et al., 2021; Habryka et al., 2020; Sowa et al., 2019, Guldas et al., 2022). Leaka et al., (2020) found that the mentioned type of honey is consumed by consumers. Flavoured creamed honey can be a suitable alternative for consumers who like a spreadable product with an original taste and nutritional/functional benefits (Mateescu et al., 2020).

Another Slovak study (Šedík et al., 2019) showed that honey enriched with cacao powder was considered by Slovak consumers as healthier alternative to commercial chocolate spreads and would be purchased mostly by those who considered their healthy eating habits as healthy one. In addition, Šedík et al., (2018) identified that the most preferred flavoured honeys are honey with ginger, nuts or pollen. Oravecz and Kovács (2019) emphasize that honeys with the addition of elderberry, lemon grass, chilli pepper, garlic, dill, cinnamon and mint honey, which are offered on the current honey market, are the most familiar to consumers. The similar consumer study conducted in Slovakia showed that the most attractive honey additions were ginger, strawberry, raspberry, and cinnamon. The least attractive were honey with poppy and turmeric (Šedík et al., 2022).

Conclusion

The study provides a preliminary insight into consumer preferences towards flavoured honey and their consumer behaviour. Acquired results provide important data for honey producers in terms of product strategy which involves product portfolio extension by producing honey enhanced by various ingredients and flavours. The future research should be oriented not only on iGeneration but should include the whole age spectrum.

Acknowledgments

The research was funded by the project VEGA No. 1/0415/21 "Interdisciplinary research on consumer behaviour on the honey market with an emphasis on its quality and nutritional value" from The Ministry of Education, Science, Research, and Sport of the Slovak Republic, by the Grant Agency of The Slovak University of Agriculture in Nitra, grant number 14-GASPU-2021 "Analysis of consumer behaviour towards honeys enriched with health-promoting substances" and by the Operational Program Integrated Infrastructure within the project: Demand-driven research for the sustainable and innovative food, Drive4SIFood 313011V336, co-financed by the European Regional Development Fund.

References

Bigliardi, B., & Galati, F. (2013). Innovation trends in the food industry: The case of functional foods. *Trends in Food Science & Technology*, *31*(2), 118-129. https://doi.org/10.1016/j.tifs.2013.03.006

Bogdanov, S., Jurendic, T., Sieber, R., & Gallmann, P. (2008). Honey for nutrition and health: A Review. *Journal of the American College of Nutrition*, *27*(6), 677-689. https://doi.org/10.1080/07315724.2008.10719745

Brohm, D., & Domurath, N. (2017). 3. The Sustainability Trend. *Consumer Trends and New Product Opportunities in the Food Sector*, 33-41. https://doi.org/10.3920/978-90-8686-852-0_3

de Oliveira, R.G. (2018). Nutritional composition and medical properties of honey from stingless bees. *Nutrition & Food Science International Journal*, *7*(2), 42-43.

Gazdecki, M., & Goryńska-Goldmann, E. (2018). *Relationships on food markets – consumers' perspective*. Wydawnictwo Uniwersytetu Przyrodniczego w Poznaniu.

Gazdecki, M., Leszczyński, G., & Zieliński, M. (2021). Food sector as an interactive business world: A framework for research on Innovations. *Energies*, *14*(11), 3312. https://doi.org/10.3390/en14113312

Grabek-Lejko, D., Miłek, M., Sidor, E., Puchalski, C., & Dżugan, M. (2022). Antiviral and antibacterial effect of honey enriched with Rubus spp. as a functional food with enhanced antioxidant properties. *Molecules*, *27*(15), 4859. https://doi.org/10.3390/molecules27154859

Grunert, K.G. (2017a). *Consumer trends and new product opportunities in the Food Sector*. Academic Publishers.

Grunert, K.G. (2017b). 2. The health trend. *Consumer Trends and New Product Opportunities in the Food Sector*, 15-31. https://doi.org/10.3920/978-90-8686-852-0_2

Guldas, M., Gurbuz, O., Cakmak, I., Yildiz, E., & Sen, H. (2022). Effects of honey enrichment with spirulina platensis on phenolics, bioaccessibility, antioxidant capacity and fatty acids. *LWT*, *153*, 112461. https://doi.org/10.1016-/j.lwt.2021.112461

Gündoğdu, E., Çakmakçı, S., & Şat, İ. G. (2019). An overview of honey: its composition, nutritional and functional properties. *Journal of Food Science and Engineering*, *9*(1), 10-14. https://doi.org/10.17265/21595828/2019.-01.003

Habryka, C., Socha, R., & Juszczak, L. (2020). The influence of honey enrichment with bee pollen or bee bread on the content of selected mineral components in multifloral honey. *Potravinarstvo Slovak Journal of Food Sciences*, *14*, 874-880. https://doi.org/10.5219/1329

Horská, E., Predanócyová, K., Šedík, P., Grunert, K.G., & Hupková, D. (2022). Consumer perception of functional foods and determinants of functional foods consumption in the Slovak Republic. *British Food Journal*, *125*(7), 2478-2492. https://doi.org/10.1108/bfj-07-2022-0656

Huang, Z., Zhu, Y.D., Deng, J., & Wang, C.L. (2022). Marketing healthy diets: The impact of health consciousness on Chinese consumers' food choices. *Sustainability*, *14*(4), 2059. https://doi.org/10.3390/su14042059

Hudecová, M., Šedík, P., & Nagyová, Ľ. (2021). Analysis of Consumer Behaviour on the Bee Products Market in Relation to the Health Trends. *Conference: Challenges of Nowadays in the Light of Sustainability 8th VUA YOUTH Scientific Session,* 60-69.

Irene Goetzke, B., & Spiller, A. (2014). Health-improving lifestyles of organic and functional food consumers. *British Food Journal*, *116*(3), 510-526. https://doi.org/10.1108/bfj-03-2012-0073

John, R., & Singla, A. (2021). Functional Foods: Components, health benefits, challenges, and major projects. *DRC Sustainable Future*, *2*(1), 61-72. https://doi.org/10.37281/drcsf/2.1.7

Jurek, J.M. (2022). Health benefits of Functional Foods. *Journal of Biomedical Research & Environmental Sciences*, *3*(12), 1307-1316. https://doi.org/10.37871/jbres1598

Juszczak, L., Florkiewicz, A., Socha, R., Gałkowska, D., & Piotrowska, Anna. (2019). Effect of honey supplementation with bee products on quality parameters and mineral composition. *Emirates Journal of Food and Agriculture*, 990. https://doi.org/10.9755/ejfa.2018.v30.i12.1864

Karpyn, A., McCallops, K., Wolgast, H., & Glanz, K. (2020). Improving consumption and purchases of healthier foods in Retail Environments: A systematic review. *International Journal of Environmental Research and Public Health*, *17*(20), 7524. https://doi.org/10.3390/ijerph17207524

Keskin, M., Keskin, Ş., & Kolaylı, S. (2021). Health-promoting benefits of Honey. *Preparation of Phytopharmaceuticals for the Management of Disorders*, 303-306. https://doi.org/10.1016/b978-0-12-820284-5.00024-1

Ketwaropaskul, B., Kantachan, T., Duangphakdee, Orawan., & Soontrunnarudrungsri, A. (2017). Consumer Behavior and Acceptance Towards Different Unifloral Honey. *19 th Food Innovation Asia Conference 2017 (FIAC 2017)*, 86-94.

Leaka, S., Lavanya, S.M., Mahendran, K., & Praveena, S. (2020). Market profile and consumer purchase pattern of Honey in tamil nadu. *Journal of Entomology and Zoology Studies*, *8*(5), 1255-1258. https://doi.org/10.22271/-j.ento.2020.v8.i5r.7680

Mateescu, C., Duta, D., Onisei, T., Şerbancea, F., Utoiu, C., Manolache, F.A., Rascol, M., Ionescu, V., Popescu, C., & Dune, A. (2020). Flavored cream honey—A healthy food choice for consumers. In *International Symposium*, 236-245.

Miłek, M., Grabek-Lejko, D., Stępień, K., Sidor, E., Mołoń, M., & Dżugan, M. (2021). The enrichment of honey with*aronia melanocarpa*fruits enhances its*in vitro*and*in vivo*antioxidant potential and intensifies its antibacterial and antiviral properties. *Food & Function*, *12*(19), 8920-8931. https://doi.org/10.1039/d1fo02248b

Nagyová, L., & Košičiarová, I. (2017). 5. The convenience and bundling trends. *Consumer Trends and New Product Opportunities in the Food Sector*, 65-82. https://doi.org/10.3920/978-90-8686-852-0_5

Oraman, Y. (2019). The consumers' functional food trend: Market orientation, market opportunities. *The European Proceedings of Social and Behavioural Sciences*. https://doi.org/10.15405/epsbs.2019.01.02.38

Oravecz, T., & Kovács, I. (2019). Qualitative study of preferences and attitudes towards honey consumption in Hungary. *Analecta Technica Szegedinensia*, *13*(2), 52-58. https://doi.org/10.14232/analecta.2019.2.52-58

Osés, S.M., Pascual-Maté, A., Fernández-Muiño, M.A., López-Díaz, T.M., & Sancho, M.T. (2016). Bioactive properties of honey with propolis. *Food Chemistry*, *196*, 1215-1223. https://doi.org/10.1016/j.foodchem.2015.-10.050

Petz, M., & Haas, R. (2017). 4. The authenticity trend. *Consumer Trends and New Product Opportunities in the Food Sector*, 43-64. https://doi.org/10.3920/978-90-8686-852-0_4

Pita-Calvo, C., & Vázquez, M. (2017). Differences between honeydew and blossom honeys: A Review. *Trends in Food Science &; Technology*, *59*, 79-87. https://doi.org/10.1016/j.tifs.2016.11.015

Pocol, C.B., & Teselios, C.M. (2012). Socio-economic determinants of honey consumption in Romania. *Journal of Food, Agriculture & Environment*, *10*(2 Part 1), 18-21.

Predanócyová, K., Šedík, P., & Horská, E. (2022). Exploring consumer behavior and attitudes toward healthy food in Slovakia. *British Food Journal*, *125*(6), 2053-2069. https://doi.org/10.1108/bfj-06-2022-0517

Ribeiro, M.I., Fernandes, A.J., Cabo, P.S., & Diniz, F.J. (2019). Trends in honey purchase and consumption in trás-os-Montes Region, Portugal., *Economy of Region*, *15*(3), 822-833. https://doi.org/10.17059/2019-3-15

Sánchez-Martín, V., Haza, A.I., Iriondo-DeHond, A., del Castillo, M.D., Hospital, X.F., Fernández, M., Hierro, E., & Morales, P. (2022). Protective effect of thyme and chestnut honeys enriched with bee products against benzo(a)pyrene-induced DNA damage. *International Journal of Environmental Research and Public Health*, *19*(24), 16969. https://doi.org/10.3390/ijerph192416969

Socha, R., Juszczak, L., Pietrzyk, S., & Fortuna, T. (2009). Antioxidant activity and phenolic composition of Herbhoneys. *Food Chemistry*, *113*(2), 568-574. https://doi.org/10.1016/j.foodchem.2008.08.029

Sowa, P., Tarapatskyy, M., Puchalski, C., Jarecki, W., & Dżugan, M. (2019). A novel honey-based product enriched with coumarin from melilotus flowers. *Journal of Food Measurement and Characterization*, *13*(3), 1748-1754. https://doi.org/10.1007/s11694-019-00092-w

Sparacino, A., Merlino, V.M., Blanc, S., Borra, D., & Massaglia, S. (2022). A choice experiment model for honey attributes: Italian consumer preferences and socio-demographic profiles. *Nutrients*, *14*(22), 4797. -https://-doi.org/10.3390/nu14224797

Stubbs, W. (2019). Strategies, practices, and tensions in managing business model innovation for Sustainability: The case of an Australian bcorp. *Corporate Social Responsibility and Environmental Management*. https://-doi.org/10.1002/csr.1786

Šedík, P., Horská, E., Ivanišová, E., Kačániová, M., & Krasnodębski, A. (2019). Consumer behaviour of young generation in Slovakia towards cocoa-enriched honey. *Potravinarstvo Slovak Journal of Food Sciences*, 13(1), 18-24. https://doi.org/10.5219/1013

Šedík, P., Horská, E., Skowron-Grabowska, B., & Illés, C. B. (2018). Generation Marketing in strategic marketing management: Case study of honey market. *Polish Journal of Management Studies*, *18*(1), 326-337. https://doi.org/10.17512/pjms.2018.18.1.24

Šedík, P., Hudecová, M., & Predanócyová, K. (2023a). Exploring consumers' preferences and attitudes to honey: Generation approach in Slovakia. *Foods*, *12*(10), 1941. https://doi.org/10.3390/foods12101941

Šedík, P., Pocol, C.B., & Ivanišová, E. (2020). Interdisciplinary approach towards consumer acceptability of flavoured honey: Case of young generation in Slovakia. *Bulletin of University of Agricultural Sciences and Veterinary Medicine Cluj-Napoca. Food Science and Technology*, *77*(2), 57. https://doi.org/10.15835/buasvmcnfst:-2020.0039

Šedík, P., Predanócyová, K., & Hudecová, M. (2022). Consumer preferences for bee products: evidence from Slovakia. *Economics Management Innovation*, 14(3), 32-41.

Šedík, P., Predanócyová, K., & Janšto, E. (2023b). *Markeing včelieho medu*. Nitra: Slovak University of Agriculture.

Weijters, B., Cabooter, E., & Schillewaert, N. (2010). The effect of rating scale format on response styles: The number of response categories and response category labels. International Journal of Research in Marketing, 27(3), 236-247.

ATTITUDES OF SLOVAK CONSUMERS TOWARDS ENVIRONMENTALLY FRIENDLY PRODUCTS AND THEIR PACKAGING

Renáta Ševčíková*, Malgorzata A. Jarossová, Katarína Chomová

Department of Marketing, University of Economics in Bratislava, Slovakia
Corresponding Author e-mail: renata.sevcikova@euba.sk

DOI: 10.56091/CTQS.Innov-18

Abstract

The interest in ecological products is growing, and consumers are trying to protect the environment through their behaviour and purchases. Packaging has a significant impact on air and soil pollution and accounts for half of marine waste. Despite an increased recycling rate in the European Union, the amount of waste produced is growing faster than actual recycling. Without EU measures in the recycling sector, the volume of plastic waste produced would increase by 46% by 2030 and by 61% by 2040 compared to 2018. The aim of this article is to find out how Slovak consumers perceive ecological products and what role ecological packaging plays in shaping sustainable behaviour. The survey was conducted using a standardized structured questionnaire and focused on Slovak consumers. The survey took place from December 2020 to February 2021, with a total of 433 respondents participating. Mathematical and statistical methods were used to examine the relationships between respondents' characteristics and their attitudes towards environmentally friendly products. Most respondents purchase environmentally friendly products in the food and drugstore category, and respondents prefer recyclable and reusable packaging. Based on our findings, we can conclude that respondents care about product packaging and try to consider the environment when making choices. The majority of respondents view environmentally friendly products very positively, and there was a statistically significant relationship between a respondent's income and their attitude towards environmentally friendly products. The most important factor for respondents when buying environmentally friendly products is product quality. It is crucial for manufacturers and product sellers to ensure that environmentally friendly products are distinguishable from regular products. Packaging that can attract attention and clearly indicates that it is an environmentally friendly product would increase product sales.

Keywords: environmentally friendly products, packaging, consumer behaviour

Introduction

The market share of sustainable products is gradually increasing due to consumer concerns about environmental pollution, health concerns and product safety crises. As a result of these concerns, consumers have changed their behaviour towards purchasing sustainable products. Many previous studies have shown that sustainable products have a competitive advantage over conventional products (Seo et al., 2016).

The sustainability of a product can be assessed on the basis of the economic, environmental, and social aspects of resource consumption and value creation during its life cycle (Fiksel et al.,1998). A product that has a low potential environmental impact can be classified as a sustainable product (Ghadimi et al., 2013).

Companies have learned over the past decade that responsible business practices can give them a competitive advantage and contribute to the success of the organization overall. While many companies have changed their practices to meet the needs of the modern 'green consumer', some have leveraged this 'green market' for their own success (Zadek, 2007).

Sustainability is becoming a central theme today. With the rise in awareness and importance of sustainability and the increase in environmental regulations, sustainable packaging is now more customer-centric than ever (Jain & Hudnurkar, 2022).

Sustainability is often analyzed using the Triple Bottom Line (TBL) approach (Eilert, 2005), which is based solely on economic, social, and environmental impacts, with packaging playing a critical role in each of these three dimensions.

1. Economic impact – can mitigate the direct and indirect costs of operations through material change, optimal handling of goods, fast transportation, and efficient storage.
2. Social impact – can reduce and recover food waste by promoting product protection and ensuring worker safety through more efficient ergonomic designs.
3. Environmental impact – can reduce the carbon footprint created by ensuring optimal use of packaging materials and designs during the lifetime of goods.

Theoretical background

Consumers are changing their attitudes, behaviour, and approach to consumption, becoming more aware of changes in the environment and the impact of their consumption behaviour on it. In general, they are happy to identify with companies that strive to protect the environment. However, this concern of many consumers does not necessarily translate into actual purchasing habits (Orzan, et al., 2018). The price of a product is considered to be one of the key factors influencing consumer purchasing decisions. It is the understanding of consumers' willingness to buy green products that is very important for companies because, for example, high price is a barrier to green consumption (Gleim et al., 2013).

Willingness to be environmentally friendly is theoretically understood as the willingness of consumers to act or incline towards an eco-friendly lifestyle (Kumar et al., 2017). The antecedents are concern for the environment, environmental knowledge, and the perceived psychological consequences of their decisions. Consumers who anticipate that they will derive a positive emotional feeling or satisfaction from their environmental efforts should be more likely to be environmentally friendly than those who do not. The continuum of willingness from information seeking to willingness to pay more for environmentally friendly products is considered the most reliable indicator confirming environmentally friendly behaviour (Kautish et al., 2019).

The consumer's purchase decision-making process starts with awareness and perception. However, a positive perception of a product does not automatically mean that the consumer will buy it, as many factors influence the purchase decision. A well-known phenomenon in the field of sustainable consumer behaviour, the so-called 'attitude-behaviour gap' or 'intention-behaviour gap' means that many consumers' positive attitudes and intentions to behave sustainably do not translate into actual consumer behaviour. Barriers to purchasing sustainable products that have emerged from many studies include higher prices, lack of availability and perceived lower quality (Ketelsen et al., 2020).

It is not easy to explain why there is a difference between consumers' intentions and their subsequent behaviour, as the reasons often vary from consumer to consumer, and a factor that prevents one consumer from buying sustainable products may not be an issue for another (Stern 2000). A general finding of previous studies on the purchase of sustainable products has been that although most consumers have positive attitudes towards sustainable products, the group of consumers who actually engage in the purchase of sustainable products is small – less than 10% (Ketelsen et al., 2020).

In the past, consumers' choice of packaging has been driven by the functional properties of the packaging, convenience of use, design, and aesthetics. Only recently have the environmental implications of packaging and information on household waste come to the fore. Energy consumption, household waste and discarded products represent the biggest environmental consumption problems worldwide, but consumption patterns and the underlying structures that support them have proven difficult to change.

An important aspect of sustainable food is that there are products on the market with eco-friendly packaging. An eco-friendly packaging is packaging that, by its composition and disposal method, does not burden, pollute, or harm the environment, while also meeting all the requirements and functions necessary for preserving products. As packaging is an external element of the products, it does not affect the products themselves, therefore the environmental friendliness of the packaging is not directly related to the product itself.

Organic packaging is packaging that has the general functions of packaging, but in addition is made from environmentally friendly materials (from a minimum amount of recyclable and biodegradable materials) and is economically sustainable (Svanes et al., 2010).

The importance of the waste problem suggests that the environmental friendliness of product packaging should be added to consumer choice patterns as a relevant product attribute. There are several reasons why consumers do not choose environmentally friendly packaging despite a favorable attitude towards environmental protection. Moral reasoning is only plausible in the choice of product packaging when the environmental impact is perceived to be significant and other important attributes (e.g., high price) are not included in the specific purchasing situation. Many consumers do not understand the link between their purchasing decision and various environmental impacts unless there is clear environmental information, such as labels, to remind them of this. Other reasons include the lack of supply of environmentally friendly products and packaging on the market and the inability of consumers to distinguish between more and less environmentally friendly packaging alternatives (Rokka and Uusitalo, 2008).

The introduction of eco-friendly packaging requires more effort. Packaging performs important functions that need to be considered in the development of eco-friendly packaging. Packaging in general fulfils several functions. It prevents damage that may occur during distribution, it is an important element in selling a product as it provides specific information about the product. It can attract the consumer's attention and can influence their purchase intentions. Packaging influences the consumer's evaluation of the product; if the packaging is well designed, it can elicit a positive evaluation of the product (Seo et al., 2016).

Packaging design is important in conveying product characteristics to consumers. For example, the color of the packaging can influence consumers' perception of the taste of the product. Therefore, consumers' opinions are very important in the whole packaging design process, including the design of eco-friendly packaging (Ketelsen et al., 2020).

Magnier et al. (2016) found that regardless of whether the product was considered a healthy or unhealthy food, the perceived quality of the organically packaged product was higher than that of the conventionally packaged product. This implies that organic packaging has benefits that increase the value of the product. Organic packaging does not affect the product's attributes, so it does not directly affect the product's rating, but this factor positively and indirectly influences the overall rating.

Methodology

The aim of this study is to find out how the Slovak consumer perceives environmentally friendly products and what role eco-friendly packaging plays in shaping sustainable behaviour.

The survey took place from December 2020 to February 2021 and was conducted through an online questionnaire created in Google Docs. It was distributed to respondents via email or shared on social networks. A total of 433 respondents took part in the survey. The objective of the survey was to identify the purchasing behaviour of the respondents in the product categories – low technology products, medium technology products, high technology products and environment friendly products. Within this paper, some sub-results in the environmentally friendly product category are presented.

We used analytical and statistical methods (descriptive statistics and correlation analysis) to evaluate the results of our survey and analyse the data. We examined the relationships between variables using correlation coefficients, which were tested for statistical significance of the model. Due to the nature of our data under study, we used Spearman's correlation coefficient.

The Spearman correlation coefficient r_S is defined as the sample correlation coefficient computed from the pairs $(R1, Q1)'$, …, $(Rn, Qn)'$ and is given by the relation (Cohen et al., 2013):

$$r_s = 1 - \frac{6 \sum_{i=1}^{n} (R_i - Q_i)^2}{n(n^2 - 1)}$$

Spearman's rank correlation coefficient r_S takes values from the interval <-1,1>. Values close to ±1 reflect a more monotonic dependence between the X and Y variables. If $r_S > 0$ we speak of monotonic direct dependence, if $r_S < 0$ we speak of monotonic indirect dependence. A value of $r_S = 0$ indicates that there is no monotonic relationship between variables X and Y (Lyocsa et al., 2013). The IBM SPSS Statistics 29 software was used to calculate the statistical relationships between the variables.

Results

As part of the primary research, we conducted a survey through the method of inquiry, which was focused on Slovak consumers. A total of 433 respondents participated in the survey, of which 343 (79.2%) were women and 90 (20.8%) were men. The survey was conducted across all age groups, starting from the age of fifteen. Most respondents indicated that their highest level of education attained was high school with a diploma (184; 42.5%). Respondents most often purchase environmentally friendly products in the product categories of food (316 respondents), drugstores (243 respondents) and textiles and clothing (192 respondents). The detailed distribution of respondents' answers is shown in Figure 1.

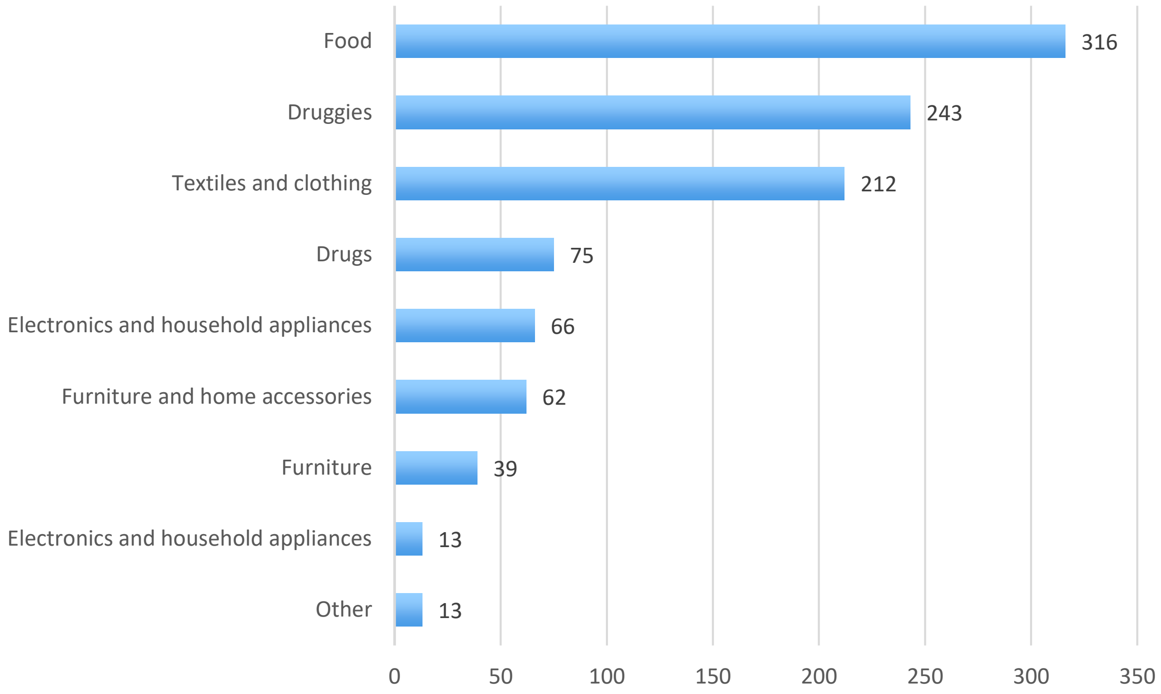


Fig. 1. Most frequently purchased product categories by respondents

Source: own study.

Products produced in an environmentally and socially sustainable way are usually more expensive than conventionally produced products. KPMG's 2021 Customer Experience Survey assessed the willingness to pay more for products and services from companies that strive to meet ethical and social principles and behave responsibly towards the environment. The results show that this model appeals to the majority of respondents regardless of age. Across all age groups, the majority of customers declare their willingness to accept a higher price for a sustainable product or service (KPMG, 2021). Although the declared acceptance of a higher price may not necessarily mean the actual purchase of a more expensive product, sustainability is becoming an increasingly important topic for customers. According to KPMG's Me, my life, my wallet survey, sustainable products, and services are preferred by a third more customers than before the pandemic. And up to 80% of respondents are buying brands whose activities and behaviours are in line with their beliefs. Companies should therefore clearly communicate their sustainability goals, how they are being met and the link to other activities. In our survey, there was no association between the age of respondents and their frequency of purchasing environmentally friendly products. Almost 87% of our respondents purchase environmentally friendly products frequently or at least sometimes, these results were achieved across all age categories (Fig.2).

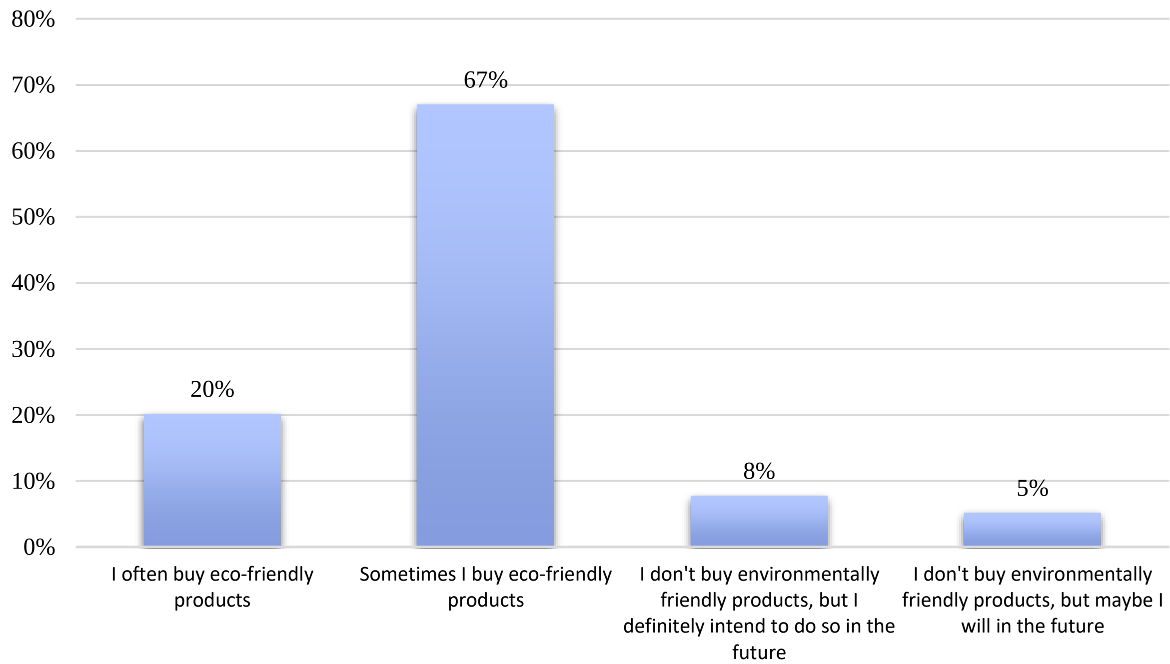


Fig. 2. Respondents' attitudes towards buying environmentally friendly products

Source: own study.

The higher price of environmentally friendly products is seen as a barrier to their purchase. The attitude of our respondents towards the purchase of such products is equally influenced by their income. Using Spearman's correlation coefficient, we confirmed a statistically significant moderate positive correlation between respondents' purchasing attitude and their income level (Fig. 3). We can conclude that the higher the respondents' income, the more often they purchase environmentally friendly products.

Correlations

			Q0	S3
Spearman's rho	Q0	Correlation Coefficient	1,000	,111*
		Sig. (2-tailed)	.	,021
		N	427	427
	S3	Correlation Coefficient	,111*	1,000
		Sig. (2-tailed)	,021	.
		N	427	427

*. Correlation is significant at the 0.05 level (2-tailed).

Fig. 3. Spearman's correlation coefficient

Source: own survey processing in SPSS program.

Our respondents most prefer recyclable packaging (352 responses) and packaging they can reuse (278 responses). Packaging that can be returned to the shop is also preferred (121 responses). Only 9 respondents prefer packaging-free products (Fig. 4). It can be concluded that respondents care about the packaging of the product and try to take the environment into account when making their choice.

Despite the fact that the network of packaging-free shops in Slovakia is constantly expanding, their development may be hampered by the fact that people do not have experience with such shopping, are not familiar with the system or are ashamed to put food in their own containers. Given the results of our survey, we would also focus on more education and support for this type of shopping.

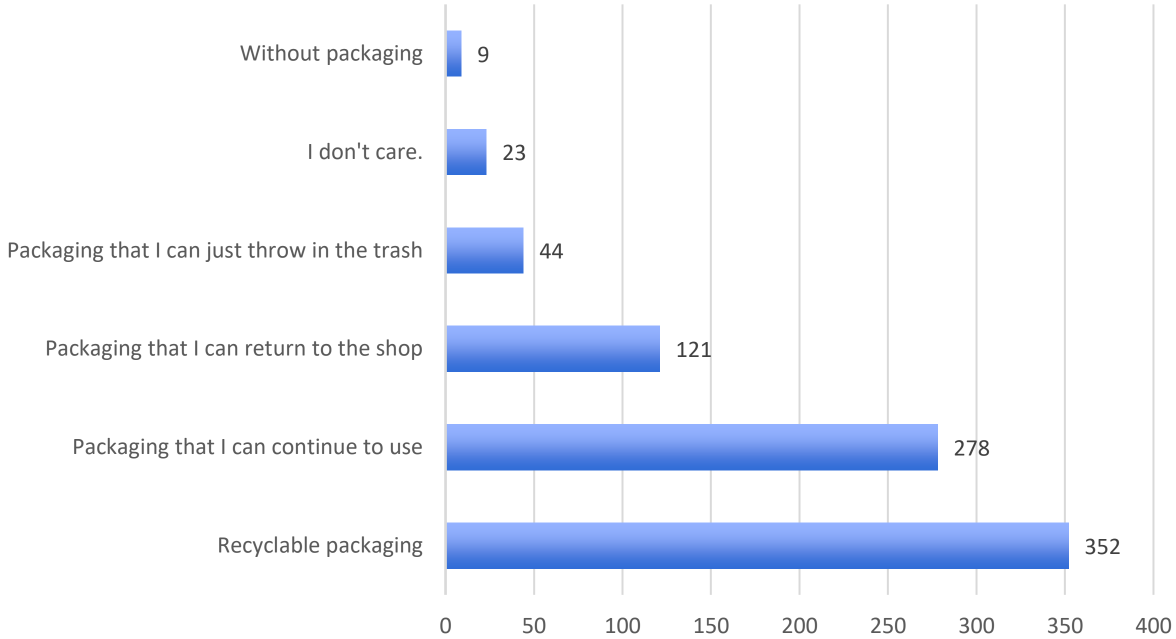


Fig. 4. Preferred packaging when purchasing environmentally friendly products

Source: own study.

Respondents were asked to rate how important each factor is to them when purchasing environmentally friendly products, with 1 being very little importance and 10 being very much importance. The most important factor for respondents when purchasing environmentally friendly products is the quality of the products, which received an overall rating of 8.64. Other most important factors still include product composition (rating of 8.36) and product information (rating of 8.11).

The price of the product (rating of 7.98) was rated significantly by respondents, as products that are environmentally friendly generally have a higher price, which can be a barrier for consumers to purchase them. The least important factors in the respondents' evaluations are the product brand, marketing campaign, and product packaging (see Fig. 5).

Fig. 5. The importance of individual factors when buying environmentally friendly products

Source: own study.

Conclusions

Environmental protection is closely related to consumer behaviour and assumes that consumers actively participate in addressing environmental issues by choosing an eco-friendly lifestyle.

The aim of this article was to determine how Slovak consumers perceive eco-friendly products and the role that eco-friendly packaging plays in shaping sustainable behaviour.

Main findings from our research:

1. Respondents most frequently purchase eco-friendly products in categories such as food, toiletries, textiles, and clothing.
2. There was no correlation found between the age of respondents and the frequency of their eco-friendly product purchases. Nearly 87% of our respondents frequently or at least occasionally buy eco-friendly products, with these results spanning across all age groups.
3. Products manufactured in an eco-friendly and socially sustainable manner are typically more expensive than conventionally produced products. The higher cost of eco-friendly products is perceived as a barrier to purchase by consumers. The purchasing attitude of our respondents towards such products is also influenced by their income.
4. Using Spearman's correlation coefficient, we confirmed a statistically significant, moderately positive correlation between respondents' purchasing attitudes and their income levels. We can conclude that the higher the income of the respondents, the more frequently they purchase eco-friendly products.
5. Most of our respondents prefer recyclable packaging and packaging that can be reused. They also prefer packaging that can be returned to the store, but only a minimal number of respondents favour products without packaging. The network of zero-waste stores is continually expanding in Slovakia, but its growth may be hindered by factors such as people's unfamiliarity with such shopping experiences, unfamiliarity with the system, or reluctance to place food items in their own containers. We recommend focusing on greater education and promotion of this type of shopping.
6. The most important factors for respondents when purchasing eco-friendly products are product quality, accurate product composition with information about the product, and product price. Although the product packaging itself was not identified by our respondents as the most significant purchasing factor, we would recommend using eco-friendly packaging forms for eco-friendly products, which according to several international studies offer advantages and positively influence the overall product rating.

We certainly see limitations of our research in their ability to be generalized to a broader population, as our representative sample was small, and the majority were in the lower age categories. Our future research could focus on exploring consumer attitudes towards sustainable packaging and how these relate to the price of products.

Acknowledgement

The paper is a partial output of the VEGA research task no. 1/0398/22 "The current status and perspectives of the development of the market of healthy, environmentally friendly and carbon-neutral products in Slovakia and the European Union" conducted at the University of Economics in Bratislava.

DUT – Driving Urban Transitions. HORIZON – CL5-2021-D2-01-16

KEGA no. 030EU-4/2022 – Integrated environmental quality management in the network of automotive suppliers.

References

Cohen, J., Cohen, P., West, S.G., & Aiken, L.S. (2013). *Applied multiple regression/correlation analysis for the behavioral sciences*. Routledge.

Eilert, S.J. (2005). New packaging technologies for the 21st century. *Meat science*, 71(1), 122-127.

Fiksel, J., McDaniel, J., & Spitzley, D. (1998). Measuring product sustainability. *Journal of Sustainable Product Design*, 7-18.

Ghadimi, P., Yusof, N.M., Saman, M.Z.M., & Asadi, M. (2013). Methodologies for measuring sustainability of product/process: a review. *Pertanika Journal of Science and Technology*, *21*(2), 303-326.

Gleim, M.R., Smith, J.S., Andrews, D., & Cronin Jr, J.J. (2013). Against the green: A multi-method examination of the barriers to green consumption. *Journal of retailing*, *89*(1), 44-61.

Jain, P., & Hudnurkar, M. (2022). Sustainable packaging in the FMCG industry. *Cleaner and Responsible Consumption*, 7, 100075.

Kautish, P., Paul, J., & Sharma, R. (2019). The moderating influence of environmental consciousness and recycling intentions on green purchase behavior. *Journal of Cleaner Production*, *228*, 1425-1436.

Ketelsen, M., Janssen, M., & Hamm, U. (2020). Consumers' response to environmentally friendly food packaging-A systematic review. *Journal of Cleaner Production*, *254*, 120123.

Kumar, B., Manrai, A.K., & Manrai, L.A. (2017). Purchasing behaviour for environmentally sustainable products: A conceptual framework and empirical study. *Journal of Retailing and Consumer Services*, *34*, 1-9.

KPMG. (2022). *Technológiami k srdcu zákazníka*. Retrieved June 15, 2023, from https://kpmg.com/-sk/sk/home/media/press-releases/2022/04/zakaznici-su-ochotni-priplatit-za-eko-produkty.html.

Lyocsa, S., Baumohl, E., & Výrost, T. (2013). *Kvantitatívne metody v ekonómii II.* Elfa, sro.

Magnier, L., Schoormans, J., & Mugge, R. (2016). Judging a product by its cover: Packaging sustainability and perceptions of quality in food products. *Food quality and preference*, *53*, 132-142.

Orzan, G., Cruceru, A.F., Bălăceanu, C.T., & Chivu, R.G. (2018). Consumers' behavior concerning sustainable packaging: An exploratory study on Romanian consumers. *Sustainability*, 10(6), 1787.

Rokka, J., & Uusitalo, L. (2008). Preference for green packaging in consumer product choices-do consumers care? *International Journal of Consumer Studies*, *32*(5), 516-525.

Seo, S., Ahn, H.K., Jeong, J., & Moon, J. (2016). Consumers' attitude toward sustainable food products: Ingredients vs. Packaging. *Sustainability*, *8*(10), 1073.

Stern, P.C. (2000). New environmental theories: toward a coherent theory of environmentally significant behavior. *Journal of social issues*, *56*(3), 407-424.

Svanes, E., Vold, M., Møller, H., Pettersen, M.K., Larsen, H., & Hanssen, O.J. (2010). Sustainable packaging design: a holistic methodology for packaging design. *Packaging Technology and Science: An International Journal*, *23*(3), 161-175.

Zadek, S. (2007). The path to corporate responsibility. In *Corporate ethics and corporate governance* (pp. 159-172). Berlin, Heidelberg: Springer Berlin Heidelberg.

AURONES ARE NATURAL FLAVONOID PIGMENTS WITH A GOLDEN YELLOW COLOR. CAN THEY BE APPLIED IN THE FOOD INDUSTRY?

Henryk Szymusiak

Department of Food Quality and Safety, Institute of Quality Science,
Poznań University of Economics and Business, Poznań, Poland
Corresponding Author e-mail: h.szymusiak@ue.poznan.pl

DOI: 10.56091/CTQS.Innov-19

Abstract

Aurones were considered as poorly represented in nature, therefore they have been often overlooked by researchers compared to the other members of the flavonoid superfamily. Aurones are found only in plant sources, most frequently together with some their biogenetic precursors and they are acknowledged as the brightest polyphenol pigments in the yellow color range.

In recent decades, aurones have been appreciated due to their their structural and functional peculiarities. The scientific community is increasingly appreciating their ability to modulate several biological pathways, their functional properties, and their potential of technological use. At the same time, their effective potential for real therapeutic applications in many diseases began to be discovered. Therefore, aurones represent a worth farther research class of natural compounds which may provide new bioactive compounds for various applications in the near future.

The review briefly summarizes the recent literature on this class of compounds, which has been analyzed from both a chemical and a functional point of view. Original articles and reviews about aurones from the last two decades have been taken into account to provide right knowledge on their occurring in plants, discovered functional properties, their potential of technological use, and thus encourage further scientific research.

Among functional properties of aurones described antioxidant properties and unique optical properties including fluorescence. Special attention is paid on potential possibilities using the golden yellow colored aurones as food additive, which exhibits at the same time also the second function – strong antioxidant properties. In the conclusion, it is stated that the fundamental barrier is surprisingly little knowledge (surprisingly few scientific publications) about toxicity of arones and also long-term procedures in the EU, up to 10 years for a new food additive to be approved.

Keywords: aurones, flavonoids, food additives, functional properties, toxicity

Introduction

When walking in nature, the characteristic that most catches the eye is a bright yellow color. This is due to aurones and turns out to be more attractive than other shades of yellow given by other parent compounds such as flavonols. Actually, overall, aurones can be acknowledged as the brightest polyphenol pigments in the yellow color range, like anthocyanins are for the red/purple spectrum (Mazziotti, Petrarolo & La Motta, 2022).

In the early XIXth century, Ludwig Clamor initiated the description of flower coloration, identifying two classes of water-soluble pigments he named anthoxanthins (from Greek anthos = flower and xanthos = yellow) and anthocyanins (from Greek kuanos = blue). However, he unconsciously missed an additionnal category whose color was overlooked among the large amounts of carotenoids in flowers. This omission was corrected only 85 years later when Gustav Klein described for the first time a new class of flower constituents: the anthochlor pigments (from Greek chlōrós = bright green to yellow) (Boucherle et al., 2017).

This classification was all along essentially color-based, however it was clearly correlated with chemical structures being elucidated later. Indeed the white/yellow anthoxanthins (bright yellow in alkaline medium) contained flavones and flavonols, while the bright yellow anthochlors (red in alkaline medium) contained chalcones and aurones. The first occurrences of the latter structures were reported in 1941 (Geissman, 1941, as cited in Boucherle et al., 2017) and 1943 (Geissman & Heaton, 1943, as cited in Boucherle et al., 2017). A decade later, the term “aurone” (from Latin aurum = gold), inspired both by the bright golden color and by their structural analogy with flavones and chalcones (Fig. 1), was proposed by Bate-Smith and Geissman (1951, as cited in Boucherle et al., 2017).

Aurones (**1**, Fig. 1**)** belong to a minor class of flavonoids. Similarly, to other types of flavonoids, aurones contain a molecular framework formed by 15 carbon atoms, with the general structure of C_6–C_3–C_6. As a rule, naturally occurring secondary metabolites of this group are brightly colored compounds in hydroxylated, methoxylated, or glycosylated forms. Aurones are found only in plant sources, most frequently accompanied by their biogenetic precursors – 2'-hydroxychalcones **2**, as well as isomeric flavones **3** and isoflavones **4** (Fig. 1).

An aurone (IUPAC name 2-Benzylidene-1-benzofuran-3(2H)-one) is a heterocyclic chemical compound, which is a type of flavonoid (Nakayama, 2002). Aurones may be acknowledged as the lower structural counterparts of the best-known flavones (**3**, Fig. 1), a subclass of flavonoids. There are two isomers of the molecule, with (E)- and (Z)-configurations. Most natural aurones are in a (Z)-configuration, which is the more stable configuration.

Since their discovery in 1943, data about the place of aurones in the plant kingdom have arisen very slowly. Though these molecules still remain marginal among flavonoids subclasses, the number of occurrences reports strongly increased in recent years, progressively bringing aurones into the light. To date, the chemical structures of more than 100 different aurones have been identified, characterized by distinctive hydroxylated, methoxylated, and glycosylated substitution patterns (Mazziotti et al., 2022).

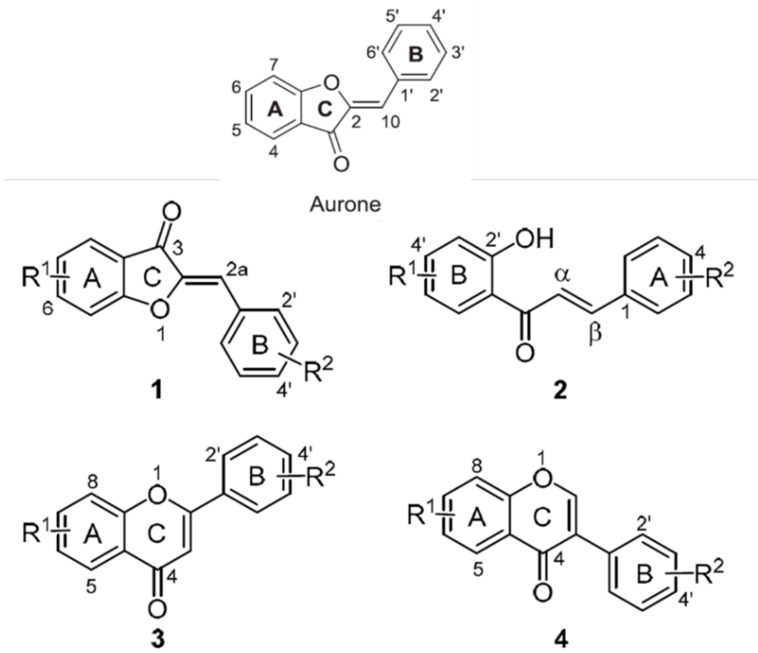


Fig. 1. The most important classes of natural flavonoids and numbering of atoms in their molecules: 1- aurones, 2- 2'-hydroxychalcones, 3- flavones, 4- isoflavones

Source: own study.

Aurones have been described as phytoalexins that are used by the plants in their defense mechanism against various infections (Boucherle et al., 2017). They play an important role in the pigmentation of some flowers and fruits and contribute especially to the bright yellow color of flowers. They also exhibit a strong and broad variety of biological activities. For example, they have been described as antifungal agents and insect antifeedant agents Zwergel et al., 2012, and references therein). Not widely distributed in nature, aurones are one of the less common and lesser-known representatives of a flavonoid subclass. This is probably the reason why they have received little attention in comparison to the structurally similar and widely investigated flavones and isoflavones (Zwergel et al., 2012).

Simultaneously, their effective potential to viable therapeutic uses has begun to be discovered (Sui et al., 2021). Aurones have a wide range of pharmacological activities, such as antibacterial, antiviral, antiparasitic, anti-inflammatory, antimalarial, antitumor, antiplasmodial, anti-inflammatory, neuropharmacological, and more (Li et al., 2022; Sui et al., 2021). Therefore, aurones represent a worth farther research class of natural compounds which may provide new bioactive compounds for various applications in the near future.

The aim of the article is a concise review of the current knowledge on aurones and an attempt to answer the question whether aurones can be used as safe dyes or food additives.

Occurrence of aurones in the plant kingdom

The yellow Snapdragon flower, defined by the scientific name of *Antirrhinum majus*, is probably one of the best sources for aurones included in the vacuoles of the epidermal cells of the flowers (Al-Snafi, 2015).

The first examples of aurones were characterized in 1940 in Asteraceae (Geissman & Heaton, 1943, as cited in Mazziotti at al.,, 2022), the family of sunflowers, which synthesize the most common 4-deoxy-derivatives of the family including sulfuretin (**5**, Fig. 2), maritimetin (**6**), leptosidin (**7**), and their corresponding glycosides. The species *variabilis* and *sulphureus* mainly express sulfuretin (**5**) and its glycosylated counterparts in leaves and petals. In the *bidens* species, maritimetin (**6**) has been isolated while, in the genus Coreopsis, compounds such as sulfuretin, maritimetin, but also leptosidin may be found.

Aurones are also synthesized in many dicotyledons including Anacardiaceae, Cactaceae, Fabaceae, Gesneriaceae, Moraceae, Oxalidaceae, Plumbaginaceae, Rubiaceae, Rhamnaceae, Rosaceae, and Plantaginaceae family (Boucherle et al., 2017). Moreover, they have been also found in some species of monocotyledons as well as in Bryophytes (Davies et al., 2020). Generally, the 4-deoxy-aurones are mainly found in the flowers of the Asteraceae (Mazziotti et al., 2022). The 4-hydroxylated derivatives, such as aureusidin (**8**) and bracteatin (**9**), are more common in other plant families, such as in Plantaginaceae, and particularly in the genera Misopates and Linaria, as well as in Rubiaceae and Plumbaginaceae. The ornamental flower of the snapdragon plant is the reference natural source of aurones that may be found in the petals, as high concentrations of the glycosylated form of aureusidin (**8**), but also bracteatin (**9**) (Al-Snafi, 2015).

Although aurones are mainly detected in petals or leaves, they have also been in nectar, seeds, wood, and also bark. What is interesting, hispidol (**10**) and leptosidin (**7**), with their glycosylated derivatives, have been found in the seeds of plants such as *Retama raetam* and *Psophocarpus tetragonolobus*, both belonging to the Fabaceae family (Boucherle et al., 2017). Sulfuretin (**5**) gives the yellow color of the young stems of the deciduous shrub *Cotinus coggygria*, belonging to the Anacardiaceae family, so much so that since ancient times it has been extracted as a pigment to be used as a textile dye (Valianou et al., 2009). Sulfuretin (**5**) and fisetin (7,3',4'-trihydroxyflavonol), which are usually used as markers for the identification of the yellow dye, were identified in the extracts from ecclesiastical post-Byzantine garments (fifteenth to eighteenth century). Preliminary experiments suggested that although the amounts of the dye components decrease with light ageing, the relative ratio of fisetin and sulfuretin, after artificially accelerated light ageing, seems to be almost unaffected by such degradation processes raised by light (Valianou et al., 2009).

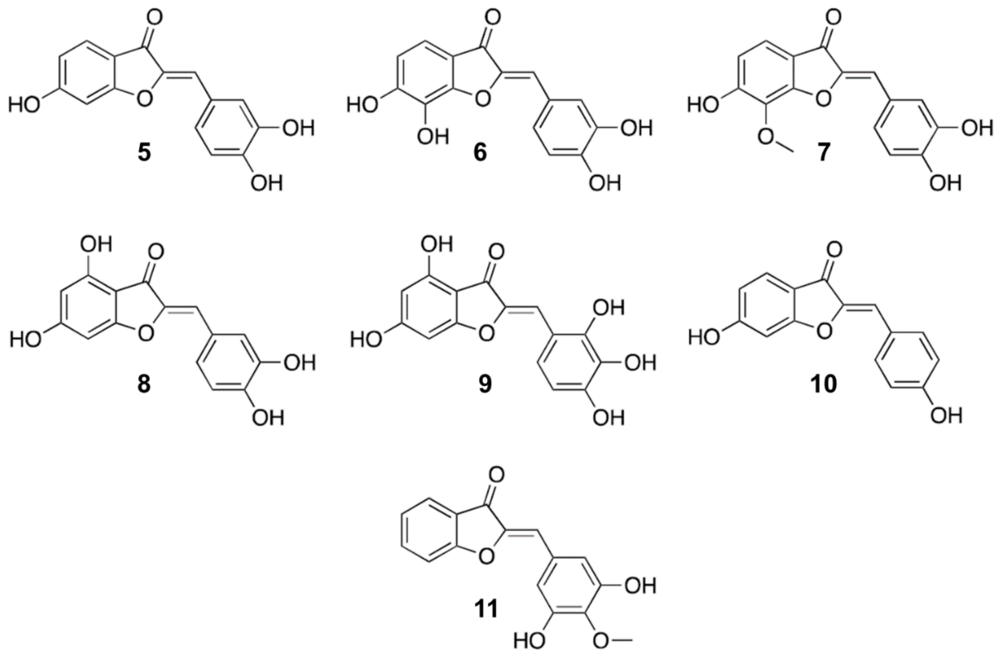


Fig. 2. Chemical structures of 4-deoxy- and 4-hydroxy-aurones: 5- sulfuretin, 6- maritimetin, 7- leptosidin, 8- aureusidin, 9- bracteatin, 10- hispidol, 11- 3′,5′-dihydroxy-4′-methoxyaurone

Source: own study.

Selected functional properties of aurones

Flower coloration and pollination

Flower colour has emerged from an evolutionary. Plants have incorporated appropriate pigments over time, whose tones have matched with insects, birds or lizards color perception. One conspicuous characteristic of aurones is their bright yellow color, as compared to analogous chalcones, flavonols (pale yellow), flavones, isoflavones or flavanones (colorless).

These visual contrasts translate into differences in UV-visible absorbance spectra, where maximum absorbance wavelenths (λ_{max}) from the intense Band I undergo bathochromic shift as the degree of conjugation increases. Flavones, flavanones and isoflavones exhibit UV absorption only before 350 nm, and do not provide visible coloration. By contrast, λ_{max} usually reaches values of 390-430 nm for aurones, vs. 365-390 nm for chalcones and 350-390 nm for flavonols, eventually with a concomitant hyperchromic effect. Both shifts are clearly seen in the case of sulfuretin (**5**), butein (3,4,2',4'-tetrahydroxychalcone) and fisetin (7,3',4'-trihydroxyflavonol), while only the bathochromic shift is seen when comparing maritimetin (**6**) and okanin (3,4,2',3',4'-pentahydroxychalcone) (Boucherle et al., 2017). The glycosylation at position 6 of aurones, which often occurs in flowers, induces further ~5 nm bathochromic shifts and leads to very high λ_{max} values, e.g., 413-415 to 418-419 nm for maritimetin (**6**) and maritimein (6-glucoside-maritimetin) respectively, 398-401 to 407 for aureusidin (**8**) and aureusin (6-glucoside-aureusidin) respectively, 399 to 404 for sulfuretin (**5**) and sulfurein (6-glucoside-sulfuretin), respectively. On the other hand, aurones exhibit fluorescent properties, uncommon among flavonoids, but this characteristic could not be involved in biological processes and especially pollinator attraction, as reported recently (Iriel & Lagorio, 2010).

So, aurones appear to be the brightest flavonoid pigments in the yellow range, with the counterpart anthocyanins in the red-purple range. Therefore, they seem to be important components of the “nectar guides”, that are UV-absorbing and sharply contrasted patterns known to attract pollinators, such as birds or bumblebees. Just these patterns encourage them to further investigate the flower and ultimately forage for nectar. They were also recently reported to deter nectar robbing by bumblebees to the benefit of legitimate nectar access (Leonard et al., 2013). Probably, both yellow colour and UV absorption pattern contribute crucially to efficient bee pollination, and the emergence of these characteristics, combined in presence of aurones, represents an edifying adaptation of flowers to bee's behavior (Papiorek et al., 2016).

It should be added that the unusual colours of the flowers containing aurones are also of great interest from a commercial point of view. In this regard, the use of aurones are considered in order to create transgenic plants endowed with bright yellow flowers through genetic engineering approaches thus opening up the obtainment of novel bright-yellow flowers for plant species lacking this colour variant (Mazziotti et al., 2022).

Antioxidant activity

Due to their poly-hydroxylated nature, aurones are expected to show antioxidant properties by quenching reactive oxygen species (ROS). High potential for ROS scavenger activity has been acknowledged not only for the aurones showing 3',4'-dihydroxy-, but also for 4'-hydroxy- and 3',4',5'-trihydroxy-substitution patterns. Senthil Kimar and Kumaresan (2011) demonstrated the high antioxidant properties of bracteatin (**9**). Moreover, a higher radical scavenging potential was recorded for 3',4' dihydroxyaurones (e.g., sulfuretin, maritimetin, aureusidin or leptosidin), versus the 3',4'-dihydroxyflavone luteolin (Boucherle et al., 2017). For example, the properties of aureusidin (**8**) have been found similar to those of flavonol and flavanol counterparts (respectively quercetin and epicatechin), which are classically considered as the best antioxidants among flavonoids (Vaganek, et al., 2012). Once formed, phenoxy radicals at position 4' of aurones also appeared to be particularly stable and thus less susceptible to act as pro-oxidant.

However, the experimental studies of aurones as antioxidants has been largely neglected and the few reported results are often very discordant across studies. Nevertheless, a few recent reports showed that 2,2-diphenyl-1-picrylhydrazyl (DPPH) radical scavenging capacity of aurones is quite equivalent to those of other flavonoid analogues. For example, maritimetin (**6**) and its chalcone counterpart okanin shared similar IC_{50} values (4.1 mM and 3.4 mM respectively), and exhibited much higher antioxidant potencies than the corresponding flavanone isookanin which showed an IC_{50} of 7.9 mM (Okada *et al.,* 2014). Aureusidin (**8**) was also found as a DPPH radical scavenger (IC_{50} = 5.1 mM), similar to the flavanone eriodictyol (IC_{50} = 4.8 mM), and slightly weaker than the flavone luteolin and the flavonol quercetin with IC_{50} = 3.1 mM and 2.7 mM respectively (Luo et al., 2014). In general, the same order of magnitude was often observed for all 3',4' dihydroxyflavonoids tested (~2-10 mM). Good scavenging activity of the more biologically relevant superoxide radical anion $O^{\cdot 2-}$ was also recorded with maritimetin (**6**) with IC_{50} = 6.5 mM versus 670.5 mM for the reference vitamin C (Nenadis & Sigalas, 2008). This value is comparable to those of flavonoid analogues of maritimetin, including the chalcone okanin with IC_{50} = 2.2 mM, the flavonol melanoxetin with IC_{50} = 2.5 mM or the flavanonol analogue 3,7,8,3',4'-pentahydroxydihydroflavone with IC_{50} = 10.2-11.9 mM (Li & Chang, 2013). The values strongly vary between different studies. It indicates that farther studies comparing the antioxidant potency of aurones with other flavonoids by using different radical scavenging assays are still needed.

Aurones as fluorophores

The fluorescent potential of some aurone derivatives, suggesting their possible use for biomolecular investigations was demonstrated (Shanker et al., 2011). The aurone skeleton provides a small molecular framework on which a variety of novel fluorescent probes can be designed. Organic molecules having fluorescence properties in the visible region of the electromagnetic spectrum are very useful investigative tools in biological systems. However, to be used for this purpose, compounds should bring only minimal perturbations to the biological macromolecules under study. Therefore, they should be characterized by possibly small dimensions. The currently available fluorophores, including xanthenes such as fluorescein and eosin, or cyanines, do not fully comply with this criterion. Studies on the potential application of aurones in the field of fluorescence are proving to be rather promising. Series of aurone derivatives were synthesized as possible fluorescent probes that can be excited by visible light. The emission maxima and intensities of the molecules are strongly dependent on the nature of the substituent and the solvent polarity. The emission intensity increases and the maximum wavelength decreases in less polar solvents; thus, the aurones may be useful probes for hydrophobic sites on biological molecules.

Can aurons be a food colouring additive?

By definition the substances that are added to food to maintain or improve the safety, freshness, taste, texture, or appearance of food are known as food additives. Colouring is added to food to replace colours lost during preparation, or to make food look more attractive. A color additive is any dye, pigment or substance which when added or applied to a food, drug or cosmetic, or to the human body, is capable (alone or through reactions with other substances) of imparting color. FDA is responsible for regulating all color additives to ensure that foods containing color additives are safe to eat, contain only approved ingredients and are accurately labeled. In 2012, the European Food Safety Authority (EFSA) proposed the tier approach to evaluate the potential toxicity of food additives. It is based on four dimensions: toxicokinetics (absorption, distribution, metabolism and excretion); genotoxicity; subchronic (at least 90 data) and chronic toxicity and carcinogenity; reproductive and developmental toxicity (Vettorazzi et al., 2020).

The colors of flavonoids in general have been appreciated and used for virtually the entirety of recorded history and yet the application of aurones as dyes or pigments has not been reported or studied, even for non-food products (Schmitt & Handy, 2019).

According to our knowledge, Schmitt and Handy (2019) are the only researchers that have evaluated toxicity a series of natural and synthetic aurones (17 aurone derivatives) and tested the compounds' potential as fabric dyes. In the same paper the authors evaluated also the influence of different substituents at the benzofuranone ring on the optical properties recording the UV-Vis spectra of the 17 products. It was found that the position of the substituent was generally more important than its type. Different substituents at the 4- or 5-positions of the benzofuranones caused a redshift of the absorption maximum by ca. 10 nm compared to the unsubstituted compound (aurone), while hydroxylation at the 6-position caused a significant blue shift of about 40 nm.

While these results on the impact of the benzofuranone portion of aurones on their optical properties are interesting, if one were to think about using them as dyes, toxicity is also an important consideration.

Although aurones are a priori considered as relatively non-toxic, Schmitt and Handy (2019) conducted a preliminary study of their toxicity at a fairly high concentration (200 µM) on the series of compounds using a standard HEP G2 inhibition assay. Compared to a currently used yellow dye (tartrazine), the aurones were similar to more toxic. Within the aurone series, though, an interesting pair of trends was observed. First of all, it was observed that all hydroxylated aurones are comparatively more toxic, displaying >50% inhibition at 200 µM (for tartrazine, % inhibition = 6.81). With methyl groups are similarly mostly more toxic. For the halogens, however, location is fairly important, with the 6 or 7 position being much less toxic (% inhibition = 25.07±18.77 and 3.64±3.64, respectively) and dramatically better than the unsubstituted base compound (% inhibition = 86.27±1.09), with the unexpected exception of 7-bromo compound (% inhibition = 5.85±11.12). Whether this trend is general or not for aurones is an interesting question for future study.

In respect to the question, whether aurones (as single compounds or their mixtures) can be used a food coloring additive, There can only be one answer: not yet. This means much more studies are needed, at least using the approach to evaluate the potential toxicity proposed by EFSA (Vettorazzi et al., 2020).

Concluding remarks

In the past few years, the naturally occurring molecule aurone has gained significant scientific attention. Molecular structure of aurones are fascinating scaffold which confer the bright golden colour to some ornamental flower such as snapdragon petals or edible sunflowers (in salads) petals.

The remarkable versatility of aurones, evidenced by an increasing amount of scientific evidence, makes these compounds worthy of wider scientific studies and practical applications. However, the prospect of using them for technological, medical and other functional purposes raises the problem of their availability. Therefore, in addition to further researching their biological significance and potential toxicity, it is crucial to develop synthetic strategies to obtain them in high amounts for possible commercial use. The natural aurones and their synthetic analogues have proved to be promising bioactive compounds with broad spectrum of activities including anticancer properties. The fluorescence phenomena of some aurone derivatives, suggests their possible use for biomolecular investigations, for instance, the properly substituted aurone derivatives may be useful probes for hydrophobic sites on biological molecules.

An unique bright golden colour of natural aurones and at the same time their strong antioxidant activity that is quite equivalent to those of other flavonoid analogues, are so tempting that one would like to use these compounds as a legal coloring food additive on an industrial scale.

Unfortunately, the toxicity of aurones, even those naturally occurring in edible or medicinal plants, has not been studied in details. There is still a long way to go before meeting the requirements set by EFSA.

In the EU, it can take up to 10 years for a new food additive to be approved. This includes five years of safety testing, then two years for evaluation by EFSA, and another three years before the additive receives EU-wide approval for use in all European Union countries.

References

Al-Snafi, A.E., (2015). The pharmacological importance of Antirrhinum majus-A review. *Asian Journal of Pharmaceutical Science and Technology, 5*, 313-320.

Bate-Smith, E.C., & Geissman, T.A. (1951). Benzalcoumaranones. *Nature, 167*, 688. https://doi.org/10.1038/-167688a0

Boucherle, B., Peuchmaur, M., Boumendjel, A. & Haudecoeur, R. (2017). Occurrences, biosynthesis and properties of aurones as high-end evolutionary products. *Phytochemistry, 142*, 92-111.

Davies, K.M., Jibran, R., Zhou, Y., Albert, N.W., Brummell, D.A., Jordan, B.R., … Schwinn, K.E. (2020). The evolution of flavonoid biosynthesis: A bryophyte perspective. *Frontiers in Plant Sciences, 11*, 7. doi: 10.3389/-fpls.2020.00007

Geissman, T.A. (1941). Anthochlor pigments. The pigment of Coreopsis douglasii. *Journal of American Chemical Society, 63*, 656-658.

Geissman, T.A. & Heaton, C.D. (1943). Anthochlor pigments. IV. The pigments of Coreopsis grandiflora. *Journal of American Chemical Society, 65*, 677-683.

Iriel, A., & Lagorio, M.G. (2010). Is the flower fluorescence relevant in biocommunication? *Naturwissenschaften, 97*, 915-924.

Leonard, A.S., Brent, J., Papaj, D.R., & Dornhaus, A. (2013). Floral nectar guide patterns discourage nectar robbing by bumble bees. *PLoS One, 8*, e55914.

Li, H.Y., & Chang, S.T. (2013). Antioxidant potency of phenolic phytochemicals from the root extract of Acacia confusa. *Industrial Crops and Products, 49*, 871-878.

Li, Y., Zhao, H., Niu, C., Aisa, H.A., & Houa, X. (2022). Synthesis and Antimicrobial Activity of Aurone Derivatives Containing Heterocyclic Substituents. *Russian Journal of General Chemistry, 92*(8), 1562-1573.

Luo, Y., Li, X., He, J., Su, J., Peng, L., Wu, X., … Zhao, Q. (2014). Isolation, characterization, and antioxidant activities of flavonoids from chufa (Eleocharis tuberosa) peels. *Food Chemistry 164*, 30-35.

Mazziotti, I., Petrarolo, G. & La Motta, C. (2022). Aurones: A Golden Resource for Active Compounds. *Molecules, 27*, 2. doi.org/10.3390/molecules27010002

Nakayama, T. (2002). Enzymology of aurone biosynthesis. *Journal of Bioscience and Bioengineering. 94*(6): 487-91. doi:10.1016/S1389-1723(02)80184-0.

Nenadis, N., & Sigalas, M.P. (2008). A DFT study on the radical scavenging activity of maritimetin and related aurones. *Journal of Physical Chemistry A, 112*, 12196-12202.

Okada, Y., Okita, M., Murai, Y., Okano, Y., & Nomura, M. (2014). Isolation and identification of flavonoids from Coreopsis lanceolata L. petals. *Natural Products Research, 28*, 201-204.

Papiorek, S., Junker, R.R., Alves-dos-Santos, I., Melo, G.A.R., Amaral-Neto, L.P., Sazima, M., Lunau, K. (2016). Bees, birds and yellow flowers: pollinator-dependant convergent evolution of UV patterns. *Plant Biology, 18*, 46-55.

Schmitt, J. & Handy, S.T. (2019). A golden opportunity: benzofuranone modifications of aurones and their influence on optical properties, toxicity, and potential as dyes. *Beilstein Journal of Organic Chemistry, 15*, 1781-1785. doi.org/10.3762/bjoc.15.171

Senthil Kimar, K. & Kumaresan, R. (2011). A Quantum chemical study on the antioxidant properties of aureusidin and bracteatin. *International Journal of Quantum Chemistry, 111*, 4483-4496.

Shanker, N., Dilek, O., Mukherjee, K., McGee, D.W. & Bane, S.L. (2011). Aurones: Small molecule visible range fluorescent probes suitable for biomacromolecules. *Journal of Fluorescence, 21*, 2173-2184.

Sui, G., Li, T., Zhang, B., Wang, R., Hao, H., & Zhou, W. (2021). Recent advances on synthesis and biological activities of aurones. *Bioorganic and Medicinal Chemistry, 29*, 115895-115917.

Vaganek, A., Rimarcik, J., Lukes, V., & Klein, E. (2012). On the energetics of hemolytic and heterolytic OH bond cleavage in flavonoids. *Computational and Theoretical Chemistry, 991*, 192-200.

Valianou, L., Stathopoulou, K., Karapanagiotis, I., Magiatis, P., Pavlidou, E., Skaltsounis, A.L., & Chryssoulakis, Y. (2009). Phytochemical analysis of young fustic (Cotinus coggygria heartwood) and identification of isolated colourants in historical textiles. *Analytical and Bioanalytical Chemistry, 394*, 871-882.

Vettorazzi, A., López De Cerain, A., Sanz-Serrano, J., Gil, A.G., & Azqueta, A. (2020). European Regulatory Framework and Safety Assessment of Food-Related Bioactive Compounds. *Nutrients, 12*(3), 613. doi:10.3390/nu12030613.

Zwergel, C., Gaascht, F., Valente, S., Diederich, M., Bagrel, D., & Kirsch, G. (2012). Aurones: Interesting natural and synthetic compounds with emerging biological potential., *Natural Product Communications, 7*, 389-394.

CONSUMER ATTITUDES TOWARDS FOOD WASTE – A REVIEW

Anna Sylwia Tarczyńska
Department of Dairy Science and Quality Management, Faculty of Food Science,
University of Warmia and Mazury in Olsztyn, Olsztyn, Poland
**Corresponding Author e-mail: sylwiaol@uwm.edu.pl*

DOI: 10.56091/CTQS.Innov-20

Abstract
Food loss and food waste (FLW) have substantial environmental, social and economic consequences. Nowadays, sustainably meeting the food demands of a growing population based on finite resources while protecting the environment is one of the great challenges. FLW affects food security and food nutrition, the sustainability of food systems and undermines the long-term resilience of the global food system by aggravating ecosystem damage. Food is an essential factor in SDGs: no poverty, zero hunger, good health and wellbeing, clean water and sanitation, affordable and clean energy, responsible consumption and production, climate action and life on land. Civilisation changes affect the attitudes of consumers related to food waste. Most food is wasted by households. The structure of wasted food products are comparable in different countries. The most wasted products are bread, vegetables, fruits, cold cuts and sausages.

The analysis of attitudes of individual groups of society directs actions to be taken in order to reduce food waste. Consumers are classified into different clusters. All studies identified a group of respondents who treated the problem of food waste disrespectfully. At the same time, in each study there was a group of “saving food” consumers. Other identified consumer segments are different, depending on the group studied and the methods of agglomeration used. In general, it can be stated that young people living in single and double households contribute to large amounts of food waste. Consumer awareness of food waste problem is increasing, especially among young people. Unfortunately, awareness does not correspond to consumer behaviour.

The purpose of this study is systematic review of the scientific literature on consumer attitudes, depending on the studied socio-demographic and other factors shaping consumer attitudes in relation to food waste.

Keywords: food waste, consumer attitudes, segmentation, SDGs

Introduction

Unsustainable production and consumption inevitably lead to food waste. Wasted food is “food produced for human consumption that has not been consumed” (Przezbórska-Skobiej & Wiza, 2021). Food waste is related to the final consumption phase (household, restaurants, retail and transport) and is a consequence of consumer behaviour (Graham-Rowe & Sparks, 2014; Parfitt et al., 2010).

Food waste is caused by irrational shopping, food exceeding the expiry date, improper storage, the lack of food-related knowledge (i.e., lack of understanding of food labels), certain retailer practices (e.g., special offers), unfinished meals, which corresponds to busy and unpredictable lifestyles etc. (Gaiani et al., 2018). Reducing food loss and waste can contribute to environmental sustainability by lowering production costs and increasing the efficiency of food systems, as well as it can improve food security and nutrition security. Percentage of food lost after harvesting and during transport, storage and processing stands at 13.8% globally. Regional estimates suggest that the highest level of food loss occurs in Central and Southern Asia (20%), followed by Europe and Northern America (15.7%). The lowest food losses were estimated in Australia and New Zealand (5.8) (United Nations, 2020). At EU level, the total food waste measured in 2020 reached more than 58.5 million tonnes of fresh mass. Household food waste represented more than 31.2 million tonnes of fresh mass, with a 53% share of the total., The remaining shares of total food waste were from the processing and manufacturing stages (20%), primary production sector (10%), restaurants and food services (9%) and retail and other distribution of food sectors (7%). In 2020 in the EU, around 127 kg of food per inhabitant was wasted. Households generated about 70 kg per inhabitant/per year. Nowadays, reducing food waste and preventing it is becoming one of the key issues of the 21st century in the context of food supply chain management (EUROSTAT, 2023). Household food waste was measured and analysed, applying different methodologies including diaries, self-report methods such as surveys and interviews, and direct measurement and waste composition analysis (Vittuari et al., 2020).

Food is an essential factor in Sustainable Development Goals (SDGs), such as no poverty (SDG 1), zero hunger (SDG 2), good health and wellbeing (SDG 3), clean water and sanitation (SDG 6), affordable and clean energy (SDG 7), responsible consumption and production (SDG 12), climate action (SDG 13) and life on land (SDG 15). SDG 12 is made up of 11 individual targets, covering areas including policies, business, food, resource use, waste and behaviour. Halving food waste is one of the individual targets of SDG 12: “By 2030, halve per capita global food waste at the retail and consumer levels and reduce food losses along production and supply chains, including post-harvest losses”.

In the context of preventing food waste, it is important to understand the factors influencing consumer behaviours and attitudes. A number of studies have focused on consumer segmentation in terms of attitudes towards food waste. A key strength of the segmentation is clustering the consumers according to their current behaviour, perception of the problem and predisposition to adopt new behaviours (Delley & Brunner, 2017). Segmentation has been used to investigate consumers’ attitudes and behaviours towards wasting food. Population segmentation is the step in the direction of a better understanding of consumers’ behaviour.

Knowing the key factors impacting consumer behaviour that cause food waste is essential for the development of effective educational programs to reduce this negative phenomenon (Tarczyńska et al., 2023).

The aim of this paper is systematic review of the scientific literature on consumer attitudes, depending on the studied socio-demographic and other factors shaping consumer attitudes in relation to food waste. This work can contribute to better understanding of food waste causes by profiling consumers' attitude.

Materials and methods

The investigation is based on the systematic literature review, known for its explicit and practical way of identifying, selecting and critically evaluating results (Moldovan et al., 2022). As mention above, the main aim of this study is to introduce the state-of-art of the characteristics of consumer attitudes regarding food waste. This aim involves gathering and analysing primary studies on identifying of consumer behaviour and segmentation them regarding food waste. In this context, the following research question (RQ) was formulated: What are consumer attitudes towards food waste? To identify the peer-reviewed literature on the topic of consumer segmentation in relation to food waste, three databases were searches: Web of Science, Scopus and Pub Med in June 2023. The research terms used were TI=(food waste) AND ALL=(consumer attitudes) AND ALL=(consumer behaviour) AND ALL=(cluster). Studies were identified on the basis of inclusion and exclusion criteria (Table 1) and then assessed full text articles.

Table 1. Inclusion and exclusion criteria to select relevant papers

Inclusion Criteria	Exclusion Criteria
• Peer-reviewed literature and full-text presentations • Dates: last 10 years: 2013 to June 2023 • Setting/sample: Household • Language: English • Study design: qualitative and quantitative studies • Segmentation of research population – clusters of consumers	• Editorials, letters and book reviews • Works prior to 2013 unless considered seminal • Samples from primary production, food processing, hospitality industry • Non-English language • Literature outside of the scope of the research (literature which does not discuss segmentation of consumers related to food waste, consumers were not clustered)

Source: own study.

Figure 1 presents a diagram outlining how the search of database and review of articles resulted in 171 in-scope articles. Additionally, reference lists were searched in all papers identified for full text articles. The systematic reviews on food waste have not included, reviews not fitting inclusion criteria. When all papers were collated and those meeting the criteria selected, a critical appraisal of the studies was completed.

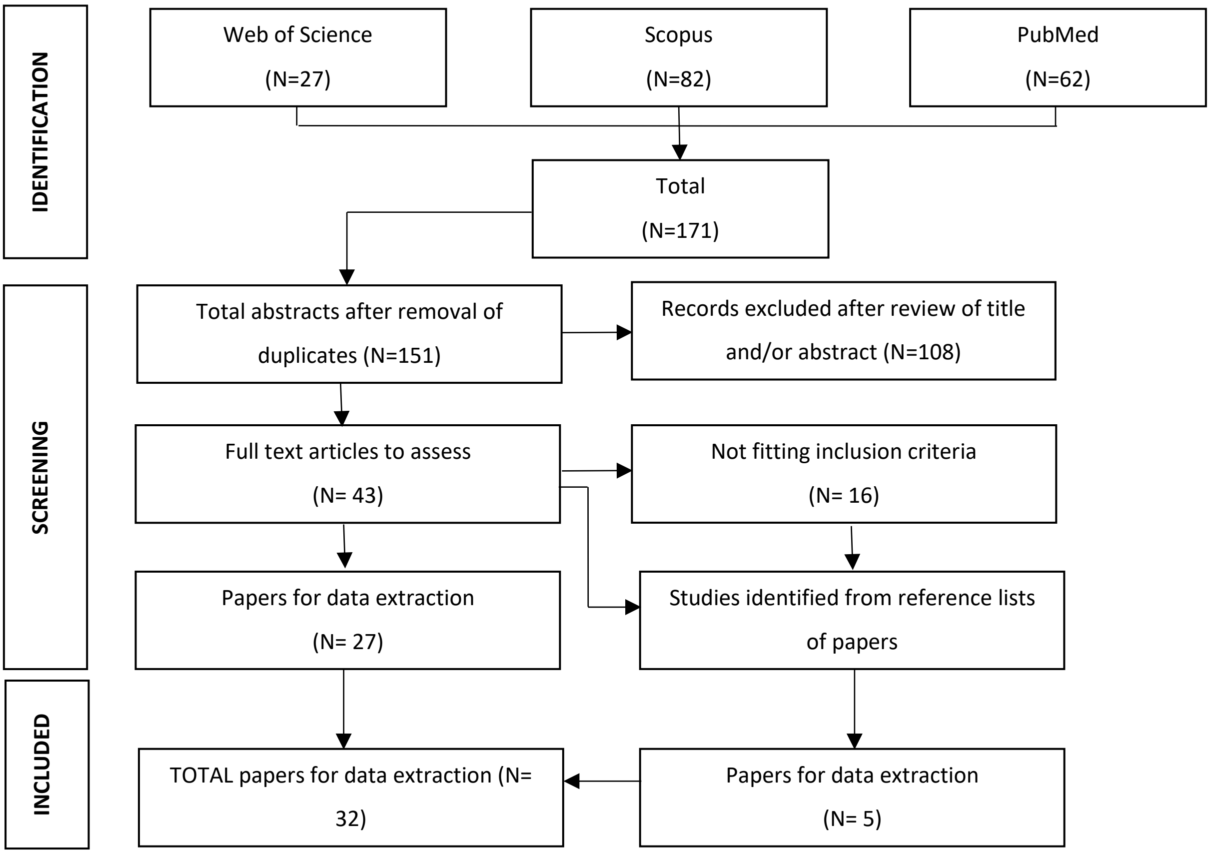


Fig. 1. Flow diagram for systematic literature review and results to select relevant papers

Source: own study.

Results and discussion

Following the research strategy, a total of 171 articles were identified. The initial screening identified 20 duplicates (two or three times over the three databases), leaving 151 papers. After review title and abstracts 108 papers were excluded (not fitting inclusions criteria). On reading the 43 full text articles, 16 were excluded because they did not identify consumer clusters related to food waste. Reference list searching of the 43 papers for full paper search identified another 5 papers for data extraction. The total number of papers identified for data extraction, from the database and reference list search was 32.

The exploration of consumers' attitudes towards food waste and their segmentation was carried out by many researchers, the results of their work were published in different journals (Table 2).

Table 2. Final set of selected studies with segmentation of consumer attitudes towards food waste

No.	Author(s)	Country	Names of the clusters
1.	Annunziata A. et al., (2020)	Italy	1. The blue cluster – consumers who wasted less than 10%, the most concerned about the environmental, economic and social consequences of food waste. 2. The orange cluster – consumers who wasted between 10% and 30% of food, sensitive to environmental resource waste. 3. The green cluster – consumers who wasted between 30% and 50%, sensitive to supermarket offers 4. The red cluster – consumers who were not able to quantify the amount of food wasted.
2.	Annunziata A. et al., (2022)	Italy	1. Self-Indulgent 2. Proactive 3. Discouraged
3.	Aschemann-Witzel J. et al., (2021)	Germany Netherlands Denmark Sweden Norway	1. Well-planning cook and frugal food avoider 2. Young Foodie 3. Established 4. Convenience and price orientated low income 5. Uninvolved young male wasters
4.	Aschemann-Witzel J. et al., (2018)	Germany Netherlands Denmark Sweden Norway	1. Cooking-involved and spontaneous 2. Price versus quality-oriented and disliking cooking 3. Very involved and cooking-engaged 4. Good food-involved and price-dismissive 5. Least concerned, normative and social
5.	Bilska B. et al., (2020)	Poland	1. Saving food 2. Wasting vegetables and fruits 3. Wasting food
6.	Borg K. et al., (2022)	Australia	1. Considerate Planners 2. Under Planners 3. Over Providers
7.	Bravi L. et al., (2019)	Italy	1. Proactive consumers in food waste 2. Hesitant Consumers in Food Waste 3. Uninterested Consumers in Food Waste
8.	Coskun A. (2021)	Turkey	1. Conservers 2. Considerate 3. Reluctant, 4. Prodigals
9.	Di Talia E. et al., (2019)	Italy	1. Non-aware consumers 2. Consumers not aware but not wasteful 3. Conscious consumers

10.	Dudziak A. et al., (2022)	Poland	No labelled 1. Respondents who throwing away food only sometimes. 2. Respondents who throwing away food 2-3 times a week. 3. Respondents who admit that the frequency of throwing food away is sporadic.
11.	Flangan A., Priyadarshini A. (2021)	Ireland	1. Caring consumers 2. Uncaring consumers
12.	Fonseca, J.R.S. (2013)	Portugal	1. Non-food waste citizens 2. Food waste citizens
13.	Falasconi L. et al., (2016)	Italy	1. Careful 2. Virtuous 3. Aware 4. Unconcerned
14.	Gaiani S. et al., (2018)	Italy	1. The conscious-fussy 2. The frugal consumer 3. The exaggerating cook 4. The conscious-forgetful type 5. The unskilled cook 6. The confused type 7. The exaggerated shopper
15.	Islam M. (2020)	Korea	1. Considerate food wasters 2. Unwitting food wasters 3. Ruthless food wasters
16.	Knezevic B. et al., (2019)	Croatia	1. Consumers concerned about economic effects of food waste 2. Unaware consumers neglecting food waste 3. Well-informed consumers 4. Fully aware consumers but not ready to take health risk
17.	Macková M., Stávková J. (2019)	Czech Republic	1. Unintentional food economisers 2. Consumers affected by systematic education 3. Re-education
18.	Mallinson L.J. et al., (2016)	UK	1. Epicures 2. Traditional consumers 3. Casual consumers 4. Food detached 5. Kitchen evaders
19.	Muresan I.C. et al., (2022)	Romania	1. The wasters 2. The careless consumers 3. The careful consumers
20.	Nabi N. et al., (2021)	Australia	No labelled 1. Cluster 1 comprised of consumers with age group 45-54, consumers are generally check the expiry date. 2. Cluster 2 comprised of consumers with age group 45-54, consumers are somewhat motivated to manage foods that are thrown away, they purchase food items based on the shop-ping list sometimes.

21.	Närvänen E. et al., (2023)	Finland	1. Non-food waste 2. Trust in date labels 3. Safety first 4. Occasional wasters
22.	Pércsi K.N. et al., (2023)	Hungary	1. Local patriots 2. Food travel 3. Quality oriented ones 4. Waste conscious
23.	Pocol C.B. et al., (2020)	Romania	1. Careless 2. Precautious 3. Ignorant
24.	Richter B. (2017)	Germany	1. Guilty food wasters 2. Unwitting food wasters 3. Careless food wasters
25.	Romani, S. et al., (2018)	Italy	1. Virtuous 2. Moderate 3. Waster
26.	Szymkowiak A. et al., (2022)	Poland	1. Taste and health-oriented customers 2. Convenience-oriented customers 3. Balanced customers
27.	Theodoris P.K., Zacharatos T.V. (20222)	Greece	1. 20s-40s food waste fighters 2. 20s-40s – food wasters 3. Unaware consumers – food wasters 1. Total food waste fighters 2. The typical young female Food Wasters 3. Aware consumers – food waste fighters 4. The typical young male food wasters
28.	Vittuari M. et al., (2020)	Italy	1. Pragmatic Consumers 2. Thrifty Altruists 3. Aware Wasters
29.	Tarczynska A.S. et al., (2023)	Poland	1. Aware students 2. Disengaged students 3. Aware but disengaged
30.	Schwodt S., Obersteiner G. (2018)	Austria	1. Eager Avoiders 2. Uninformed but eager 3. Informed but uninterested 4. Uninformed squanderers (Group 4)
31.	Tomaszewska M. et al., (2020)	Poland	No labelled Clusters A-D depending on shopping habits, storage and meal preparation, handling of cooked meals and personal and work place hygiene.
32.	Juergens U. (2023)	Germany	1. Smart 2. Spontaneous 3. Comfortable 4. Sustainable

The study presented in Table 2 aimed to identify the main variables and factors that may affect consumer behaviour for generation of food waste. The researchers focused on the analysis of factors affecting food waste. Among the identified factors were: purchase planning, purchase routines, excessive purchases and impulsive shopping, focus on price, over-purchasing, inadequate packaging size, routine food order, food preparation and home storage, moral and religion attitudes, psychological factors, lack of knowledge and skills regarding food handling, as well as age, gender, schooling, household size and income, household structure, residency, region. Depending on the adopted segmentation methods and criteria, the researchers identified from 2 to 7 clusters of consumers attitudes related to food waste. The analysis of the identified clusters shows that in each of the studies two or three groups of consumer attitudes were identified. All studies identified a group of respondents who treated the problem of food waste disrespectfully and a group of "saving food" consumers. At the same time, in those study there was a group of consumers, who are more or less aware of the problem of food waste but they do not active in the prevention of the food waste in their households. The most frequently indicated reasons for such an attitude are lack of time, fast pace of life, and lack of belief that actions in a single household can have a noticeable effect. Other identified clusters are more specified in terms of socio-demographic characteristics, shopping routines or diet. Taking into account the size of identified clusters and the date of conducted research, a positive trend was observed. More and more consumers are aware of the problem of food waste and try to reduce it in their households. In this context, rising food prices have a significant impact on consumer behaviour. As an example, Aschemann-Witzel et al., (2018) made a survey in five countries: Germany, Netherlands, Denmark, Sweden and Norway. On the basis in the conducted research, they divided consumers into five groups according to their lifestyle: "cooking-involved and spontaneous", "'price versus quality-oriented and disliking cooking", "'very involved and cooking-engaged'", "good food-involved and price-dismissive", and "least concerned, normative and social". Concerning food waste measures consumers aggregating in cluster "'price versus quality-oriented and disliking cooking" were not very food involved, although they paid most attention to price as a criterion when selecting food and they reported low levels of food waste in their own household, in particular for prepared dishes. The cluster were balanced in terms of gender, of medium age, and of relatively lower education. Macková et al., (2019) categorised Czech consumers into clusters: "unintentional food economisers", who do not waste food because they need to be frugal, "consumers affected by systematic education" since primary school, this includes consumers who are aware of all the negative consequences of food waste but they waste food because they have sufficient financial resources and "re-education", the typical food-wasters whose consumer behaviour is determined by sufficient or surplus income. Attitudes of Croatian consumers were analysed by Knezevic et al., (2019).

Their results showed there are five factors that represent the food waste attitudes of young people: concern about economic aspects of food waste, health concern, concern about environmental impact of food waste, as well as awareness and concern about expiration date. Based on those factors, the researchers segmented consumers into four groups: “consumers concerned about economic effects of food waste”, “unaware consumers neglecting food waste”, “well-informed consumers”, and “fully aware consumers, but not ready to take health risk”. Mallinson et al., (2016) pointed out, that the standard size of pre-packaged food tends to be too large for single person households and the cost of smaller formats is disproportionately expensive.

Another way of segmentation consumers related to food waste, which could be useful for planning anti-waste compagnies, made by Aschemann-Witzel et al., (2021) indicates five clusters related to the food-lifestyle: (1) “uninvolved young man waster”, (2) “convenience and price oriented low income”, (3) “well-planning cook and frugal food avoider”, (4) “young foodies” and (5) “established”. Respondents belonging to cluster 1 are young, male respondents who assess food waste as relatively less important. Cluster 2 consists of respondents who are uninvolved or less involved with food, who focus on price, have a preference for convenience foods and often correlate with lower income customers. Cluster 3 includes older respondents, females, sometimes with a fairly high income, who are characterised by a certain involvement with food, planning meals, using less convenience food and who report the lowest amount of food waste. The fourth cluster consists mainly of young people or females. It is characterised by high involvement with food and high importance given to the issue of food waste, who consider meals as an opportunity for social events and sometimes do not pay attention to meal planning or food prices. The fifth profile includes respondents with certain food involvements, in particular a culinary interest, who give less importance to price and use convenience food less, they are more highly educated, have a higher income or are elderly consumers.

Consumer attitudes regarding food waste in Poland were studied by Bilska et al., (2020), Dudziak et al., (2022), Szymkowiak et al., (2022), Tarczyńska et al., (2023) and Tomaszewska et al., (2020). The results obtained were similar in all studies regardless of the study group and the number of identified clusters. They identified cluster of food wasters, cluster of saving food consumers and aware but disengaged consumers. The results obtained by Polish researchers are comparable to those of scientists from other countries.

The issue of food waste and lost have substantial environmental (e.g., energy, soil, water, greenhouse gas emissions, non-productive use of natural resources, such as agricultural land and water and waste from non-renewable energy), social (e.g., failure to secure food for a wider population, increasing food prices and negative effect on nutrition levels) and economic (e.g., direct loss for all actors along the supply chain, profit reduction, disposal and treatment costs and negative impact on financial resources for other investments) consequences (Papargyropoulu et al., 2014; Luo et al., 2022) and most of the consumers are aware of that. In most of the analysed articles, attention was paid to the impact of reducing food waste in the implementation of SDGs, especially SDG 12. The Food Waste Index, measures food waste at retail and consumer level (households and food service) in tones. It was estimated that in 2019, 931 million tons of food were thrown away by households, retailers, restaurants and other food services. This amounts to 17% of the total food available to consumers, twice previous estimates (United Nations, 2021).

Summing up the analysed articles, it should be stated that researchers identify consumer attitudes mainly through their behaviour regarding handling food and shopping routines. They indicate that young people waste relatively the most food despite high awareness of the impact of waste on environmental, economic and social aspects. The researchers also pointed to the need to conduct further research on food waste by specific consumer groups (e.g., young people, silver generation, green consumers, rural and urban areas), because only then it will be possible to design and properly address anti-waste campaigns. In addition, attention should be paid to cultural and emotional aspects that affect the amount of food thrown away in households. It is also important to pay attention to the occurrence of crisis situations, such as the Covid 19 pandemic, which may significantly affect the handling of food in households and thus increase the level of food wase.

Conclusions

The results of this systematic review clearly indicate that food waste is an interdisciplinary problem. Factors affecting food waste are the subject of research by sociologists, psychologists, food technologists, commodity scientists, environmental protection specialists and others. The results also show that over the years, consumer behaviour can change, so the constant analysis of influencing factors is important for public policies to achieve SDGs. It was evident from all studies that changing consumer attitudes towards food waste can have a direct effect on the level of food waste.

Answering the formulated research question, it should be stated that consumer attitudes are similar in individual countries and the group of consumers who care about reducing food waste is growing. However, there is still a large group of consumers who are not interested in changing their behaviour related food waste.

Acknowledgments

Project financially supported by Minister of Education and Science in the range of the program entitled "Regional Initiative of Excellence" for the years 2019-2023, Project No. 010/RID/2018/19, amount of funding 12.000.000 PLN.

References

Annunziata, A., Agovino, M., Ferraro, A., Mariani, A. (2020). Household food waste: A case study in southern Italy. *Sustainability*, 12(4), 1495. https://doi.org/10.3390/su12041495

Annunziata, A., Muca, F.L., Mariani, A. (2022). Preventing Household Food Waste in Italy: A Segmentation of the Population and Suggestions for Action. *Sustainability*, 14(12), 7005. https://doi.org/10.3390/su14127005

Aschemann-Witzel, J., de Hooge, I.E., Almli, V.L. (2021). My style, my food, my waste! Consumer food waste-related lifestyle segments. *Journal of Retailing and Consumer Services*, 59, 102353. https://doi.org/10.1016/-j.jretconser.2020.102353

Aschemann-Witzel, J., de Hooge, I.E., Almli, V.L., Oostindjer, M. (2018). Fine-Tuning the Fight Against Food Waste. *Journal of Macromarketing*, 38(2), 168-184. https://doi.org/10.1177/0276146718763251

Bilska, B., Tomaszewska, M., Kołożyn-Krajewska, D., Piecek, M. (2020). Segmentation of Polish households taking into account food waste. Foods, 9(4), 379. https://doi.org/10.3390/foods9040379

Borg, K., Boulet, M., Karunasena, G., Pearson, D. (2022). Segmenting households based on food waste behaviours and waste audit outcomes: Introducing Over Providers, Under Planners and Considerate Planners. *Journal of Cleaner Production*, 351, 131589. https://doi.org/10.1016/j.jclepro.2022.131589

Bravi, L., Murmura, F., Savelli, E., Viganò, E. (2019). Motivations and actions to prevent food waste among young Italian consumers. *Sustainability*, 11(4), 1110. https://doi.org/10.1016/j.jclepro.2022.131589

Coskun, A. (2021). Identification of different user types for designing household food waste interventions. *International Journal of Sustainable Engineering*, 14(4), 609-617. https://doi.org/10.1080/19397038.2021-.1886372

Di Talia, E., Simeon,e M., Scarpato, D. (2019). Consumer behaviour types in household food waste. *Journal of Cleaner Production*, 214, 166-172. https://doi.org/10.1016/j.jclepro.2018.12.216

Dudziak, A., Stoma, M., Derkacz, A.J. (2022). Circular Economy in the Context of Food Losses and Waste. *Sustainability*, 14(16), 10116. https://doi.org/10.3390/su141610116

Falasconi, L., Cicatello, C., Franco, S., Segre, A., Setti, M., Vttuari, M., Cusano, I. (2016). Consumer approach to food waste: Evidences from a large scale survey in Italy. *Italian Review of Agricultural Economics,* 71, 266-278. https://doi.org/10.13128/REA-18646

Flanagan, A., Priyadarshini, A. (2021). A study of consumer behaviour towards food-waste in Ireland: Attitudes, quantities and global warming potentials. *Journal of Environmental Management*, 284, 112046. -https://doi.org/-10.1016/j.jenvman.2021.112046

Fonseca, J.R.S. (2013). A Latent Class Model to discover Household Food Waste Patterns in Lisbon City in Support of Food Security, Public Health and Environmental Protection. *International Journal on Food System Dynamics*, 4(3), 184-197. https://doi.org/10.18461/ijfsd.v4i3.433

Gaiani, S., Caldeira, S., Adorno, V., Segrè, A., Vittuari, M. (2018). Food wasters: Profiling consumers' attitude to waste food in Italy. *Waste Management*, 72, 17-24. https://doi.org/10.1016/j.wasman.2017.11.012

Islam, M. (2020). Are Students Really Cautious about Food Waste? Korean Students’ Perception and Understanding of Food Waste. *Foods*, 9(4), 410. https://doi.org/10.3390/foods9040410

Juergens, U. (2023). Does Food Shopping Behaviour Determine Food Waste Vulnerability in Private Households? Quantitative Analysis on Case Studies from Germany. *Sustainability*, 15(6), 4818. https://doi.org/10.3390-/su15064818

Knezevic, B., Kurnoga, N., Anic, I.D. (2019). Typology of university students regarding attitudes towards food waste. *British Food Journal*, 121(11), 2578-2591. https://doi.org/10.1108/BFJ-05-2018-0316

Luo, N.; Olsen, T.; Liu, Y.; Zhang, A. (2022). Reducing food loss and waste in supply chain operations. *Transportation Research E: Logistics and Transportation Review,* 162, 102730. https://doi.org/10.1016/-j.tre.2022.102730

Macková, M.; Stávková, J. (2019). Czech consumers’ attitudes to food waste. *Agricultural Economics-Czech*, 65(7), 314-321. https://doi.org/10.17221/364/2018-AGRICECON

Mallinson, L.J., Russell, J.M., Barker, M.E. (2016). Attitudes and behaviour towards convenience food and food waste in the United Kingdom. *Appetite*, 103, 17-28. https://doi.org/10.1016/j.appet.2016.03.017

Muresan, I.C., Harun, R., Andreica, I., Chiciudean, G.O., Kovacs, E., Oroian, C.F., Brata, A.M., Dumitras, D.E. (2022). Household Attitudes and Behavior towards the Food Waste Generation before and during the COVID-19 Pandemic in Romania. *Agronomy*, 12(3), 746. https://doi.org/10.3390/agronomy12030746

Nabi, N., Karunasen, G.G., Pearson, D. (2021). Food waste in Australian households: Role of shopping habits and personal motivations. *Journal of Consumer Behaviour*, 20(6), 1523-1533. https://doi.org/10.1002/cb.1963

Närvänen, E., Mesiranta, N., Saarijärvi, H., Nevalainen, J. (2023). Examining consumer food waste through grocery retailers' customer data: Segments and practical implications. *International Journal of Consumer Studies*, 47(4), 1273-1290. https://doi.org/10.1111/ijcs.12903

Papargyropoulu, E., Lozano, R., Steiinberger, J.K., Wright, N., bin Ujang, Z. (2014). The FoodWaste Hierarchy as a Framework for the Management of Food Surplus and FoodWaste. *Journal of Cleaner Production,* 76, 106-115. https://doi.org/10.1016/j.jclepro.2014.04.020

Pércsi, K.N., Ujj, A., Jancsovszka, P. (2023). Segmentation of Hungarian Consumers Based on Circular Economy Values and Awareness of Food Waste.*Sustainability*, 15(11), 8838. https://doi.org/10.3390/su15118838

Pocol, C.B., Pinoteau, M., Amuza, A., Burlea-Schiopoiu, A., Glogovețan, A.-I. (2020). Food waste behavior among Romanian consumers: A cluster analysis. *Sustainability*, 12(22), 9708. https://doi.org/10.3390/su12229708

Richter, B. (2017). Knowledge and perception of food waste among German consumers. *Journal of Cleaner Production*, 166, 641-648. https://doi.org/10.1016/j.jclepro.2017.08.009

Romani, S., Grappi, S., Bagozzi, R.P., Barone, A.M. (2018). Domestic food practices: A study of food management behaviors and the role of food preparation planning in reducing waste. *Appetite*, 121, 215-227. https://doi.org-/10.1016/j.appet.2017.11.093

Schwodt, S., Obersteiner, G. (2018). Development of tailor-made food waste prevention measures based on consumer type analysis. *Scientific Papers-Series A-Agronomy*, Vol. LXI, No. 1.

Szymkowiak, A., Borusiak ,B., Pierański, B., Kotyza, P., Smutka, L. (2022). Household Food Waste: The Meaning of Product’s Attributes and Food-Related Lifestyle. *Frontiers in Environmental Science*, 10, 918485. https://-doi.org/10.3389/fenvs.2022.918485

Tarczynska, A.S., Malinowska, E., Urbanowicz, A. (2023). Attitudes and Behaviours of Young Consumers towards Wasting Food: Case Study Based on Polish Students. *Sustainability*, 15, 3328. https://doi.org/10.3390/-su15043328

Theodoridis, P.K., Zacharatos, T.V. (2022). Food waste during Covid- 19 lockdown period and consumer behaviour – The case of Greece. *Socio-Economic Planning Sciences*, 83, 101338. https://doi.org/10.1016/j.seps.-2022.101338

Tomaszewska, M., Bilska, B., Kołożyn-Krajewska, D. (2020). Do Polish Consumers Take Proper Care of Hygiene while Shopping and Preparing Meals at Home in the Context of Wasting Food? *International Journal Of Environmental Research And Public Health*, 17, 2074. https://doi.org/10.3390/ijerph17062074

Vittuari, M., Falasconi, L., Masotti, M., Piras, S., Segrè, A., Setti, M. (2020). 'Not in My Bin': Consumer's understanding and concern of food waste effects and mitigating factors. *Sustainability*, 12(14), 5685. https://doi.org/10.3390/su12145685

DIGITAL PRODUCT PASSPORT (DPP) AS AN IMPORTANT MECHANISM SUPPORTING THE CIRCULAR ECONOMY

Mariusz Tichoniuk

Department of Industrial Products and Packaging Quality, Institute of Quality Science,
Poznań University of Economics and Business, Poznań, Poland
**Corresponding Author: e-mail:* mariusz.tichoniuk@ue.poznan.pl

DOI: 10.56091/CTQS.Innov-21

Abstract

The concept of "cradle-to-grave" product tracing is not a new approach in the fight for sustainable production and consumption. Collecting information about the product's environmental impact at every stage of the life cycle helps in designing products and methods of production and utilization that will be more appropriate to the circular economy. However, the effectiveness of such an approach requires gathering reliable and useful information about the product. The Circular Economy Action Plan (CEAP) adopted by the European Commission in 2020 and subsequent normative documents introduced the so-called Digital Product Passport (DPP) as a tool for collecting and sharing data on product's characteristics and origin. Batteries and accumulators will be covered first by the "passport obligation", followed by textiles and construction materials. Subsequently, DPP regulations are planned for electrical and electronic devices, and over time the system is to ensure digital tags for various products. It would allow for the convenient recording of transactional and sustainability-based data. The data carriers could be various technical solutions available via smart device applications based on already existing identification and communication standards (such as GS1).

The article presents the areas that can be supported by the introduction of the Digital Product Passport in the effective functioning of the circular economy and increasing the products' sustainability, repairability, and recyclability. Not only the benefits were shown, but also the anticipated limitations and reservations that appear from manufacturers, consumers, re-sellers, and recycling entities.

Keywords: circular economy, Digital Product Passport (DPP), product traceability

Introduction

Information about the product and its properties at each stage of the life cycle can be very useful in determining its environmental impact and potential for post-use management (Koppelaar et al., 2023, Reich et al., 2023). In light of the current regulations on general product safety (Regulation (EU) 2023/988), all participants of the supply and distribution chain should ensure that all products available on the European market are safe and remain in compliance with EU regulations.

The information for product identification and the entities responsible for it, as well as, detailed product use instructions and safety information, could be also provided in a digital form by electronic means of communication, such as a QR or data matrix codes. Ensuring product traceability and information on the manufacturer and other relevant economic operators throughout the entire supply chain helps to take effective and proportionate corrective measures against dangerous products, such as targeted recall (Piwowarczyk, 2023).

In turn, according to the EU harmonized legislation on products covered by this regulation, they must meet the requirements of the above-mentioned EU rules from the moment of introduction of the product on the market, throughout the period of its availability and usability, until its final use will be achieved (Regulation (EU) 2023/988). The manufacturer or other relevant economic operators has an obligation to:

- keep the technical documentation, declaration of conformity, and documentation necessary to demonstrate the product's compliance with the requirements for 10 years from the date of placing the product on the market;
- place on the product (and in the cases described in specific regulations – on the packaging, in the attached document, or on the label) information enabling the identification of the product;
- put on the product (and in the cases described in specific regulations – on the packaging, in the attached document or on the label) manufacturer's name, registered trademark (if it has one), and address.

All information required by law must be available to each participant of the supply chain, including consumers, but their practical use boils down to ensuring the required product traceability and implementing safety procedures in case of a threat to the consumer's life or health (e.g., required product withdrawal). Information on the conditions of product use and service, as well the waste management are available to consumers, but the convenience of access to this data is often limited. The implementation of information about the product (its current traceability) as part of the environmental impact assessment (in the entire cycle – production, use, and disposal) is also problematic, as it often requires additional data related to its production technology, transport/storage conditions and expected final consumption (van Capelleveen et al., 2023).

On 30 March 2022, the European Commission put forward a proposal for a regulation to establish a general framework for setting ecodesign requirements for sustainable products and to repeal current rules that focus on energy-related products only. The proposal for a Regulation on Ecodesign for Sustainable Products (RESP) addresses product design, which determines up to 80% of a product's lifecycle environmental impact.

Green Deal – new proposals, presented by European Commission on 30 March 2022, provide a variety of solutions to make sustainable products the norm on EU market and boost Europe's resource independence (European Commission 2022a) (Fig. 1). According to the document almost all physical goods on the European market should be more friendly to the environment, compatible with the circular economy and energy efficient thorough their whole lifecycle (from the design, through to daily use, repurposing and end-of-life). The communication was a kind of overview of different initiatives in the Circular Economy package implemented actually or in the near future in the European Union. This approach is also called a Sustainable Product Initiative (SPI), which includes six areas of activities (Fig. 1):

1. Ecodesign Working Plan 2022-2024 – for higher energy efficiency and circularity of energy-related products (e.g., batteries);
2. Complementary sectoral rules – focused on construction and other product categories (including packaging);
3. Strategy for Sustainable and Circular Textiles – to bind eco-design requirements including durability, reparability, and recycled fiber content as well as to limit fast fashion, textile waste, and destruction;
4. New rules to empower consumers for the green transition – including consumer protection against greenwashing and planned product obsolescence;
5. Global action – to facilitate a broad discussion between countries and stakeholders on sustainable production and consumption and to promote sustainable business models at a global level;
6. Support for circular business models – to guide and enhance the introduction of circular business.

The initiatives mentioned above focus on disseminating the principles of eco-design and the transparency and availability of information about products, and are in line with the European Union's policy focusing on counteracting so-called the planned obsolescence of products and the destruction of unsold goods.

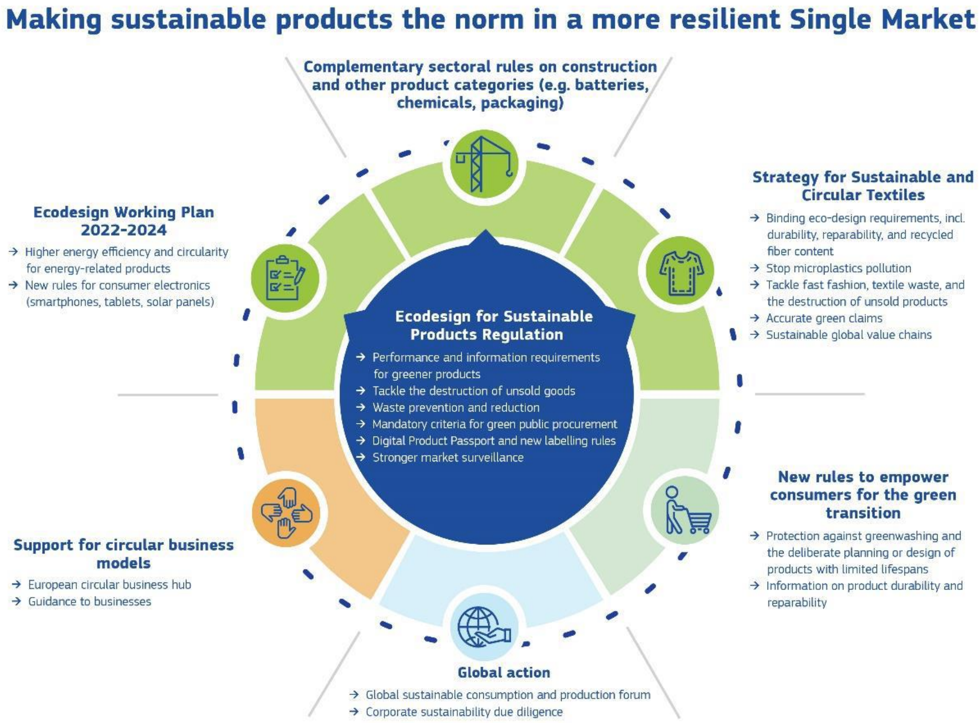


Fig. 1. Overview of initiatives in the Circular Economy package summarized in the EU communication of 30/03/2022

Source: European Commission 2022a.

The circular economy aims to close the material loop and reduce waste, but an important condition for achieving this goal is the availability of product data throughout its life cycle (Plociennik et al., 2022). Resource collectors (recyclers) want to know what material they can recover, producers want to determine the recyclability of their products, and consumers want to know the environmental impact of individual products (Berger et al., 2023). The proposal for a Regulation on Eco-design for Sustainable Products assumes the creation of a Digital Product Passport (DPP) for the electronic recording, processing, and electronic exchange of product information between companies in the supply chain, authorities, and consumers (Koppelaar et al., 2023). As a part of the Sustainable Product Initiative (SPI), the passport will be introduced to store and share all relevant information in the product lifecycle supporting circularity, transparency, and sustainability along the entire value chain (Fig. 2). The Digital Product Passport should contain a set of information important for consumers as well as for manufacturers and public authorities, regarding environmental impact (products' environmental footprint), recycling information (details about how to recycle the product effectively) and repair instructions (guidance on how to repair the product easily).

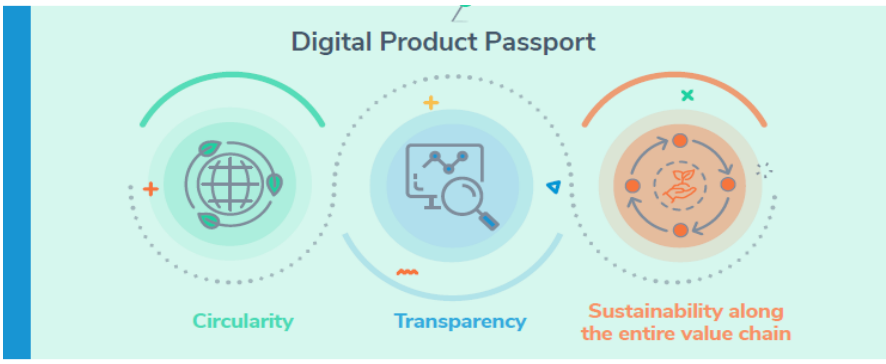


Fig. 2. Areas of support through a Digital Product Passport across the entire value chain

Source: ecostandard.org 2023.

According to the Circular Economy Action Plan (CEAP) adopted by the European Commission in 2020, textiles should be more durable, repairable, reusable, and recyclable. A new attitude should also ensure that textile production takes place in full respect of social rights (European Commission, 2022a). The consumption of textiles has the fourth highest impact on the environment and climate change in the European Union (right after food consumption, housing, and mobility). Additionally, textile is the third highest area of intake for water and land use, and fifth highest for the use of primary raw materials (European Commission, 2022b). In accordance with the CEAP policy, all textile products available on the EU market should be long-lived and recyclable, made as much as possible of recycled fibers, free of hazardous substances, and produced with respect to social rights and the environment. By 2030 economically profitable re-use and repair services should be widely available and consumers will benefit longer from textile products. The producers have to take responsibility for their products along the value chain and therefore and therefore it is required to introduce a complete and reliable source of information on textile products in the form of a product passport.

A very important goal of the CEAP plan is to boost the EU market for construction products, which in the light of the new legal regulations, are to be more sustainable and environmentally friendly (European Commission, 2022a). The construction products industry encompasses 430,000 companies in the European Union with a turnover of €800 billion. The whole construction ecosystem represents almost 10% of the EU value added. It employs ca. 25 million people in over 5 million firms. Generally, buildings are responsible for ca. 50% of resource extraction and consumption and more than 30% of the EU's total waste generated per year. In addition, buildings are responsible for 40% of the EU's energy consumption and 36% of energy-related greenhouse gas emissions.

The introduction of CEAP standards for the construction industry should create a harmonized framework to assess and communicate the environmental impact of construction products. New requirements will ensure that the design and manufacture of construction products are in accordance with the state of the art, which is intended to ensure more durable, repairable, recyclable, and easier to re-manufacture building elements (Langley et al., 2023). The Digital Product Passport is intended to provide information to evaluate these properties. A similar plan is prepared for electronic devices. The European Commission has also adopted an Ecodesign and Energy Labelling Working Plan 2022-2024 to cover new energy-related products. This was prepared to update and develop the environmental requirements for products that are already regulated. This sector of the EU market is also particularly important from the point of view of a sustainable economy because the group of consumer electronics (i.e., smartphones, tablets, solar panels) generates the fastest-growing waste stream (European Commission 2022b). The energy-related products will also be among the first product groups to be subject to the DPP obligation.

The next two chapters present the main advantages and limitations in the implementation of the Digital Product Passport and its support for the circular economy.

Doors that can be (widely) opened with a Digital Product Passport

Eco-design / impact on product design

The knowledge about the environmental impact of a product, its manufacturing process, and/or raw materials applied, helps to design more eco-friendly products throughout their entire life chain. The Eco-design Directive (2009) prescribes energy-related ecodesign criteria for certain products and communicates this through energy labels. It’s estimated that in 2021 these regulations saved consumers €120 billion and led to a 10% lower annual energy consumption by the products in their scope (Steal 2023). The introduction of the Digital Product Passport is partly a preparation for the implementation of the so-called Directive for Sustainable Products (ESPR) that will replace the current Ecodesign Directive (2009/125/EC) and introduce more eco-design criteria for a broader range of products (Nickel, 2023). The ESPR rules are addressed to product design, which determines up to 80% of a product's lifecycle environmental impact. The new requirements are intended to make products more durable, reliable, reusable, upgradable, reparable, easier to maintain, refurbish and recycle, and energy and resource-efficient (Fig. 3).

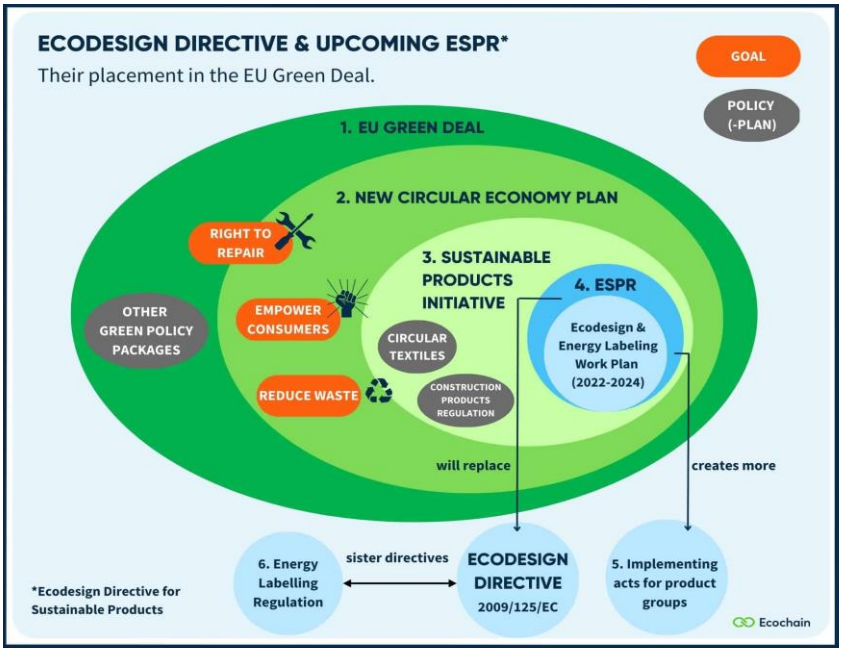


Fig. 3. Green Deal policy framework around ESPR (green) and the ESPR's relationship to the Ecodesign directive (blue)

Source: Nickel 2023.

Producers with appropriate knowledge (obtained from the Digital Product Passports) will be able to choose products and processes that support the circular economy models. On the other hand, product-specific DPP information requirements will ensure consumers know the environmental impacts of their purchases (Protokol, 2023). The ESPR regulations make it easier to repair or recycle products and facilitate waste reduction. Improved traceability and more complete data about product durability could help influence the creation of products optimized for their expected usage. This data can also improve logistics and enhance the 'just in time' management of products and resources (Patorska et al., 2023). The ESPR proposal also contains measures to end the destruction of unsold consumer goods, as well as expand green public procurement, and provide incentives for sustainable products.

Consumer empowerment and increase of environmental consciousness

Wider availability of information about products may have a significant impact on consumer behavior and stimulate the development of a specifically organized economy, e.g., in a circular approach. Consumers are becoming increasingly conscious of the environmental impact of products and are starting to pay more and more attention to sustainable products (Protokol, 2023).

The Introduction of the Digital Product Passport can educate better-informed consumers who will pay attention to their rights to long-term use of products. The lifetime of a product should not be limited through design features. Software updates, consumables (e.g., ink cartridges, light bulbs, coffee pads), spare parts, and accessories will be demanded by environmentally conscious consumers and they must be available for an appropriate period. The “digital passport” containing accurate and up-to-date information about the product would be set up to increase transparency and enable consumers to make informed purchasing choices (Popp, 2023).

Data credibility / a new dimension of product traceability

The Digital Product Passport is intended to facilitate the collection and sharing of this data for all interested stakeholders in the full product life cycle. DPP will be a virtual document that enables each consumer to check “the product's journey” throughout its life cycle (van Capelleveen et al., 2023). Such conscious consumers will be more aware of their choices when purchasing passport-labeled products, have greater repair and recycling options, and can increase their knowledge of environmental impact, thus reducing the amount of waste generated (Mazurek, 2023). The passport will be useful also for public authorities in more effective control and detection of counterfeit products, as well as misleading declarations regarding the product's compliance with environmental protection standards (so-called greenwashing).

According to CERP, a passport is a set of data enabling product identification with a unique identifier, which will be available electronically via a data carrier (e.g., QR code, barcode, or NFC tagging). Basic product data will be available offline (without the need for an Internet connection). Thanks to this data, it will be possible to know the composition and origin of individual components throughout the life cycle of the product. Looking at it more broadly, it can be said that the passport creates the so-called "digital twin" of a physical product that will be directly identified with the physical product by means of a data carrier. Reading will be possible through an application on a mobile device such as a smartphone or tablet. The new way of sharing information will not replace the forms currently used (e.g., manuals, labels), but will be a digital complement to them (Protokol, 2023).

New business creation / accelerating the development of the circular economy and post-consumption

Inefficiencies in product information can create business opportunities across the value chain. The introduction of the Digital Product Passport could stimulate underserved markets that suffer from restricted information about the products and their environmental impact during the whole life cycle (Patorska et al., 2023).

The diagram presented by the Nordic Innovation organization on the circular business models workshops indicates five business development opportunities that can be supported by improved product information flow (Fig. 4).

Fig. 4. Five business models reduce the inefficiencies and create value for companies

Source: Nordic Innovation 2023.

Identification and cessation of the use of unsustainable materials can be introduced already at the product design stage, when the impact of these materials on the environment is known, e.g., through data from the product passport. Another opportunity to increase company efficiency is to identify underutilized or unused products and assets whose use be improved based on the information obtained. Using DPP-related data, it is possible to estimate a more accurate product lifespan, which is difficult with limited information about repair options and maintenance. Sustainable companies should also not allow the end-of-life value of products to be wasted by not managing valuable components, materials, or even energy (Berger et al., 2023). The last of the indicated possibilities that can be supported by developed product knowledge is the ability to engage the consumer in all stages of the product life cycle, where the collected and transmitted information constitutes valuable support for the development of sustainable products. Additionally, engaging consumers in product creation and management also allows the company to offer additional services and add-on sales (Nordic Innovation 2023).

The indicated examples of business development opportunities resulting from increased product information focus on the possibilities for selected enterprises but the Directive for Sustainable Products (ESPR) aimed at supporting product reuse and repair sector as well. It is estimated that by developing services in this area, an additional 300,000 jobs can be created in the EU economic area (Patorska et al., 2023).

For example, Rene H. Reich with coworkers performed a survey among 28 experts and indicated that DPPs should foster recycling, repurposing, remanufacturing, refurbishing, repairing, and reusing electronics. All this will result in improved circular product strategies. Additionally, there is a proven need for a greater focus on the phase-centric concept of the DPPs incorporating product use information besides the static "cradle-to-gate" product information (Reich et al., 2023).

Obstacles to be overcome (milestones to go)

Standardization

The Digital Product Passport will be not only a source of information but also a driving force to introduce requirements regarding the standardization of data provided with the product. The wide range of product specifications and classifications requires the introduction of coherent regulations in different countries taking into account product characterization and traceability requirements (Muradin & Foltynowicz, 2019; Koppelaar et al., 2023). Entrepreneurs involved in international trade understand this very well and support the introduction of a product passport and similar solutions in this regard (Kjellberg, 2022). There are many global and European standardization authorities, but taking into account the degree of internationalization and the openness of the structure towards product information standards, the GS1 standards seem to be the best candidate for implementation in the digital product passport (Patorska et al., 2023). Figure 5 shows schematically what data groups should be included in the scope of DPP. Many of them are closely related to the development of circular business models and a sustainable approach. Information about the product's environmental impact is necessary in both cases and can be expressed in many of the aspects shown in the chart.

GS1 standards can also be adapted to collect data related to reducing the adverse impact of the product life cycle on the environment. In 2022, GS1 Polska conducted a survey among GS1 System Participants. The study involved enterprises from various economic areas including trade, transport and logistics, industrial production, and health care (Stanek-Kowalczyk 2023). Nearly three-quarters of respondents said that GS1 standards support the sustainability of their organizations and help them meet the Sustainable Development Goals defined by the United Nations. The indicated positive aspects of applying GS1 standards included: ensuring the safety of products and services (40% of respondents), monitoring the supply chain (44%), shortening the time of individual delivery transactions, and reducing the number of formalities related to them (39%). Additionally, the use of GS1 standards allowed for a reduction in the consumption of raw materials (24%) and the number of wasted products (22%).

If the GS1 standards that carry product information provided so many effects consistent with the goals of introducing the Digital Product Passport, it can be concluded that such consistent and standardized data can be the basis for the success of product passporting.

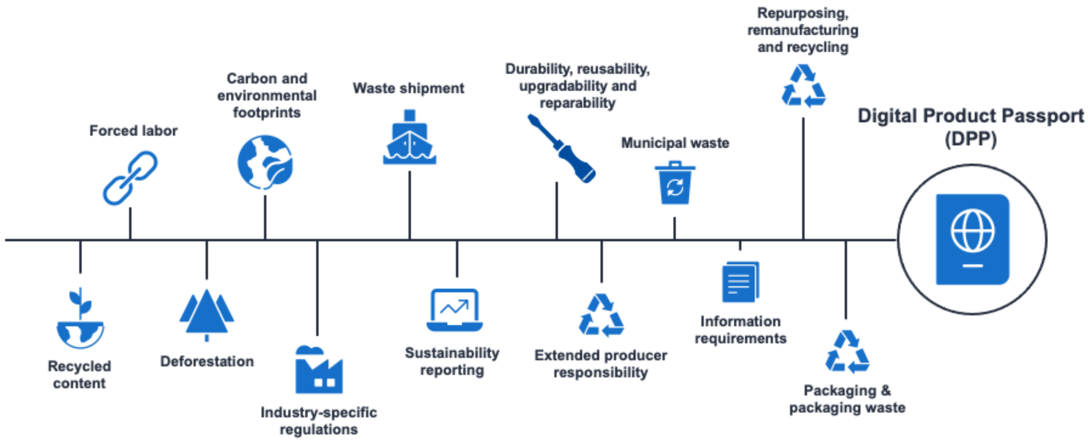


Fig. 5. The scope of data related to the Digital Product Passport

Source: Kjellberg 2022.

Data sharing

The authors of the EU law want to implement DPP gradually, while industrial entrepreneurs (managers) should proactively reconfigure data flows to take into account the decision-making process in the reverse supply chain (Jensen et al., 2023). However, it should be remembered that DPP is not only a data register and requires appropriate IT support in collecting and sharing information. Figure 6 shows how data recorded in a product passport can support circular business models involving manufacturers, retailers, and consumers, as well as recyclers and public sector authorities. To ensure the usefulness of DPPs and the data they provide, the system for collecting and distributing them should be publicly available, reliable, and user-friendly (Mazurek, 2023). To achieve this goal, data should be based on open standards, in an interoperable format, machine-readable, structured, and searchable. This is related to the standardization requirement mentioned above, but also to the need for openness and availability of the required information. The product passport won’t work in isolation and should be developed through cooperation. The common language of sustainability established by DPP should encourage collaboration across industries and should support innovation in sustainable practices. Market participants with easy access to product information can learn from each other's successes and challenges, creating a collective push towards greener solutions and approaches (Piwowarczyk, 2023). Data management experts conclude that the entire product data storage system should be decentralized, and thus created and maintained by business entities.

The data should follow the product from the manufacturer, through the wholesaler/retailer, to the user, and finally to the recycler. This approach will expand the availability of product information, which will also be owned by the buyer of the product, who has it in a digital version that will not be under the control and influence of a central system (both the manufacturer, distributor, and control units). It is also consistent with the EU Data Strategy which encourages the use of high-value public data sources available to all interested parties (Mazurek, 2023).

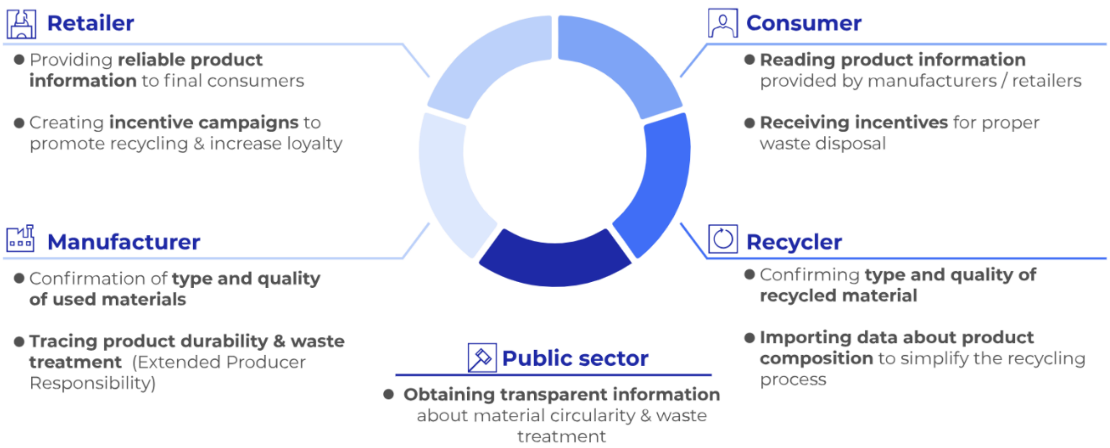


Fig. 6. Circular economy elements provided by DPP in the life cycle of products

Source: Billon 2023.

Traceability of products towards the whole life cycle

The general idea of Digital Product Passports is to make information directly related to the product easily available in digital form. It should improve the organization and operation of the circular economy and sustainability maintenance throughout the product life cycle (Walden, Steinbrecher & Marinkovic, 2021). Product traceability is particularly useful during the product's availability on the market (transport, storage, distribution), where we can directly check how the product is disseminated on the market and among end users, and indirectly estimate its possible impact on the environment (e.g., consumption of raw materials for production and distribution or type and amount of post-use waste) (Reich et al., 2023). The obvious advantage of traceability improved by DPP is the ability to identify and control critical sections ("bottlenecks") of the circular economy of individual products. On the other hand, such high traceability may be resisted by individual members of the supply chain, who may be afraid of too much transparency and ease access to product information.

Implementation costs

According to the Deloitte report on the impact of international, open standards on circularity in Europe (Patorska et al., 2022) the estimated costs connected with the introduction of Digital Product Passport will be generated by the integration and market modification in the next 10 years. It could be possible three scenarios depending on different DPP implementation models. The costs of the development of institutional centrally managed standards and specification models could reach between 9 billion and 18 billion euros. Much higher costs are associated with the competing proprietary standards and systems used by manufacturers and retailers (Langley et al., 2023). The adaptation of different data standards for the integration and aggregation of data required by DPP could create costs in the range of 63 billion to 152 billion euros. The most economically justified solution would be to use a DPP model based on open global and decentralized standards, which would cost from EUR 3 to just over EUR 7 billion over a 10-year period. This would certainly alleviate the risk of duplicating systems for collecting and processing data on products and their manufacturers/distributors, and would also increase the efficiency of the economy (Patorska et al., 2022).

Conclusions

The introduction of the Digital Product Passport for the indicated areas of business activity could generate big organizational and economic problems at first, but if properly prepared, this system will be able to operate with a little human intervention and could be implemented in subsequent sectors and branches of the economy at lower costs and with fewer difficulties. The DPP will provide convenience to consumers through easy access to the most important information and the ability to check the authenticity of given products. It limits the data disruption along the supply chains and supports in making sustainable choices. Similarly, entrepreneurs who care about sustainable development throughout the life cycle of their products will have an opportunity to reliably provide information on the best features of these products.

The Digital Product Passport has the potential to support the circular economy and make circular business models viable, mainly because it could enable consumers to better assess product sustainability and help identify which product has an undesirable environmental impact. Of course, the introduction of a passport still requires a lot of effort, including mandatory and standardized information about products available on the market, support of product eco-design, long lifetime and improved material recovery, and accessibility of product information both for consumers and market surveillance authorities.

Data accessibility needs to be guaranteed and contain the necessary level of detail. The Digital Product Passport should not be introduced for isolated sectors only, because its impact on the circular economy development strongly depends on depends strongly on its ubiquity and ease of use.

References

Berger K., Baumgartner R.J., Weinzerl M., Bachler J., Preston K., Schöggl J.-P. (2023) Data requirements and availabilities for a digital battery passport – A value chain actor perspective. *Cleaner Production Letters*, 4, 100032, https://doi.org/10.1016/j.clpl.2023.100032

Billon (2023) Digital Product Passport, https://billongroup.com/enterprise-solutions/trusted-documentmanagement/digital-product-passport Billon Group [access: 10/10/2023]

ecostandard.org (2023) Sustainable Products Initiative – A new digital product passport, https://ecostandard.org/news_events/sustainable-products-initiative-a-new-digital-product-passport/ [access: 1/09/2023]

European Commission (2022a), Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions on making sustainable products the norm, Brussels, 30.3.2022, COM(2022) 140 final

European Commission (2022b) Green Deal: New proposals to make sustainable products the norm and boost Europe's resource independence, An official website of the European Union, -https://ec.europa.eu/commission-/presscorner/detail/en/ip_22_2013 [access: 02/06/2023]

Jensen S.F., Kristensen J.H., Adamsen S., Christensen A., Waehrens B.V. (2023) Digital product passports for a circular economy: Data needs for product life cycle decision-making. Sustainable Production and Consumption 37, 242-255, https://doi.org/10.1016/j.spc.2023.02.021

Kjellberg S. (2022) Prepare Now for the EU Digital Product Passport. https://kezzler.com/blog/prepare-now-for-the-eu-digital-product-passport/ Kezzler AS Blog [access: 02/06/2023]

Koppelaar R.H.E.M., Pamidi S., Hajósi E., Herreras L., Leroy P., Jung H.-Y., Concheso A., Daniel R., Francisco F.B., Parrado C., Dell'Ambrogio S., Guggiari F., Leone D., Fontana A. (2023) A Digital Product Passport for Critical Raw Materials Reuse and Recycling, *Sustainability* 2023, 15, 1405. https://doi.org/10.3390/su15021405

Langley D.J., Rosca E., Angelopoulos M., Kamminga O. Hooijer C. (2023) Orchestrating a smart circular economy: Guiding principles for digital product passports. *Journal of Business Research*, 169, 114259, https://doi.org/10.1016/j.jbusres.2023.114259

Mazurek P. (2023) Cyfrowy Paszport Produktu – elektroniczny dokument pokazujący całą drogę produktu. Konfederacja Lewiatan. https://lewiatan.org/cyfrowy-paszport-produktu-elektroniczny-dokument-pokazujacy-cala-droge-produktu-2/ [access: 10/10/2023]

Muradin M., Foltynowicz Z. (2019) The Circular Economy in the Standardized Management System. Amfiteatru Economic, 21 (Special Issue No. 13), pp. 871-883. https://doi.org/10.24818 /EA/2019/S13/871

Nickel L. (2023) Ecodesign Directive for Sustainable Products (ESPR): 2024 Overview. https://ecochain.com/blog-/espr-2024-overview/ Ecochain [access: 20/12/2023]

Nordic Innovation (2023) Circular Business Models Workshops: The Fundamentals 2. -https://www.youtube.com-/watch?v=AYnbrYJoVew Nordic Circular Economy Playbook, Nordic Innovation, Oslo, Norway [access: 02/06/2023]

Patorska, J., Łaszek, A., Leoniewska-Gogola, J., Maciborski, D., Fusiara, A. (2022) Impact of international, open standards on circularity in Europe. Deloitte, Poland. -file:///C:/Users/user/Downloads/pl_Impact-_of_international_open_standards_on_circularity_in_Europe_April2022_2-1.pdf [access: 02/06/2023]

Piwowarczyk M. (2023) Kompletny przewodnik po DPP (Digital Product Passport) – jak przygotować się na nadchodzące regulacje w 2024 roku? https://pl.ergonode.com/blog/the-ultimate-guide-to-dpp-digital-product-passport-how-to-prepare-now-as-a-company-for-upcoming-regulations-in-2024 Ergonode. [access: 20/12/2023]

Plociennik, C., Pourjafarian, M., Nazeri, A., Windholz, W., Knetsch, S., Rickert, J., Ciroth, A., Precci Lopes, A. D. C., Hagedorn, T., Vogelgesang, M., Benner, W., Gassmann, A., Bergweiler, S., Ruskowski, M., Schebek, L., & Weidenkaff, A. (2022). Towards a digital lifecycle passport for the circular economy. *Procedia CIRP*, *105*, 122-127. https://doi.org/10.1016/j.procir.2022.02.021

Popp D. (2023) Ecodesign: more environmentally-friendly and energy-efficient products. European Parliament News. -https://www.europarl.europa.eu/news/en/press-room/20230707IPR02429/ ecodesign-more-environmentally-friendly-and-energy-efficient-products [access: 10/10/2023]

Protokol (2023) Digital Product Passport (DPP): A Complete Guide. https://www.protokol.com/ insights/digital-product-passport-complete-guide/ [access: 02/10/2023]

Regulation (EU) 2023/988 of the European Parliament and the Council of 10 May 2023 on general product safety, amending Regulation (EU) No 1025/2012 of the European Parliament and of the Council and Directive (EU) 2020/1828 of the European Parliament and the Council, and repealing Directive 2001/95/EC of the European Parliament and of the Council and Council Directive 87/357/EEC

Reich R.H., Ayana, J., Alaerts, L., Van Ackera K. (2023) Defining the goals of Product Passports by circular product strategies. 30^{th} CIRP Life Cycle Engineering Conference. *Procedia CIRP*, 116, 257-262. https://doi.org/10.1016/-j.procir.2023.02.044

Stanek-Kowalczyk A. (2023) „Zielony" język danych: jak standardy GS1 wspierają zrównoważony rozwój. Kod Eksperta. https://www.kodeksperta.pl/zielony-jezyk-danych-jak-standardy-gs1-wspieraja-zrownowazonyrozwoj/ [access: 10/10/2023]

Steal D. (2023) Ecodesign Directive for Sustainable Products (ESPR): 2023 Overview. *Ecochain*. https://ecochain.com/blog/espr-2023-overview/ [access: 22.10.2023]

van Capelleveen G., Vegter D., Olthaar M., van Hillegersberg J. (2023) The anatomy of a passport for the circular economy: a conceptual definition, vision and structured literature review. *Resources, Conservation & Recycling Advances*, 17, 200131, https://doi.org/10.1016/j.rcradv.2023.200131

Walden J., Steinbrecher, A., Marinkovic, M. (2021) Digital Product Passports as Enabler of the Circular Economy, Chemie Ingenieur Technik, Special Issue: *Industrielle Ressourcenstrategien für eine zirkuläre Wirtschaft*, Nov. 2021, pp 1717-1727. https://doi.org/10.1002/cite.202100121

MODIFICATION OF WATER VAPOUR BARRIER PROPERTIES OF COMPOSTABLE FILMS USED FOR FOOD PACKAGING

Marta Biegańska, Karolina Wiszumirska*, Katarzyna Kusowska

Department of Industrial Products and Packaging Quality, Institute of Quality Science,
Poznań University of Economics and Business, Poznań, Poland
**Corresponding Author e-mail: karolina.wiszumirska@ue.poznan.pl*

DOI: 10.56091/CTQS.Innov-22

Abstract
Surface modification of compostable packaging film was carried out by hand-coating with a chitosan solution, obtaining a coating with a thickness of 20 μm. The modified film was tested for determination of water vapor transmission rate (WVTR) by weight method based on ASTM E96/E96M-16, tensile strength (ISO 527-3:2018), puncture (EN 14477:2004), and sensory analysis (DIN 10955:2004). Modification through the application of the coating improved WVT by 23%, increased mechanical strength by 16%. However, the increase in stiffness resulted in a decrease in puncture resistance. It was also shown that the modified film did not change the taste or odor when in direct contact with food products. The research is a pilot study.

Keywords: packaging, compostable materials, chitosan, WVT, coating

Introduction

Food packaging is one of the most important actors in the food supply chain as it protects and preserves the quality and safety of food products and extends the shelf-life. As a consequence, the food packaging has a share in the material and energy consumption within food life cycle, as well as contribution to its emissions, waste generation and related environmental impacts. Packaging has the contribution to the impacts that occur in the end-of-life phase when product has been already consumed. Therefore, challenge for assessing the sustainability of food products is the availability of widespread recycling of packaging waste.

Compostable packaging materials produced from renewable raw materials have been known for many years, but due to their limited usability and the lack of widespread collection systems in the bio-waste fraction in Poland, they have so far been niche solutions. However, with the implementation of the SUP Directive (Directive (EU) 2019/904) into the Polish law and the Regulation of the European Parliament and of the Council on packaging and packaging waste, amending Regulation (EU) 2019/1020 and Directive (EU) 2019/904, and repealing Directive 94/62/EC (PPWR) project, it is assumed that these materials will be given due support to function more widely in the market in various packaging applications.

Fig. 1. Examples of the use of compostable materials in the market

Source: own study.

The implementation of SUP Directive into the Polish law has resulted in the updating of four Polish laws:

1) the Act of 14th April 2023 on amending the Act on the obligations of entrepreneurs with regard to the management of certain waste and the product fee, and certain other acts;
2) the Act of 13th June 2013 on packaging and packaging waste management;
3) the Act of 14th December 2012 on waste;
4) the Act of 11th May 2001 on the obligations of entrepreneurs with regard to the management of certain waste and the product fee.

In terms of using the correct nomenclature for types of packaging material made partly or wholly of plastics, it is necessary to follow the updated definition. This is because a distinction has been made between "plastic" and "unmodified natural polymer", which creates new obligations for entrepreneurs that introduce packaging or products made from them and means that very precise vocabulary is required, especially in B2C communications. "Unmodified natural polymers" under this definition are "non-chemically modified substances" that occur naturally in the environment, on their own, unprocessed, or processed only by manual, mechanical or gravitational means through dissolution in water, flotation, extraction from water and steam distillation or heating only to remove water or substances that are extracted from air by any means. Another important distinction is whether the polymerisation process took place in nature or is the result of an industrial process using living organisms, so polymers produced by the fermentation process are not considered natural polymers, as the polymerisation did not take place in nature but in man-made manufacturing and fermentation processes under industrial conditions. Hence, the polyhydroxyalkanoate (PHA) group, for example, is not a category of natural polymers. As a general rule, if a polymer is obtained by an industrial process and the same type of polymer exists in nature, the polymer produced does not qualify as a natural polymer. The term "non-chemically modified substances" means a substance whose chemical structure remains unchanged, even if it has undergone a chemical process or treatment, or a physical mineralogical transformation, e.g., to remove impurities. Only the difference between the introduced and the obtained polymer should be considered, ignoring any modifications that may have taken place during the production process, as these are not relevant to the polymer's degradation properties. This means that, e.g., processed cellulose, in the form of viscose, lyocell and a cellulose coating, is not considered chemically modified, as the resulting polymers are chemically unmodified compared to the introduced polymer. Cellulose acetate is considered chemically modified because (compared to the natural polymer introduced) the chemical modifications to the cellulose that occur during the manufacturing process remain present at its end. If the changes in the polymer's chemical structure are the result of reactions that occur only during the natural polymer's extraction process (e.g., the process of obtaining wood pulp for the extraction of cellulose and lignin), they are not considered to be the result of the natural polymer's chemical modification. Accordingly, paper resulting from the wood pulp acquisition process is not considered to be composed of chemically modified natural polymers (Commission guidelines on single-use plastic products in accordance with Directive (EU) 2019/904 of the European Parliament and of the Council on the reduction of the impact of certain plastic products on the environment).

Plastics manufactured using modified natural polymers or plastics manufactured using bio-based, fossil or synthetic input substances that do not occur naturally are covered by the requirements of the SUP Directive. Therefore, the modified definition of plastics covers polymer-based rubber goods as well as bio-based and biodegradable plastics, both derived from biomass and intended to biodegrade over time. Paper cups with a bio-based and biodegradable plastic coating made available to consumers are therefore single-use products containing plastics and are covered by the requirements of the SUP Directive.

Biodegradation is a naturally occurring process combining physical, chemical and biological transformations, during which materials are converted into water, carbon dioxide (or methane in the case of anaerobic processes) and compost, thanks to the presence of microorganisms. Compostable biodegradable plastics do not accumulate in the environment, provided they are kept in strictly controlled conditions of an industrial composting plant (or a backyard composter). However, if they are spread uncontrolled in the open, with wind or water, they can represent the same physical contamination as other non-biodegradable materials. In order to be considered compostable, biodegradable plastic must be able to decompose, in accordance with the harmonised standards for recyclable packaging by composting and anaerobic digestion (Act of 11th May 2001). The rate and efficiency of the biodegradation process depends on external factors, such as oxygen availability, temperature and humidity. The decomposition time and the quality of the resulting products must comply with standardised defined composting standards, e.g., EN 13432:2000. Such packaging can be labelled as industrially or backyard compostable.

Compostable packaging means packaging capable of physical, chemical, thermal or biological decomposition that will ensure the ultimate decomposition of the majority of the finished compost into carbon dioxide, biomass and water and will not hinder the separate collection and composting process or the activity into which the packaging is introduced under industrially controlled conditions. The aim of their use is to eliminate cross-contamination in the residual waste streams and to increase the quality of the raw materials obtained in the remaining recycling processes. Compostable packaging should be collected together with organic waste from households, but should not be combined with the plastic packaging waste stream (in Poland this is a common fraction for liquid beverage plastic, metal packaging and laminates marked in yellow), as it may contaminate other plastics streams and thus hinder mechanical recycling. In accordance with the PPWR project, tea bags, coffee or tea capsules, sticky labels attached to fruit and vegetables, very lightweight plastic shopping bags will have to be compostable under industrially controlled conditions in bio-waste treatment facilities.

From 31 December 2023, bio-waste will have to be separately collected and (organically) recycled. In Italy and Spain, compostable bags are already being used for separate waste collection, which has improved the rate of separate collection. Compostable bags are also commonly used in these countries for bulk fruit and vegetables.

Biodegradable packaging can be produced from a variety of renewable raw materials, which are usually waste from other industries, from sugar cane, cereal waste, oilseed waste, but also by-products like cooking oil. Biodegradable packaging can also be produced from non-renewable raw materials, such as thermoplastic polyester (PLA – polylactide). Biodegradability is therefore not due to the source of the raw materials. The diverse category of plastics, often referred to as "bioplastics", contains three distinct categories of plastics with different properties, which raises significant difficulties of interpretation in B2B and B2C communications and its misunderstanding is a source of erroneous green claims. To avoid the problem of miscommunication and to ensure that the materials meet the composability criterion (EN 13432:2000), mandatory third-party certification and an unambiguous labelling system using pictograms are assumed for the future.

Legal provisions concerning the safety of compostable plastics for direct food contact

All packaging materials intended to come into direct contact with food must comply with the requirements for safe use under the specified conditions based on the requirements of Regulation (EC) No 1935/2004, in particular Article 3 under which the materials must not release substances into the food in quantities that could bring about changes in the food's composition, must not impair the food's organoleptic features and must be manufactured in accordance with the principles of good manufacturing practice (GMP) and the specific provisions contained in separate Regulations. In the case of bioplastics, they are also regulated by Commission Regulation (EU) No 10/2011 while substances used in their manufacturing must be listed as substances permitted for use and must meet global and specific migration requirements according to sanctioned rules.

Aim of the project

The study's objective was to determine whether compostable packaging materials could be used for short-term food packaging, e.g., snacks. This experiment aims to test whether it is possible to replace small packaging formats that, due to their size or material type, cannot be recycled in practice and on a large scale in waste streams. Choosing a compostable material whose size does not affect its recyclability, could bring new added value. The condition of new application is the lack of negative impact in other aspects related to maintaining food quality and safety.

Materials and methods

Project was focused on the surface modification of a compostable packaging material to improve barrier properties. Dry snacks were chosen, so the key modification task was to protect the product against moisture. An aqueous solution of chitosan was used, yielding a coating with a thickness of 20 μm. The modified film was tested for basic parameters relevant to product protection; these included the following:

1) water vapour transmission rate (WVTR) using the weighing method based on (ASTM E96/E96M-16),
2) tensile strength (ISO 527-3:2018),
3) puncture resistance (EN 14477:2004), and
4) sensory analysis in direct contact with a food product (DIN 10955:2004; DIN 4120:2004), triangle method, carriers as test material: chocolate and biscuits.

In the packaging industry, chitosan is known to be used alone and in mixtures. Water barrier novel blends of chitosan with EVOH copolymers from water/isopropanol solutions of acetic acid exhibit antimicrobial activity (Sabu et al., 2021). Chitosan can be used as an antimicrobial packaging film in a dry environment with very low relative humidity and mild temperatures (4-23°C) to preserve the antimicrobial activity of the film itself (Fernandez-Saiz et al., 2010). Chitosan and its derivatives have been successfully used to package fresh-cut produce, such as lychees (Dong et al., 2004), mangoes (Chien et al., 2007) and mushrooms (Eissa, 2008). A biodegradable laminate of a chitosan-cellulose has proved to be a suitable packaging material for MAP and storage of broccoli (Makino & Hirata, 1997).

Preparation and application of an aqueous chitosan solution coating

Chitosan with a molecular weight of 120,000 g/mol was obtained by a controlled radical degradation reaction. For this purpose, 50 g of chitosan and 2.25 cm^3 of H_2O_2 (hydrogen peroxide) was added to 500 g of water. The reaction was carried out for 2 hours at 80°C using a magnetic stirrer at 250 rpm. A thick, clear solution with a dark yellow colour was obtained. It had a pungent, sour smell, characteristic of acetic acid. The cooled solution was filtered using a Büchner funnel. A 1 M acetic acid solution (to lower the pH) and glycerol (as plasticiser) were used in order to be enable dissolving the chitosan and obtaining a coating with a suitable degree of plasticity. A compostable starch film containing approval for direct food contact was used.

The solution was applied to the film using a TQC Sheen kit and a 20 μm thick hand coating rod. The film samples with the coating solution applied were dried in a Binder laboratory dryer for 20 minutes at 50°C. The samples were then conditioned for 48 h and tested afterwards. After the coating process, the film was characterised by its susceptibility to be rolled with the uncoated side inwards, which required the sheets to be immobilised and stabilised. The thickness of the unmodified film was 0.021±0.002 mm, while after coating the average thickness of the modified film was 0.041±0.004 mm.

Test Results

Determination of water vapor transmission (WVTR) ASTM E96/E96M-16

An analysis of the water vapour transmission rate of the materials tested was carried out based on the ASTM E96/E96M-16 standard. EZ-Cup vessels from the Thwing-Albert Instrument Company were used. The vessels were filled with silica gel, dried to a solid mass, acting as a moisture absorbing agent, up to 75% of the vessel's height. The 74 mm diameter film samples were then prepared and placed between the flange gaskets. The effective moisture transmission area was 63.5±0.1 mm. The samples were placed in a desiccator with an aqueous NaCl solution for 7 days. The dishes were weighed every 24 hours using a RADWAG PS 750/X electronic balance. The WVTR was expressed in [g/(m^2×24h)] according to the following formula:

$$WVTR = \frac{m_2 - m_1}{\mathrm{A} \cdot \mathrm{t}}$$

where:

m_2 – final mass of sample, g,

m_1 – starting mass of sample, g,

A – water vapour transmission area, m^2,

t – test duration, 24 hours.

The analysis allowed for determining the tested samples' water vapour permeability stabilisation point. For the compostable film without modification, this point was determined on test day 3 (after 72 h), where the WVTR value was 128.372±2.752 [g/(m^2×24h)].

For the surface-modified chitosan compostable film, stabilisation was also achieved on test day 3. In this case, the WVTR value was 98.885±0.667 [g(m^2×24h)]. The test results show that coating the film with a layer of chitosan coating allows for a 23% reduction in the water vapour transmission rate. The test results are presented in Fig. 2. Material coating improved WVTR by 23%.

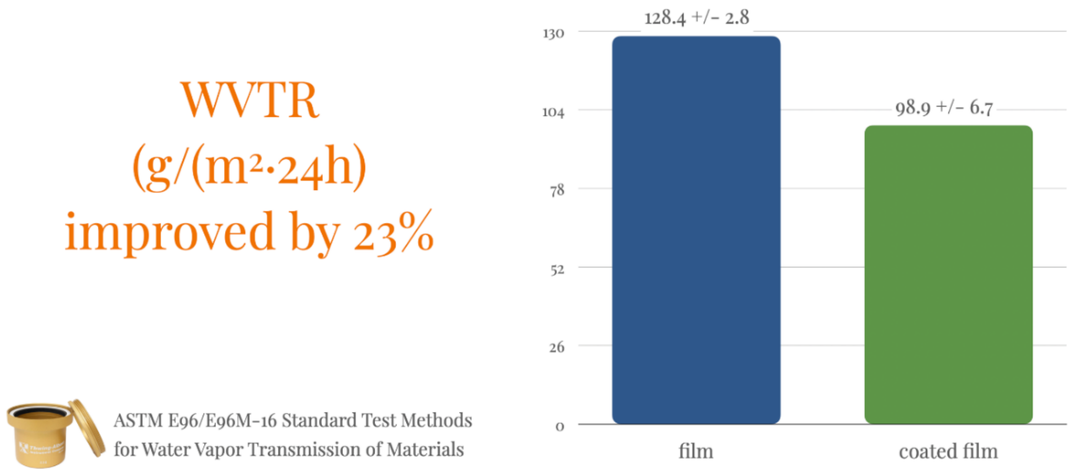


Fig. 2. Material's WVTR before and after surface modification with a chitosan coating

Source: own study.

Tensile strength

Tensile strength was measured using a Zwick/Roell Z005 universal strength testing machine in accordance with ISO 527-3:2018. Samples with their working section's width of 15mm and length of 50mm were placed between the instrument's pneumatic jaws. The test rate was 200 mm/minute. The test was performed in two directions: machine direction (MD) and cross direction (CD). The following were recorded during the test: force (N) and elongation (mm). Strength (MPa) and strain at strength (%) were determined from the data. The test results are presented in Fig. 3. Coating improved strength in machine diection (MD) by 16%, no changes were shown in cross direction.

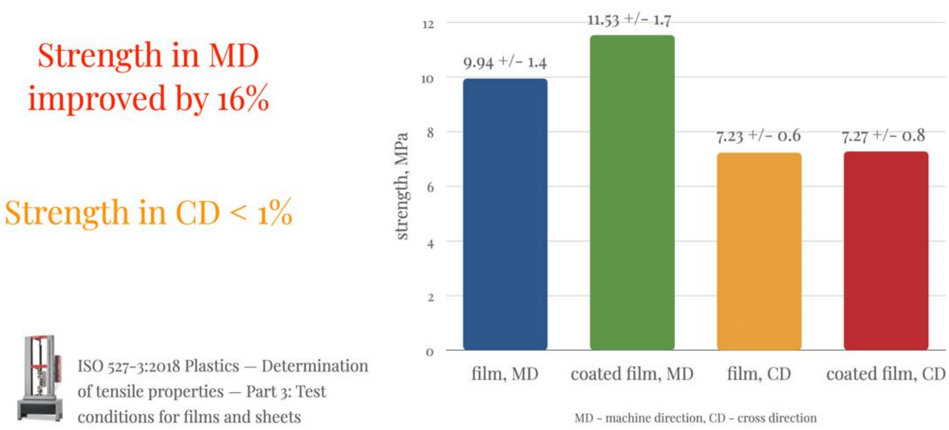


Fig. 3. Material's tensile properties in MD and CD before and after surface modification with a chitosan coating

Source: own study.

While an improvement in strength (MPa) was noted in the machine direction (MD), this was a consequence of the increased rigidity of the film, which lost its elasticity and had little elongation in both directions (MD, CD). The test results are presented in Fig. 4. Coating caused high film stiffness which resulted in a significant decrease in the elongation of the material.,

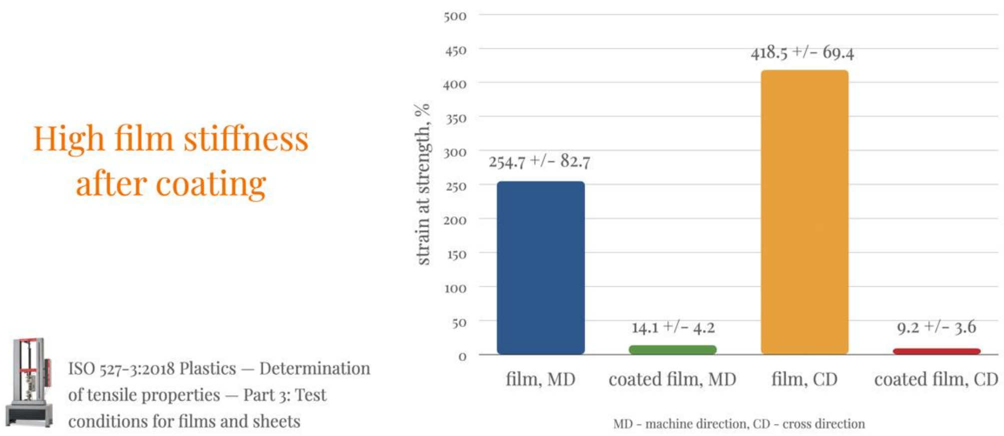


Fig. 4. Material's strain at strength [%] in MD and CD before and after surface modification with a chitosan coating

Source: own study.

Puncture resistance

The puncture strength was measured using a Zwick/Roell Z005 universal strength testing machine equipped with a special punch head and punch pin in accordance with EN 14477:2004. The test was performed in two variants, i.e., on the coated external side and on the uncoated internal side. The test rate was 100 mm/min. The puncture force [N], elongation at puncture [mm] and puncture work [mJ] were recorded during the test. The test results are presented in Fig. 5. Coating caused a significant decrease in the elongation of the material but at the same time, it increased puncture resistance.

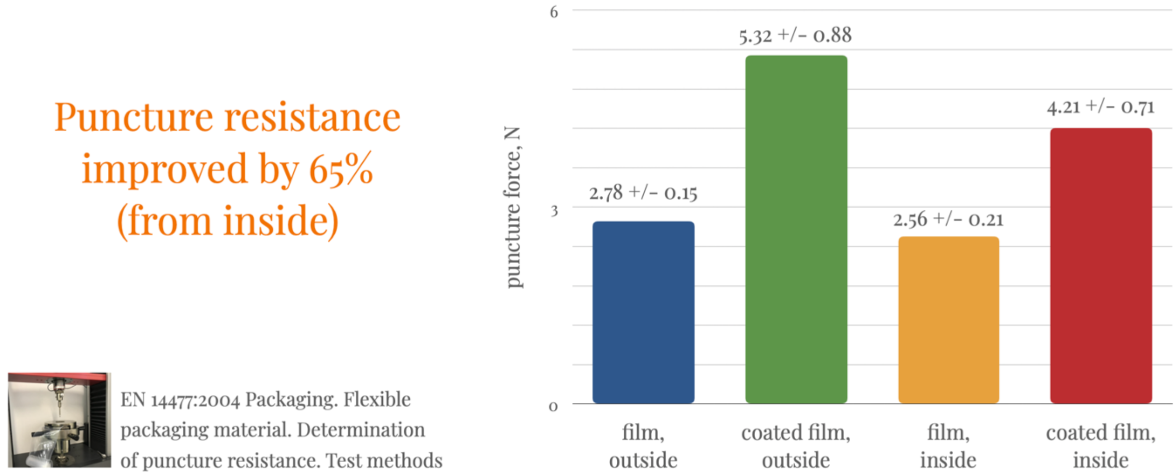


Fig. 5. Determination of puncture resistance on the material's inner and outer sides before and after surface modification with a chitosan coating

Source: own study.

Sensory analysis of packaging materials

The test was conducted based on DIN 10955:2004. It was intended to check whether the packaging material received has an odour of its own or whether its direct contact with the test substances affects the odour and/or taste of food products in an unacceptable way. Two popular carriers were chosen as test material: Wedel grated milk chocolate (anhydrous and fatty product) and Krakus biscuits (dry and moisture-sensitive product). The test and control samples (in a glass container) were stored for 10 days at 20°C (chocolate) and 40°C (biscuits).

The test was conducted using an eight-person sensory panel. The test was carried out using the triangle method according to (DIN 4120:2004), which involves assessing three samples simultaneously, two of which are identical., Products stored in a glass vessel (control sample) and in a chitosan-modified film were compared. The test participants rated the products' odour and taste according to the following scale:

- 0 – foreign undetectable odour/taste,
- 1 – foreign barely perceptible (difficult to identify) odour/taste,
- 2 – foreign moderate odour/taste,
- 3 – foreign moderately strong odour/taste,
- 4 – foreign strong odour/taste.

The median score of the individual products was used as the final score, and the difference between the score of a single assessor and the median could not be more than 1.5.

Fig. 6. Sensory analysis evaluation

Source: own study.

The test showed that no changes in the smell or taste of the product were detected, therefore the material was assessed as sensory neutral (Fig. 6).

Conclusions

Modification through the use of a coating resulted in a 23% improvement in WVTR and a 16% increase in mechanical strength. However, the increase in rigidity resulted in a decrease in puncture resistance. It has also been shown that the modified film does not alter taste or odour when in direct contact with food products. The tests should be expanded to include a set of overall and specific migration tests and, in the case of compostability certification, must comply with EN 13432. The research was a pilot study.

References

Act of 14th April 2023 on amending the Act on the obligations of entrepreneurs with regard to the management of certain waste and the product fee, and certain other acts.

Act of 13th June 2013 on packaging and packaging waste management.

Act of 14th December 2012 on waste.

Act of 11th May 2001 on the obligations of entrepreneurs with regard to the management of certain waste and the product fee.

ASTM E96/E96M-16 Standard Test Methods for Water Vapor Transmission of Materials.

Chien, P. J., Sheu, F., & Yang, F. H. (2007). Effects of edible chitosan coating on quality and shelf life of sliced mango fruit. *Journal of Food Engineering*, *78*(1), 225-229.

Commission guidelines on single-use plastic products in accordance with Directive (EU) 2019/904 of the European Parliament and of the Council on the reduction of the impact of certain plastic products on the environment.

Commission Regulation (EU) No 10/2011 of 14 January 2011 on plastic materials and articles intended to come into contact with food.

DIN 10955:2004 Sensory analysis – Testing of packaging materials and packages for foodstuffs.

DIN 4120:2004 Sensory Analysis – T esting Of Packaging Materials And Packages For Foodstuffs.

Directive (EU) 2019/904 of the European Parliament and of the Council of 5 June 2019 on the reduction of the impact of certain plastic products on the environment.

Dong, H., Cheng, L., Tan, J., Zheng, K., & Jiang, Y. (2004). Effects of chitosan coating on quality and shelf life of peeled litchi fruit. *Journal of Food Engineering*, *64*(3), 355-358.

Eissa, H.A.A. (2008). Effect of chitosan coating on shelf-life and quality of fresh-cut mushroom. *Polish Journal of Food and Nutrition Sciences*, *58*(1).

EN 13432:2000 Packaging – Requirements for packaging recoverable through composting and biodegradation – Test scheme and evaluation criteria for the final acceptance of packaging.

EN 14477:2004 Packaging – Flexible packaging material – Determination of puncture resistance – Test methods.

Fernandez-Saiz, P., Ocio, M.J., & Lagaron, J.M. (2010). Antibacterial chitosan-based blends with ethylene-vinyl alcohol copolymer. *Carbohydrate Polymers*, *80*(3), 874-884.

ISO 527-3:2018 Plastics — Determination of tensile properties — Part 3: Test conditions for films and sheets.

Makino, Y., & Hirata, T. (1997). Modified atmosphere packaging of fresh produce with a biodegradable laminate of chitosan-cellulose and polycaprolactone. *Postharvest Biology and Technology*, *10*(3), 247-254.

Sabu, T., Alavi, S., Sandeep, K.P., Kalarikkal, N., Varghese, J., & Yaragalla, S. (2021). *Polymers for Packaging Applications*. Apple Academic Press, p. 370.

Regulation of the European Parliament and of the Council on packaging and packaging waste, amending Regulation (EU) 2019/1020 and Directive (EU) 2019/904, and repealing Directive 94/62/EC. (PPWR).

Regulation (EC) No 1935/2004 of the European Parliament and of the Council of 27 October 2004 on materials and articles intended to come into contact with food and repealing Directives 80/590/EEC and 89/109/EEC.

NEAR-INFRARED (NIR) SPECTROSCOPY AS A NON-DESTRUCTIVE TOOL FOR FRUIT QUALITY MONITORING: A MINI-REVIEW

Katarzyna Włodarska*, Katarzyna Pawlak-Lemańska, Jarosław Chmielewski, Ewa Sikorska

Department of Technology and Instrumental Analysis, Institute of Quality Science,
Poznań University of Economics and Business, Poznań, Poland
**Corresponding Author e-mail: katarzyna.wlodarska@ue.poznan.pl*

DOI: 10.56091CTQS.Innov-23

Abstract

The quality of food product could be defined through various characteristics, including nutritional value, physicochemical properties, microbiological safety, sensory attributes, as well as shelf-life stability. The quality parameters of fruits can be tested using chemical methods, however these methods are time consuming, expensive and destructive because they usually require sample preparation procedures. Furthermore, the reagent and energy consumptions of these measurements have a negative impact on the environment. Therefore, the application of optical spectroscopic techniques, which enable rapid and simple, simultaneous determination of several parameters may be valuable alternative to traditional, laboratory methods. The purpose of this mini-review is to outline the recent applications of near-infrared (NIR) spectroscopy and spectral data analysis using chemometrics in fruit quality monitoring. Particular attention was paid to the usage of NIR spectra in monitoring fruit maturity as well as quality during storage on the example of studies of apples and strawberries. Successful application of NIR spectroscopy for both qualitative purposes and quantitative evaluation of quality parameters was demonstrated. Emerging technologies such as NIR spectroscopy have great potential to be used by harvesting systems in monitoring maturity, postharvest sorting and quality evaluation during storage.

Keywords: near-infrared spectroscopy, food quality, fruit maturity, storage, non-destructive testing

Introduction

An unhealthy diet and physical inactivity are among the main risk factors of some chronic diseases. The traditional diets and lifestyles are changing across the world. In recent years consumers have become more aware of diverse health benefits of non-processed or low processed food in preventing these burdens (Persic et al., 2017). Fresh fruits are an essential part of any balanced diet. In general, fruits are rich in various vitamins and minerals, dietary fibre and bioactive compounds that offer a wide range of health benefits (Borowiec et al., 2022).

The chemical composition of fruits varies with a series of factors that includes cultivar, environmental conditions, horticultural practices, region, weather conditions, harvest time, ripeness, and handling and storage conditions after harvest (de Souza et al., 2014).

Quality control is an essential element of quality management that reduces product defects and provides high quality products of the right specifications to the consumer (Garcia-Garcia et al., 2021). In general, the quality of food product could be defined through various characteristics such as nutritional value, physicochemical and sensory properties, microbiological safety, shelf-life stability, and others. In traditional analysis, the determination of each of these parameters requires the use of a separate analytical method (physical, chemical and/or sensory analysis). Most of these conventional methods are considered tedious, time consuming, and destructive, as they usually require sample preparation and pre-processing protocols before or during the analysis as well as the usage of reagents (Cozzolino, 2022). These disadvantages make traditional methods unsuitable for rapid analysis, monitoring food quality during processing and large-scale industrial applications (Cortés et al., 2019). For these reasons, the research and development of fast, accurate and non-destructive tools is increasing. Non-targeted fingerprinting methods that enable the acquisition of information about several parameters simultaneously are more appropriate for measuring food quality than standard physicochemical methods. Optical spectroscopy has become very attractive as analytical tool by the food industry, as it can provide with analytical information in a more environmentally friendly manner (Beć et al., 2020; Cozzolino, 2022).

Analytical framework of NIR spectroscopy

Near-infrared (NIR) spectroscopy is currently the most frequently used in practical applications in the agri-food sector. The spectra in NIR range (780-2500 nm) contain bands coming from overtones and combination tones of basic vibrations of groups having a hydrogen atom, mainly C–H, O–H and N–H chemical bonds. Thus, the NIR spectra enables study of organic major and minor food constituents containing these structures such as water, sugars, other carbohydrates, organic acids, polyphenolic compounds, some vitamins, and some of the amino acids. The NIR spectra may be measured directly for samples in different forms without the need of sample preparation using benchtop or portable instruments, Fig. 1A and 1B. The examples of NIR spectra of apple fruit from various cultivars are shown in Fig. 1C.

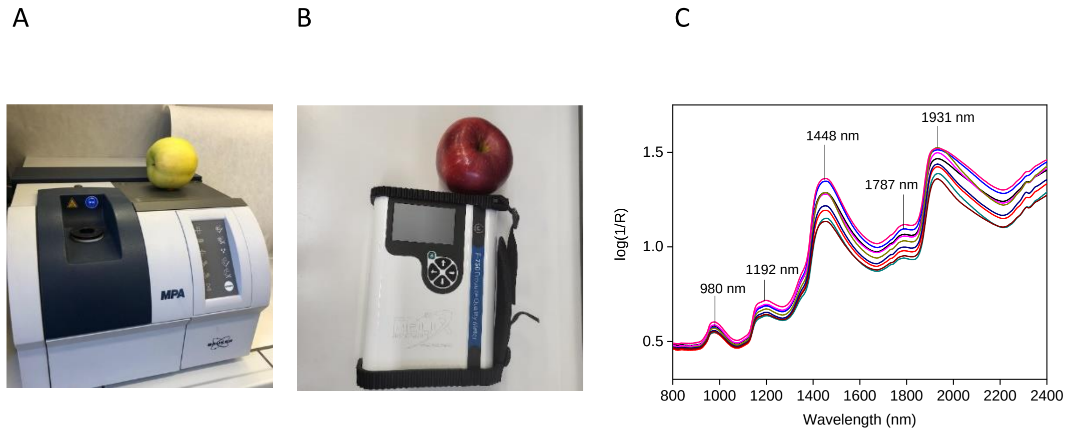


Fig. 1. FT-NIR spectrometer (MPA, Bruker Optics, Ettlingen, Germany) for recording spectra of fruits in a non-destructive manner (A); Portable spectrometer F-750 Produce Quality Meter (CID Bio Science, Inc., Camas, USA) (B); Diffuse reflectance spectra of apple fruit in the NIR range (C)

Source: own study.

The absorption bands located at around 980, 1192, 1448, 1787, and 1931 nm are related to the overtones and combination tones of O–H bonds. The bands at 1192 and 1787 nm correspond to C–H and C-H_2 the second and first overtones. The band at 1192 nm overlaps with O–H combination tones (Włodarska et al., 2021).

Near-infrared hyperspectral imaging (NIR-HSI) integrates NIR spectroscopy and imaging techniques in one analytical system that enable to obtain a complete NIR spectrum for each pixel of the hyperspectral image of the sample (Teixido-Orries et al., 2023). The three-dimensional data matrix consisting of two spatial dimensions and one spectral dimension is obtained. Optical imaging techniques are also among the major methods used for non-destructive inspection and determination of quality parameters of complex food matrices.

However, as these techniques are based on indirect measurements that produce highly complex data, both NIR spectroscopy and NIR-HSI need the support of chemometrics to extract the relevant information from the data collected (Cortés et al., 2019). The use of NIR spectroscopy for quality assessment is based on the development of multivariate calibration models. Such models describe the relationship between spectra and properties of samples determined by reference methods. Partial least squares (PLS) regression is commonly used for models' development. Optimized and validated models are used in routine analysis to determine the chemical, physical and/or sensory properties of new samples.

Based on the measurement of one spectrum, it is possible to determine all the sample parameters for which calibration models have been previously developed. For qualitative purposes various classification or pattern recognition techniques are used.

The use of NIR spectroscopy for whole fruit testing is attractive due to the possibility of non-destructive measurements. The versatile applications of NIR spectroscopy for various fruits quality assessment have been published including prediction of various chemical components, physical properties, sensory qualities, as well as microbiological safety, fruit maturity, monitoring the overall quality during food processing and/or storage, and other. In this mini review, we provided concise and detailed information about application of NIR technique in monitoring fruit maturity and fruit quality on the example of studies of apples and strawberries.

Materials and methods

Scopus database was used as the data source. Scopus is a multidisciplinary database of peer-reviewed literature that contains scientific articles, books, and conference proceedings in various fields. The formulated key words and scientific questions were: "near-infrared spectroscopy", "apple", "strawberry" and their combinations. The time scope of analysis covered the last five years (2018-2023).

Recent application of NIR spectroscopy in apple quality monitoring

Table 1 summarizes the applications of NIR spectroscopy in predicting the quality parameters of apples. Maturity has a decisive influence on the quality of harvested fruits. The maturity of at harvest may influence the way fruits are stored, transported and marketed (Zhao et al., 2023). Maturity indices of fruits can be precisely estimated by using destructive techniques. However, it is not easy to accurately describe the maturity of fruit with a single variable. In routine quality control usually only selected parameters are determined, including soluble solids content (SSC), titratable acidity (TA), firmness, size, external color (Zhao et al., 2023). NIR and Vis-NIR spectroscopies have shown promising results for harvest maturity estimation of apples such soluble solids content, titratable acidity, firmness and hardness of apples at different stages of ripening (Table 1). An important finding of studies is that non-destructive measurement of NIR spectra of intact fruit enables prediction of SSC in apple with high prediction accuracy.

Table 1. Application of NIR spectroscopy in apple quality control

Attribute	Technique	Data analysis	Reference
Soluble solids content	Vis-NIR	ANN, MNLR	Yao et al., (2023)
Soluble solids content	NIR	ANN	Guo et al., (2023)
Soluble solids content, watercore severity index	Vis-NIR	PLS	Han et al., (2023)
Hardness	NIR	PLS, ANN	Malvandi et al., (2022)
Soluble solids content, firmness	Vis-NIR	PLS	Zhang et al., (2022a)
Watercore disease	NIR	PLS-DA, LS-SVM	Zhang et al., (2022b)
Titratable acidity, pH	NIR	machine learning	Pourdarbani et al., (2022)
Soluble solids content, titratable acidity, pH, total phenolic content	Vis-NIR		Hasanzadeh et al., (2022)
Soluble solids content, titratable acidity, pH	NIR	PLS	Włodarska et al., (2021)
Soluble solids content, firmness (in cold storage)	Vis-NIR	PLS	Zhang et al., (2021)
Origin and cultivar	NIR	PCA-DA, QDA	Eisenstecken et al., (2019)
Apple variety and geographical origin	NIR	ANN	Li et al., (2018)

PLS – partial least squares, PLS-DA – partial least squares-discriminant analysis, ANN – artificial neural network, MNLR – multivariate nonlinear regression, LS-SVM – least-squares support-vector machines, QDA – quadratic discriminant analysis

Source: own study.

Apple is a valuable source of bioactive compounds including polyphenols. Hasanzadeh et al., (2022) have shown potential of Vis-NIR in predicting total phenolic content in Red Delicious and Golden Delicious apples. Eisenstecken et al., (2019) and Li et al., (2018) have demonstrated the potential of NIR combined with classification methods as a non-destructive and fast analytical method to trace the geographical origin of apples and to classify apples according to apple cultivar.

Reducing losses and waste in fresh produce is a great challenge along food producers and suppliers. The flesh of apples with serious watercore would brown and rot over time, resulting in the loss of edible quality. Han et al., (2023) and Zhang et al., (2022b) used Vis-NIR and NIR to identify apples with watercore in a non-destructive manner.

The ability to predict shelf-life can facilitate the optimisation of the food supply chain and proactively identify problems and operate to minimize losses and waste (Amodio et al., 2017; Ktenioudaki et al., 2022). Zhang et al., (2021) conducted the study of apples aimed to develop the model for predicting the SSC and firmness of apples during cold storage taking into account the time in cold storage and three levels of maturity at harvest. Application of the results of all these studies could serve as a basis for the development of an automatic system for monitoring fruit internal quality change and a sorting system.

Recent application of NIR spectroscopy in strawberry quality monitoring

Examples of NIR applications in strawberry quality assessment are summarized in Table 2.

Table 2. Application of NIR spectroscopy in apple quality control

Attribute	Technique	Data analysis	Reference
Soluble solid content, acidity, vitamin C, anthocyanin, and phenolic acid	NIR	PLS-DA	Mancini et al., (2023)
Soluble solids content, titratable acidity, colour, texture	NIR	PLS	Agulheiro-Santos et al., (2022)
Sensory shelf-life	UV-Vis-NIR	PLS	Joshi et al., (2022)
Soluble solids content, firmness	NIR	PLS	Mancini et al., (2020)
Colour (L*, C*, h°), soluble solids content, titratable acidity, total polyphenol content	Vis-NIR	PLS	Saad et al., (2022)
Soluble solids content, total phenolic content	NIR	PLS	Włodarska et al., (2019)
Pesticide residual level	NIR	PLS	Yazici et al., (2019)
Fungal decay, fructose, glucose, sucrose, total water-soluble sugar content	NIR-HSI	SVM	Liu et al., (2019)
Soluble solids content, pH, firmness, storage shelf-life	Vis-NIR	PLS, PLS-DA	Shen et al., (2018)

PLS – partial least squares, PLS-DA – partial least squares-discriminant analysis, NIR-HSI – near-infrared hyperspectral imaging, SVM – support vector machine

Source: own study.

The chemical composition of strawberries determines their flavor quality. The sweetness and sourness of fruits primarily depend on the amount of sugars and organic acids. Sweetness is an important attribute and maturity indicator, but difficult to predict using objective measurements. Some studies demonstrated that the best and most convenient predictor of fruit sweetness is soluble solids content (SSC) (Kim et al., 2023). Recently, Raman spectroscopy has been successfully used to non-destructively evaluate the chemical composition and sweet and sour taste of strawberries (Andersen et al., 2023).

A few studies have shown the potential of NIR spectroscopy in predicting SSC in strawberries (Table 2). Saad et al., (2022) explored the possibility of Vis-NIR as a valid method for non-destructive monitoring several quality properties of strawberries such as colour, TA and TSS for three different maturity stages. The latest study by Mancini et al., (2023) showed the possibility of NIR for monitoring simultaneously colour, TSS, titratable acidity, and total polyphenol content. Włodarska et al., (2019) also demonstrated the possibility of NIR in polyphenol content estimation. Joshi et al., (2022) have shown that UV-Vis-NIR can estimate the storage duration of the strawberries as well as their visual sensory shelf-life. Rapid assessment of storage time is important for the guarantee of fruit shelf-life.

NIR spectroscopy is also used in food safety evaluation. Yazici et al., (2019) demonstrated the possibility to determine pesticide residues in strawberries without the need for a comprehensive laboratory environment and chemicals. The developed model can be used in a complementary manner to LC-MS/MS or similar traditional analytical methods of pesticide analysis, particularly as a pre-screening method. Liu et al. (2019) demonstrated the possibility of using NIR-HSI to non-destructively quantify the sugar constituents of strawberry, and the potential to monitor the stages of fungal decay during storage.

Perspectives of emerging technologies for quality monitoring and management in agro-food sector

In current competitive and globalized framework for the agri-food sector there is an increasing demand for the production of higher quality products that meet high consumer expectations and requirements. For this reason, the research and development of fast, accurate and non-destructive tools that are capable of evaluating each individual product is increasing at high speed (Cortés et al., 2019). The methods used in monitoring quality of fruits should enable rapid measurements of a large number of samples, and in the place of occurrence. In order to ensure effective control of the quality of fruits, traditional analytical methods are replaced by emerging technologies including spectroscopic techniques and hyperspectral technologies coupled with chemometrics. Numerous studies demonstrated that these techniques have allowed for the accurately and precise measurement and monitoring of fruit quality. However, the benchtop spectral equipment is very expensive. For that reason, there is an increasing interest in inexpensive and portable and handheld devices (Beć et al., 2020; Cozzolino, 2022). The progress in miniaturization is accompanied by software development aimed at ease of use and suitability for operation by a non-experts, even to consumers due to the rapid development of smartphone applications, to manage different issues, such as determination of chemical composition, colour, and other physical properties, microbial spoilage, and authenticity issues (Hakkel et al., 2022; Hassoun et al., 2022).

More studies tend to use miniaturized instruments and low-cost chips to replace spectrometers, and have achieved good results (Nguyen et al., 2020; Tran & Fukuzawa, 2020). This provides a technical basis for detecting the quality and maturity of fruits in the place of cultivation, e.g., apples on trees (Zhao et al., 2023). That makes it possible for operators to quickly monitor important parameters at harvest and during all subsequent storage stages, allowing management optimization according to fruit characteristics (Beghi et al., 2014).

The application of emerging technologies at different stages of the food production chain reduces the utilisation of chemical reagents and energy, prompting for the support of sustainable food systems (Cozzolino, 2022). A shift towards greater food sustainability is urgently needed to contribute to meeting the Sustainable Development Goals (Hassoun, 2022). The agri-food sector is entering the fourth stage of the technological revolution, which is characterized by digitization, automation and robotization. NIR spectroscopy with chemometrics may contribute to achieve more automated fruit quality monitoring systems.

Conclusions

Traditional harvest and postharvest fruit quality control relies on physicochemical indicators. However, this approach has several limitations, such as time-consuming procedures, destructive techniques, and low monitoring accuracy. Emerging technologies including NIR spectroscopy could help to achieve sustainable food supply chains through monitoring food quality with high speed, low cost, non-destructive character, minimal sample preparation, no generation of toxic waste, and easy use for the operator. These technologies accelerate digitalization and automation in the agri-food sector.

References

Agulheiro-Santos, A., Ricardo Rodrigues, S., Laranjo, M., Melgão, C., & Velázquez, R. (2022). Non-destructive prediction of total soluble solids in strawberry using near-infrared spectroscopy. *Journal of the Science of Food and Agriculture, 102,* 4866-4872.

Amodio, M.L., Ceglie, F., Chaudhry, M. M. A., Piazzolla, F., & Colelli, G. (2017). Potential of NIR spectroscopy for predicting internal quality and discriminating among strawberry fruits from different production systems. *Postharvest Biology and Technology, 125*, 112-121.

Andersen, P. V., Afseth, N. K., Aaby, K., Gaarder, M. Ø., Remberg, S. F., & Wold, J. P. (2023). Prediction of chemical and sensory properties in strawberries using Raman spectroscopy. *Postharvest Biology and Technology*, 201, 112370.

Beć, K., Grabska, J., & Huck, C. (2020). Principles and applications of miniaturized Near-Infrared (NIR) spectrometers. *Chemistry – A European Journal, 27,* 1514-1532.

Beghi, R., Giovanelli, G., Malegori, C., Giovenzana, V., & Guidetti, R. (2014). Testing of a VIS-NIR system for the monitoring of long-term apple storage. *Food and Bioprocess Technology, 7*(7), 2134-2143.

Borowiec, K., Stachniuk, A., Szwajgier, D., & Trzpil, A. (2022). Polyphenols composition and the biological effects of six selected small dark fruits. *Food Chemistry, 391*, 133281.

Cortés, V., Blasco, J., Aleixos, N., Cubero, S., & Talens, P. (2019). Monitoring strategies for quality control of agricultural products using visible and near-infrared spectroscopy: A review. *Trends in Food Science & Technology, 85*, 138-148.

Cozzolino, D. (2022). Advantages, opportunities, and challenges of vibrational spectroscopy as tool to monitor sustainable food systems. *Food Analytical Methods, 15*(5), 1390-1396.

de Souza, V. R., Pereira, P. A. P., da Silva, T. L. T., de Oliveira Lima, L. C., Pio, R., & Queiroz, F. (2014). Determination of the bioactive compounds, antioxidant activity and chemical composition of Brazilian blackberry, red raspberry, strawberry, blueberry and sweet cherry fruits. *Food Chemistry, 156*, 362-368.

Eisenstecken, D., Stürz, B., Robatscher, P., Lozano, L., Zanella, A., & Oberhuber, M. (2019). The potential of near-infrared spectroscopy (NIRS) to trace apple origin: Study on different cultivars and orchard elevations. *Postharvest Biology and Technology, 147*, 123-131.

Garcia-Garcia, G., Coulthard, G., Jagtap, S., Afy-Shararah, M., Patsavellas, J., & Salonitis, K. (2021). Business process re-engineering to digitalise quality control checks for reducing physical waste and resource use in a food company. *Sustainability, 13*(22), 12341.

Guo, Z., Zhang, Y., Wang, J., Liu, Y., Jayan, H., El-Seedi, H. R., Alzamora, S. M., Gómez, P. L., & Zou, X. (2023). Detection model transfer of apple soluble solids content based on NIR spectroscopy and deep learning. *Computers and Electronics in Agriculture, 212*, 108127.

Hakkel, K., Petruzzella, M., Ou, F., Klinken, A., Pagliano, F., Liu, T., Veldhoven, P. J., & Fiore, A. (2022). Integrated near-infrared spectral sensing. *Nature Communications, 13*.

Han, C., Jifan, Y., Hao, T., Jinshan, Y., & Huirong, X. (2023). Evaluation of the optical layout and sample size on online detection of apple watercore and SSC using VIS/NIR spectroscopy. *Journal of Food Composition and Analysis, 123*, 105528.

Hasanzadeh, B., Abbaspour-Gilandeh, Y., Soltani-Nazarloo, A., Cruz-Gámez, E. D., Hernández-Hernández, J. L., & Martínez-Arroyo, M. (2022). Non-Destructive Measurement of Quality Parameters of Apple Fruit by Using Visible/Near-Infrared Spectroscopy and Multivariate Regression Analysis. *Sustainability*, 14.

Hassoun, A., Prieto, M. A., Carpena, M., Bouzembrak, Y., Marvin, H. J. P., Pallarés, N., Barba, F. J., Punia Bangar, S., Chaudhary, V., Ibrahim, S., & Bono, G. (2022). Exploring the role of green and Industry 4.0 technologies in achieving sustainable development goals in food sectors. *Food Research International, 162*, 112068.

Joshi, P., Pahariya, P., Al-Ani, M. F., & Choudhary, R. (2022). Monitoring and prediction of sensory shelf-life in strawberry with ultraviolet-visible-near-infrared (UV-VIS-NIR) spectroscopy. *Applied Food Research, 2*(2), 100123.

Kim, K., Chun, I.-J., Suh, J. H., & Sung, J. (2023). Relationships between sensory properties and metabolomic profiles of different apple cultivars. *Food Chemistry: X, 18*, 100641.

Ktenioudaki, A., Esquerre, C. A., Do Nascimento Nunes, C. M., & O'Donnell, C. P. (2022). A decision support tool for shelf-life determination of strawberries using hyperspectral imaging technology. *Biosystems Engineering, 221*, 105-117.

Li, C., Li, L., Wu, Y., Lu, M., Yang, Y., & Li, L. (2018). Apple variety identification using near-infrared spectroscopy. *Journal of Spectroscopy, 2018*, 6935197.

Liu, Q., Wei, K., Xiao, H., Tu, S., Sun, K., Sun, Y., Pan, L., & Tu, K. (2019). Near-infrared hyperspectral imaging rapidly detects the decay of postharvest strawberry based on water-soluble sugar analysis. *Food Analytical Methods, 12*(4), 936-946.

Malvandi, A., Kapoor, R., Feng, H., & Kamruzzaman, M. (2022). Non-destructive measurement and real-time monitoring of apple hardness during ultrasonic contact drying via portable NIR spectroscopy and machine learning. *Infrared Physics & Technology, 122*, 104077.

Mancini, M., Mazzoni, L., Gagliardi, F., Balducci, F., Duca, D., Toscano, G., Mezzetti, B., & Capocasa, F. (2020). Application of the non-destructive NIR technique for the evaluation of strawberry fruits quality parameters. *Foods*, 9.

Mancini, M., Mazzoni, L., Leoni, E., Tonanni, V., Gagliardi, F., Qaderi, R., Capocasa, F., Toscano, G., & Mezzetti, B. (2023). Application of near-infrared spectroscopy for the rapid assessment of nutritional quality of different strawberry cultivars. *Foods*, 12.

Nguyen, C.-N., Phan, Q.-T., Tran, N.-T., Fukuzawa, M., Nguyễn, L., & Nguyen, C.-N. (2020). Precise sweetness grading of mangoes (*Mangifera indica L.*) based on random forest technique with low-cost multispectral sensors. *IEEE Access, 8*, 212371-212382.

Pourdarbani, R., Sabzi, S., Rohban, M. H., García-Mateos, G., Paliwal, J., & Molina-Martínez, J. M. (2022). Using metaheuristic algorithms to improve the estimation of acidity in Fuji apples using NIR spectroscopy. *Ain Shams Engineering Journal, 13*(6), 101776.

Persic, M., Mikulic-Petkovsek, M., Slatnar, A., & Veberic, R. (2017). Chemical composition of apple fruit, juice and pomace and the correlation between phenolic content, enzymatic activity and browning. *LWT – Food Science and Technology, 82*, 23-31.

Saad, A., Azam, M. M., & Amer, B. M. A. (2022). Quality analysis prediction and discriminating strawberry maturity with a hand-held Vis-NIR spectrometer. *Food Analytical Methods, 15*(3), 689-699.

Shen, F., Zhang, B., Cao, C., & Jiang, X. (2018). On-line discrimination of storage shelf-life and prediction of post-harvest quality for strawberry fruit by visible and near-infrared spectroscopy. *Journal of Food Process Engineering, 41*(7), e12866.

Teixido-Orries, I., Molino, F., Gatius, F., Sanchis, V., & Marín, S. (2023). Near-infrared hyperspectral imaging as a novel approach for T-2 and HT-2 toxins estimation in oat samples. *Food Control, 153*, 109952.

Tran, N.-T., & Fukuzawa, M. (2020). A portable spectrometric system for quantitative prediction of the soluble solids content of apples with a pre-calibrated multispectral sensor chipset, *Sensors*, *20*, 5883.

Włodarska, K., Piasecki, P., Lobo-Prieto, A., Pawlak-Lemańska, K., Górecki, T., & Sikorska, E. (2021). Rapid screening of apple juice quality using ultraviolet, visible, and near-infrared spectroscopy and chemometrics: A comparative study. *Microchemical Journal, 164*, 106051.

Włodarska, K., Szulc, J., Khmelinskii, I., & Sikorska, E. (2019). Non-destructive determination of strawberry fruit and juice quality parameters using ultraviolet, visible, and near-infrared spectroscopy. *Journal of the Science of Food and Agriculture, 99*(13), 5953-5961.

Yao, Y.-n., Ma, K., Zhu, J., Huang, F., Kuang, L., Wang, X., & Li, S. (2023). Non-destructive determination of soluble solids content in intact apples using a self-made portable NIR diffuse reflectance instrument. *Infrared Physics & Technology, 132*, 104714.

Yazici, A., Tiryaki, G. Y., & Ayvaz, H. (2020). Determination of pesticide residual levels in strawberry (Fragaria) by near-infrared spectroscopy. *Journal of the Science of Food and Agriculture, 100*(5), 1980-1989.

Zhang, B., Zhang, M., Shen, M., Li, H., Zhang, Z., Zhang, H., Zhou, Z., Ren, X., Ding, Y., Xing, L., & Zhao, J. (2021). Quality monitoring method for apples of different maturity under long-term cold storage. *Infrared Physics & Technology, 112*, 103580.

Zhang, M., Shen, M., Li, H., Zhang, B., Zhang, Z., Quan, P., Ren, X., Xing, L., & Zhao, J. (2022a). Modification of the effect of maturity variation on nondestructive detection of apple quality based on the compensation model. *Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy, 267*, 120598.

Zhang, Y., Wang, Z., Tian, X., Yang, X., Cai, Z., & Li, J. (2022b). Online analysis of watercore apples by considering different speeds and orientations based on Vis/NIR full-transmittance spectroscopy. *Infrared Physics & Technology, 122*, 104090.

Zhao, X., Peng, Y., Li, Y., Guo, Q., & Wang, B. (2023). A flight sensing detector for apple maturity indexes in orchard. *Biosystems Engineering, 230*, 470-479.

3D PRINTING AS A SOURCE OF PACKAGING INNOVATION

Patrycja Wojciechowska

Department of Industrial Products and Packaging Quality, Institute of Quality Science
Poznań University of Economics and Business, Poznań, Poland
**Corresponding Author e-mail: p.wojciechowska@ue.poznan.pl*

DOI: 10.56091/CTQS.Innov-25

Abstract
Three-dimensional printing (3D printing) is an innovative process that creates physical objects using various materials such as metals, ceramic or polymers from a computer-aided design file. In 3D printing solid objects are formed from a geometrical representation by a successive addition of materials, point-by-point, line-by-line or layer-by-layer. This technique is very useful for rapid manufacturing, customized design and structural applications in the fields of agriculture, medicine, automotive, architecture, locomotive, aviation industries, as well as in packaging sector. 3D printing can accelerate early-stage product development through rapid prototyping and decrease costs of product's commercialization, because additive manufacturing of single parts or a limited number of parts is cheaper than standard plastic processing techniques like injection molding, extrusion and thermoforming. Moreover, while personalized packaging is gaining of importance, 3D printing allows customers to design and make their own highly customized packages on request. Individual packaging designs can be manufactured specifically in accordance with customer wishes and various design of prototypes. Beyond rapid prototyping of a new packaging, this technique is useful in production of packaging machinery parts, such as printing robotic arms, and spare parts on demand. Furthermore, there's a number of sustainable packaging filaments available for use with 3D printing, such as celluloid fibres, renewable biomaterials (e.g., polylactic acid), bio-thermoplastic elastomers and recycled plastics.

Keywords: 3D printing, innovation, packaging, quality

Introduction

Three-dimensional printing (3D printing), also known as additive manufacturing (AM), rapid prototyping (RP) or solid-free form fabrication (SFF) is an innovative process that creates physical objects from a computer-aided design (CAD) file. The design can be also scanned in three dimensions from an original model or object. Next, the scan is translated into a 3D printable format, such as an STL (Standard Triangle Language) file, and the printer forms successive shaped layers of appropriate filament (fluid plastic, ceramic, or metal) to build up a series of cross sections of material. The cross sections are fused by heat, drying, or solidification from cooling of extruded thermoplastic.

Due to the fact that various materials can be used as filaments this technology is suitable for numerous applications such as agriculture, medicine, automotive, locomotive and aviation industries. In construction industry, 3D printing technology is being utilized for creating scale mockups for building components. On a larger scale, AM is used for the prefabrication of full-scale building components such as interior walls and partitions, as well as whole houses (SQ4D, 2023) (Fig. 1).

Fig. 1. 3D-printed house by SQ4D

Source: (SQ4D, 2023).

It also shows high potential in the packaging sector, for example in rapid prototyping of new designs (Brody, 2014; Chen et al., 2019; Singh et al., 2018; Wojciechowska & Wolek, 2020). Due to the numerous advantages of 3D printing, and its subsequent development, this technology is currently used not only for rapid prototyping but also for manufacturing of final objects. Among the first successfully commercialized were medical devices, such as artificial heart pumps or printed corneas, jewelry collections, PGA rocket engine or steel bridge in Amsterdam (Shahrubudin, Lee & Ramlan, 2019). Additive manufacturing can also be applied in packaging, for example for rapid preparation of various prototypes or, as a cost-effective solution, in the fabrication of smart systems used for intelligent packaging and point-of-use devices, using biocompatible nontoxic materials (Chantal et al., 2022). And last but not least, the interest in additive manufacturing has started to grow also among consumers. Since 3D printers are getting less expensive and more accessible for an average buyer, personal 3D printing or domestic 3D printing is gaining in importance not only for hobbyists and enthusiasts.

Rapid development within this new market continually promotes the popularization of additive manufacturing. It is definitely a positive trend while 3D printing has the potential to increase the quality of life and welfare since it can be applied for creation of parts intended for use in education, medical and health, military, automotive, lifestyle and a variety of other purposes.

3D printing for packaging applications

Commercially available 3D printing technologies

ISO/ASTM 52900:2021 standard establishes and defines terms used in additive manufacturing (AM) technology, which applies the additive shaping principle and thereby builds physical three-dimensional (3D) geometries by successive addition of material., AM is defined as a process of joining materials to make parts from 3D model data, usually layer upon layer, as opposed to subtractive manufacturing and formative manufacturing methodologies. 3D printing processes have been categorized into seven groups (ISO/ASTM 52900:2021):

a) binder jetting (in which a liquid bonding agent is selectively deposited to join powder materials),
b) direct energy deposition (in which focused thermal energy is used to fuse materials by melting as they are being deposited),
c) material extrusion (in which material is selectively dispensed through a nozzle or orifice),
d) material jetting (in which droplets of feedstock material are selectively deposited),
e) powder bed fusion (in which thermal energy selectively fuses regions of a powder bed),
f) sheet lamination (in which sheets of material are bonded to form a part),
g) vat polymerization (in which liquid photopolymer in a vat is selectively cured by light-activated polymerization).

The above presented classification is applicable to non-food prints. In the case of 3D printing techniques applied to food production four main groups can be named (Leontiou et al., 2023):

a) selective laser sintering (SLS),
b) hot air sintering (HAS),
c) liquid binding,
d) extrusion method.

For the first time, a rapid prototyping system (RD) was applied in 1981 by Hideo Kadoma of the Nagoya Municipal Industrial Research Institute who developed system of printing solid layers of quick-drying photopolymers that corresponded with a cross-sectional slice of a CAD model (Gopal & Reddy, 2018). In 1980s Charles Hull invented stereolithography (SLA) and patented 3D printer. Besides SLA, other commercially available 3D printing technologies are (Kumar, Singh & Farina, 2018):

- Fused Deposition Modelling (FDM) called also Fused Filament Fabrication (FFM),
- Selective Laser Sintering (SLS),
- Digital Light Processing (DLP),
- Selective Laser Melting (SLM),
- Electron Beam Melting (EBM),
- Laminated Object Manufacturing (LOM),
- Direct Metal Laser Sintering (DMLS),
- Jetting Modeling / Jetting System (JM/JS),
- Three-Dimensional Printing (3DP/TDP/3D).

Stereolithography is the most widely used rapid prototyping technology. In SLA, a laser or UV light is used to cure a liquid photopolymer. The photopolymer quickly solidifies wherever the laser beam strikes the surface of the liquid. SLA enables production of the high-quality objects covering a wide range of applications. Objects that have overhangs or undercuts must be supported during the fabrication process by support structures. These are either manually or automatically designed with a computer program specifically developed for rapid prototyping. Once complete, the part is elevated above the vat and drained. Excess polymer is swabbed or rinsed away from the surfaces. Fused Deposition Modeling (FDM) is a melt extrusion process where material is extruded through a nozzle on a machine that is programmed to deposit it according to the preferred design. The use of multiple extruder heads enables simultaneous printing of parts in different colours and the application of varied materials. FDM is the second most widely used rapid prototyping technology, after SLA. A plastic filament is unwound from a coil and directed to an extrusion nozzle. The nozzle is heated to the temperature appropriate to melt the polymer which flows in a controlled manner while the mechanism can be turned on and off. The nozzle is mounted to an X-Y plotter type mechanism enabling to trace out the part contours. As the nozzle is moved over the table in the required geometry, it deposits a thin stream of plastic, layer by layer. The plastic hardens immediately after being squirted from the nozzle and bonds to the layer below. Support structures are automatically generated for overhanging geometries and are later removed by breaking them away from the object.

Granular systems, such as SLS, DMLS or EBM, typically use lasers to fuse (sinter) powder in layers to build up a part. In this process the un-fused media serves as a support to the item being produced, reducing the need for temporary supports to be integrated into the design and removed afterwards during the finishing process. In SLS, powder of a thermoplastic polymer is spread by a roller over the surface of a build cylinder. The cylinder is equipped with a piston to provide a powder. A piston moves upward incrementally to supply a measured quantity of powder for each layer. A laser beam is traded over the surface of this tightly compacted powder to selectively melt and join the grains together to form a layer of the object. After the object is fully formed, the piston is raised. Final manual finishing is carried out by brushing away excess of the. No supports are required with this method since overhangs and under cuts are supported by the solid powder bed. Before the printed part can be removed from the printer, it must be cooled down to fix it. DLP involves exposing a light selectively, from a special projector to a container of a liquid polymer. Next the exposed liquid polymer hardens and the part is built in layers. Finally, liquid polymer is drained to leave the solid part. In EBM metal powder is melted layer by layer with an electron beam in a high vacuum [McAlister & Wood, 2014; Vaezi, Drescher & Seitz, 2020; Ramya & Vanapalli, 2016; Wojciechowska & Wolek, 2020).

Potential of a three-dimensional printing in packaging innovation

3D printing can be applied in a range of industries – from automotive to toy manufacturing, jewelry making, as well as in plastic packaging. In industrial settings, use to date has mainly been focused upon rapid prototyping to evaluate product design before production, rather than to create final consumer products (McAlister & Wood, 2014). Nevertheless, the production of moulds or mould templates for use in mass production has been also considered. 3D printing in packaging and industrial applications offer several advantages, mostly in manufacturing and refining prototypes (Fig. 2).

Fig. 2. Examples of packaging prototypes presented by Zortrax

Source: (Zortrax, 2023).

Besides rapid prototyping, 3D printing is also used for short-run custom manufacturing. In this case, the printed objects are not prototypes but actual end user products. The most important benefits are time and cost reductions, particularly in the case of rapid manufacturing where customization is a key issue. It is worth noting that additive manufacturing is also very useful in printing complex geometries, precisely customized parts, objects in a variety of slight variations or materials that need to be adapted frequently in their manufacturing lifecycle. In this case 3D printing enables personalization of the final product. For domestic users there is the potential to download or upload and share part designs. 3D printing enables the flexible preparation of precise or complex structures that are difficult to obtain using traditional fabrication methods such as casting. Among the strengths of additive manufacturing reduced design constrains, reduced number of parts and supply chain, as well as efficient use of materials can also be named. As an example, a Michigan Technological University study revealed that 41-64% less energy was used to 3D print an item than to manufacture it overseas and ship it to the United States (Mikahila, 2022). Additive manufacturing can also be applied in the packaging sector for rapid prototyping, which is not only less cost-consuming and reduces the time way of final product commercialization, but also this solution offers closer-to-reality 3D prints which can be used for consumer testing (such as focus groups interviews) in order to obtain better true-life feedback from respondents (Fig. 3). Moreover, 3D printing enables fast production of CMF (color material finish) design prototypes. Full-color new container prototypes empower the design team to take their concept from the early research phases to physical testing through to final production. CMF plays a significant role in the user experience because the product's overall impression is easy to access during the whole product design process. The way it looks, feels, and even smells, can significantly affect customer's willingness to buy, and be of some use to verify how it is perceived by stakeholders (Stratasys, 2023).

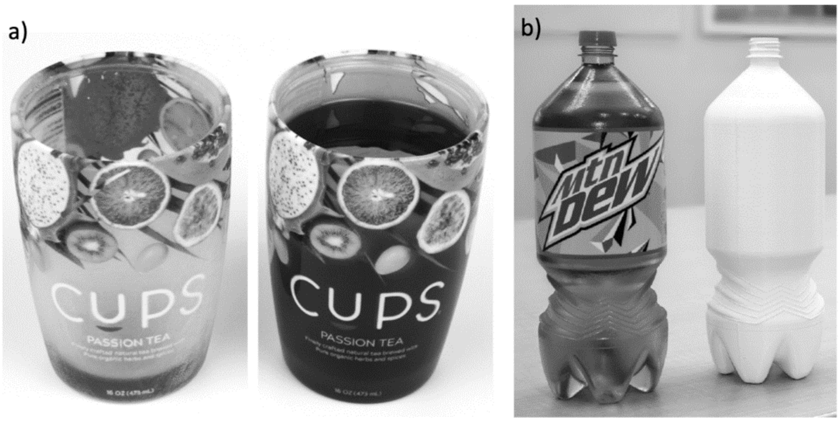


Fig. 3. Packaging prototypes utilizing 3D printing technology presented by Kinetic Vision (a) and CMF design prototypes used by PepsiCo (b)

Source: (Stratasys, 2023).

Additive manufacturing is also a promising tool in cosmetics packaging where the presence and esthetics are especially of importance. In this sector a package is the brand ambassador and its image can add value and credibility to the brand story. It is particularly worth noting when selling luxury products like perfume or personalized creams. 3D printed prototypes enable to design containers with a noticeable on-shelf presence, enhancing packaging design and production process (Fig. 4).

Fig. 4. Packaging concepts 3D printed on the Stratasys 3D printer used by Quadpack

Source: (Stratasys, 2019).

With 3D printing it is also possible to create packaging models that look and feel like the real containers, simulating organic textures and surface finishes and using varied colors. For example, the J55 an in-house 3D printer can produce more than 500,000 distinguishable color combinations and provide multi-material capabilities, enabling CMF prototypes to be introduced much faster than any traditional methods have allowed. The J55 is also a PANTONE validated 3D printer that offers improved color fidelity of the prototype by matching Stratasys CMYK colors to more than 1,900 printable PANTONE colors (Fig. 5). Before printing a prototype, product packaging files, using appropriate software such as Adobe Substance 3D Painter, are prepared in order to obtain textured models revealing the appearance of the designed container (Fig. 6) (Mehlhoff, 2021).

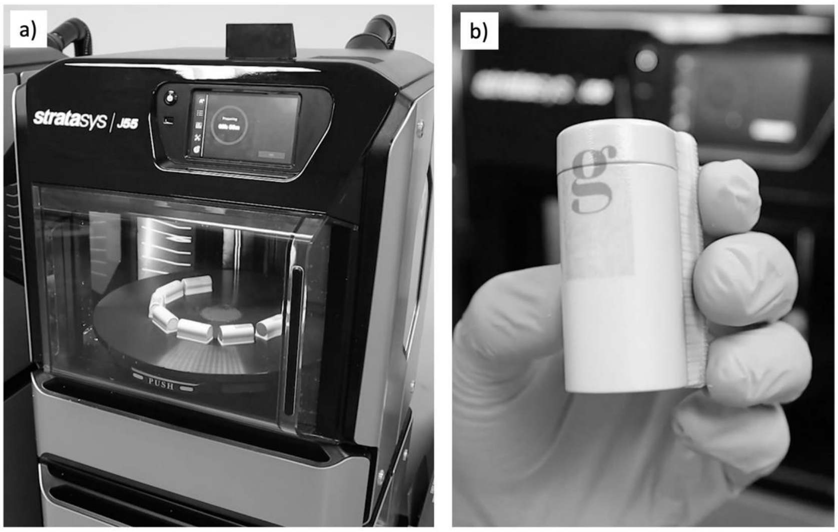


Fig. 5. The J55 PANTONE validated 3D printer (a) and finished packaging prototype (b)

Source: (Mehlhoff, 2021).

Fig. 6. 3D printed prototype (left) and Adobe Substance 3D Painter (3D painting) textured model (right)

Source: (Mehlhoff, 2021).

Interestingly, when it comes to 3D printing, fabricating parts and products can result in 70-90% less scrap waste when compared to traditional methods of manufacturing. Reduced labour costs and law costs of small production runs are also important opportunities. However, there are also some weaknesses of the application of 3D printing such as limited speed and volumes and insufficient material variety (Chen et al., 2019; McAlister & Wood, 2014). In the case of packaging, mostly one sustainable biopolymer is applied as a filament – polylactide (PLA), a biodegradable material obtained from renewable resources (e.g., corn-starch). It is widely applied in the production of medical implants, tissue engineering, orthopedic devices, and drug delivery systems (Foltynowicz & Jakubiak, 2002). PLA, showing similar properties to polystyrene, has also gained importance in the packaging industry, especially in the production of films and containers which are able to be certified as compostable (Ankiel, Wojciechowska & Wiszumirska, 2021). When it comes to 3D printing, PLA shows lower heating requirements (both in production and use of the feedstock) meaning reduced energy consumption. It has lower emissions and better print quality due to reduced shrinkage and lower embodied energy impacts: 27-59 MJ/kg compared to 95 MJ/kg for ABS (acrylonitrile butadiene styrene). In comparison with ABS, PLA has reduced strength and durability due to a lower melting point and usually slightly higher cost (McAlister & Wood, 2014) but on the contrary, PLA is made from renewable resources and is biodegradable. Wojciechowska and Wolek (2020) examined mechanical properties of packaging prototypes made of PLA and HIPS (high impact polystyrene) in order to determine the influence of the type of filament used on dimensions and compressive strength of the packages. For this purpose, three packaging configurations, with different wall thicknesses of the samples: 0.8, 1.2 and 1.6 mm were prepared using a slicer program SIMPLYFY 3D and 3D Prusa Mendel printer, printing in FDM/FFF technology, and subsequently examined. The results showed that PLA is a good alternative to HIPS, revealing good dimension accuracy, regarding nominal values of the designed packaging, and higher compression strength in comparison with adequate HIPS containers.

When it comes to sustainable filaments, it is also worth mentioning that in November 2013 an initiative was launched called “The Ethical Filament Foundation”, with the goal of producing filaments from recycled plastic waste whilst providing stable incomes for waste pickers in developing countries. Material choice has also a strong influence on the overall environmental impact. Therefore, it is important to select the lowest impact filament, aiming to optimise for the following (McAlister & Wood, 2014):

- reduced shrinkage (provides better printing tolerances and less failed prints),
- lower emissions (less toxicity risk to users and those in the printer’s vicinity),
- embodied energy (a good example is a feedstock derived from renewable and biodegradable resources such as corn-based PLA or from recycled plastics; in case it is not possible, feedstocks should be easily recyclable),
- limited finishing needs (additional finishing processes require greater additional process energy),
- heat capacity / melting point and density (for some processes, energy in use may be reduced by optimizing melting point against the strength requirements of the part to be printed).

Sustainable materials are not the only alternative important from environmental point of view. In order to reduce the waste impacts of 3D printing there are several measures worth considering (McAlister & Wood, 2014):

- selection of the lowest-waste printing technology/model (available in some 3D printer technologies, for example in the case of plastic printing, FDM-style machines generate much less waste than inkjet-style, and sintering approaches result in much more waste for polymer processes than they do for metal processing);
- purchase of feedstock from suppliers that offer cartridge and/or waste return (for plastic printing, this can reduce consumption of raw materials and materials to waste); also, it is important that printers have the flexibility to use recycled feedstock;
- the use of shredding and extrusion devices in order to enable creation of recycled feedstock from failed prints and support structures, and/or other plastic materials diverted from the waste stream (the embedded energy and additional energy use with such devices would mean that they would only have the potential to reduce environmental impacts in high volume print environments; recycled feedstocks can result in economic savings also);
- refine printer set up to ensure achievement of the best print quality (e.g., a proper positioning of the filament drum above the machine in a plastic printer can decrease the friction of the feed to the heated nozzle).

Environmental impact of 3D printing

Environmental considerations regarding additive manufacturing relate mostly to energy and resource use, as well as emissions and waste. The lifecycle impact of 3D printing has been investigated in some initial studies in the area with the conclusion that electricity in the in-use phase can be considered as one of the dominant features. However, type of the manufacturing technique the 3D printer is replacing plays also an essential role. For example, injection moulding is only suitable for higher volume production runs due to the high cost of creating injection moulds, therefore special attention to assumptions in this case, should be paid when making comparisons with AM technique. Some environmental benefits were also found in the automotive industry, such as reduced product weight and thus reduced fuel consumption, limited transportation and material losses, as well as improved functionality and possibility for printing of spare parts, also with complex geometry. The amount of LCA studies concerning the 3D printing technique's impact on the environment is successively rising and covering also other sectors. It should be underlined that the analysis must be conducted precisely case by case, while it is dependent on numerous factors such as the type of the industry, the level of detail of the input data or the boundaries of the system.

The so far presented in the scientific literature results show clearly that there is a need for further studies that aim to find the relationship between different AM processes and their relative environmental impacts (Böckin & Tillman, 2019; McAlister & Wood, 2014; Shuaib et al., 2021).

Conclusions

3D printing is an emerging market, with an increasing number of companies competing for a share of expanding sales. The number of 3D printing companies has been on a significant increase since for a decade. On the other hand, printer prices have reduced substantially in recent years due to competition and economies of scale. Additive manufacturing has gained a lot of attention as one of the most exciting innovations in the food and beverage packaging industry. It enables rapid prototyping of new designs, offering time and cost reductions, particularly in case of a short run. 3D printing shortens the overall time needed for the introduction of a new packaging on the market. This technology facilitates also the cost-effective production of personalized packaging on request, where customization is a key issue. It offers tailored construction forms, ornaments such as engravers, and the possibility of production of special-shaped containers. In the packaging industry, prototypes made with 3D printing technology enable to predict the end performance of the final product so this solution is practiced widely more often.

References

Ankiel, M., Wojciechowska, P., & Wiszumirska, K. (2021). *Innowacje opakowaniowe na rynku produktów konsumpcyjnych*. Poznań, Wydawnictwo UEP.

Böckin, D., & Tillman, A-M. (2019). Environmental assessment of additive manufacturing in the automotive industry. *Journal of Cleaner Production*, 226, 2019, 977-987. https://doi.org/10.1016/j.jclepro.2019.04.086.

Brody, A.L. (2014). 3D Printing: Rapid Prototyping from Food to Food Packaging, *Food Technology*, 68(4), 107-108.

Chen, Z., Li, Z., Li, J., Liu, Ch., Lao, Ch., Fu, Y., Liu, Ch., Li, Y., Wang, P., & He, Y. (2019). 3D printing of ceramics: A review. *Journal of the European Ceramic Society*, 39(4), 661-687. https://doi.org/10.1016/j.jeurceramsoc.-2018.11.013.

Foltynowicz, Z., & Jakubiak, P. (2002). Poli(kwas mlekowy) – biodegradowalny polimer otrzymywany z surowców roślinnych, *Polimery*, 47 (11-12), 769-774.

Gopal L.V., & Reddy, G.S.K. (2018). Design and Development of Cantilever 3D Printer Model. *IOP Conference Series: Materials Science and Engineering,* 455, 012137.

ISO/ASTM 52900:2021 Additive manufacturing — General principles — Fundamentals and vocabulary.

Kumar, R., Singh, R., & Farina, I. (2018). On the 3D printing of recycled ABS. PLA and HIPS thermoplastics for structural applications, *PSU Research Review*, 2(2), 115-137. https://doi.org/10.1108/PRR-07-2018-0018.

Leontiou, A., Georgopoulos, S., Karabagias, V.K., Kehayias, G., Karakassides, A., Salmas, C.E., & Giannakas, A.E. (2023). Three-Dimensional Printing Applications in Food Industry. *Nanomanufacturing*, *3*, 91-112. https://doi.org/10.3390/nanomanufacturing3010006.

McAlister, C., & Wood, J. (2014). The potential of 3D printing to reduce the environmental impacts of production, *ECEEE Industrial Summer Study Proceedings*, 213-221.

Mehlhoff, C. (2021). *From Substance to 3D Printed Packaging Prototypes*.https://substance3d.adobe.com/-magazine/from-substance-to-3d-printed-packaging-prototypes/

Mikahila, L. (2022). *How 3D-Printed Sustainable Packaging Meets Corporate Goals & Consumer Demands*. https://www.3dnatives.com/en/3d-printing-sustainable-packaging-corporate-goals-consumer-demands-211220214/

Ramya, A., & Vanapalli, S.L. (2016). 3D Printing Technologies in Various Applications. *International Journal of Mechanical Engineering and Technology*, 7(3), 396-409.

Shuaib, M., Haleem, A., Kumar, S., & Javaid, M. (2021). Impact of 3D Printing on the environment: A literature-based study, *Sustainable Operations and Computers*, 2, 57-63. https://doi.org/10.1016/j.susoc.2021.04.001.

Shahrubudin, N., Lee, T.C., & Ramlan, R. (2019). An overview on 3D printing technology: technological materials, and applications, *Procedia Manufacturing* 35, 1286-1296. https://doi.org/10.1016/j.promfg.2019.06.089.

Singh, R., Kumar, R., Mascolo, I., & Modano, M. (2018), On the applicability of composite PA6-TiO_2 filaments for the rapid prototyping of innovative materials and structures, *Composites Part B: Engineering*, 143, 132-140. https://doi.org/10.1016/j.compositesb.2018.01.032.

Stratasys. (2019). *J Series is key to achieving faster time-to-market*. Retrieved August 10, 2023 from https://www.stratasys.com/en/resources/case-studies/quadpack-full-color/.

Stratasys. (2023.). *Case studies*. Retrieved August 10, 2023 from https://www.stratasys.com/en/resources/case-studies/.

SQ4D. (2024). Retrieved August 12, 2023 from https://www.sq4d.com.

Tracey, Ch.T., Predeina, A.L., Krivoshapkina, E.F. & Kumacheva, E. (2022). A 3D printing approach to intelligent food packaging. *Trends in Food Science & Technology*, 127, 2022, 87-98. https://doi.org/10.1016/j.tifs.2022.05.003.

Vaezi, M., Drescher, P., & Seitz, H. (2020). Beamless Metal Additive Manufacturing. *Materials, 13,* 922, 1-36. https://doi.org/10.3390/ma13040922.

Wojciechowska, P., & Wolek, P. (2020). Design and properties of packaging prototypes made from PLA and HIPS using 3D printing technology, *Towaroznawcze Problemy Jakości. Polish Journal of Commodity Science*, 1(62), 41-49.

Zortrax. (2023). *Druk 3D w projektowaniu opakowań*. Retrieved August 8, 2023 from https://zortrax.com/-pl/applications/packaging-design/.

QUALITY ASSESSMENT OF GREEN TEA USING NIR SPECTROSCOPY

Krzysztof Wójcicki*[1], Emilia Pic

[1]Department of Technology and Instrumental Analysis, Institute of Quality Science
Poznań University of Economics and Business, Poznań, Poland,
**Corresponding Author e-mail: krzysztof.wojcicki@ue.poznan.pl*

DOI: 10.56091/CTQS.Innov-24

Abstract

Tea is consumed all over the world and is considered one of the most popular beverages, right after water and coffee. The aim of this study was to evaluate the quality of green teas using near-infrared spectroscopy coupled with chemometric data analysis. For the study, 17 samples of green teas differing in processing method, harvesting time and geographic origin was used. The samples came from 4 countries: China, Vietnam, Japan and South Korea. All of them were purchased in a Polish online store. The research was carried out in terms of: analysis of NIR spectra of dried and infused teas, total phenolic compounds in infusions (using Folin-Ciocalteu reagent), and analysis of PCA and PLS data.

According to obtained results of all PLS analyses, it can be concluded that a good correlation between NIR spectra and total phenolic compound content was obtained. This is evidenced by the relatively high values of R^2 and the relatively low values of RMSEE and RMSECV. The quality of the model was determined by the RPD value.

Based on the results obtained, it can be concluded that NIR spectroscopy is suitable for assessing the quality of green tea.

Keywords: quality assessment, spectroscopy, NIR, tea

Introduction

Tea (*Camellia sinensis*) is a vital crop with high economic value and is widely cultivated in Asian countries such as China, India, Japan, and Sri Lanka (Wang et al., 2022). There are several types of tea, including green tea, black tea, yellow tea, white tea, and oolong tea, each made using different methods. The composition of tea can vary because of differences in plant varieties, environmental conditions, processing techniques, and preparation methods (Kumar et al., 2011). ISO standards require teas to meet certain requirements for both flavor and composition. These standards apply to the quality of both black and green teas. For the evaluation of tea quality and its chemical characteristics for commercial purposes, methods of wet chemistry are traditionally used, but these methods are destructive, and time-consuming. In scientific interest is to find the rapid, more objective, and simpler analytical methods, for the routine tea analysis, which will replace the old methods.

Near-infrared spectroscopy (NIRS) is an increasingly popular technique used for nondestructive quality evaluation of food and non-food products. NIRS is prevalent in food, agricultural, pharmaceutical, and packaging industries (Andrés et al., 2007; Cozzolino et al., 2005; Woodcock et al., 2008). Using NIRS as a measurement technique has advantages of rapid, easy, and nondestructive measurements, eliminating the need for multiple chemical reagents. In recent NIRS studies, researchers developed different methods to measure food quality, including online measurement (Dixit et al., 2017), portable measurement (Basri et al., 2017), and imaging analysis (Mahesh et al., 2015).

NIRS has been successfully used to predict the main components related to the quality of finished tea. These components include tea polyphenols, amino acids, P/A values, caffeine, catechins, and theaflavins. Furthermore, NIRS is widely used to monitor the various steps of tea processing, including the withering and fermentation of black tea (Ren et al., 2023; Wang et al., 2019; Wang et al., 2022). Yan et al. (2022) demonstrated that NIR spectroscopy could be a green analysis tool that may predict the taste quality indicators in tea while identifying the authenticity of the tea. The most recent advances and applications of NIR spectroscopy and chemometrics for the quality control of tea, including the measurement of chemical compositions, the evaluation of sensory attributes, the identification of categories and varieties, and the discrimination of geographical origins was presented by (Zhu et al., 2019).

The aim of the study was to evaluate the quality of green teas by near-infrared (NIR) spectroscopy and to perform statistical analyses in terms of: principal component analysis (PCA) and least squares (PLS), as well as correlations between the content of phenolic compounds in the infusions and their obtained spectra.

Materials and methods

Research material

Seventeen green teas from China, Vietnam, Japan and South Korea purchased from the online store were tested. The teas have a common feature – they belong (according to the Chinese classification) to one type – green teas. The tea samples varied in harvesting time, leaf age, and processing method depending on the origin. For example, teas from Japan are characterized by Japan-specific fixation of the leaves by subjecting them to steam, while in China fixation is usually done by heating the leaves on a wok.

The study included not only dried tea (dried leaves), but also infusions prepared from it. The ISO 1839:1980 standard considers a specific method of infusion preparation for physicochemical testing, but the infusions used in the study were prepared according to the manufacturer's recommendations, with the aim of creating an infusion that the consumer could prepare at home. Consumers who regularly consume good-quality green tea strictly follow the rules and manufacturer's recommendations regarding brewing, due to the desirable sensory values of the infusion and its health-promoting properties The preparation of the infusions: weight, water temperature, brewing time and quantity are shown in Table 1.

Table 1. Method of preparing tea infusions

Sample	**Country/Origin**	**Weighing amount [g/250ml]**	**Brewing temperature [°C]**	**1st brewing time [s]**	**2nd brewing time [s]**
1	China	4.17	80	120	180
2	China	4.02	80	120	180
3	China	4.15	80-85	120	180
4	China	4.22	80	120	180
5	China	4.91	80	120	240
6	China	4.01	~80	120	150
7	Vietnam	3.95	~80	120	240
8	Vietnam	5.07	~80	120	240
9	Japan	4.94	80	90	60
10	Japan	6.04	75	90	30
11	Japan	4.97	75	90	180
12	Japan	6.09	~75	60	30
13	Japan	5.84	85	120	120
14	Japan	5.03	~90	120	180
15	South Korea	5.12	~80	90	30
16	South Korea	5.03	~75	90	120
17	South Korea	4.05	75	90	60

Source: own study.

Determination of the total content of phenolic compounds

The total content of phenolic compounds (TPC) in tea infusions was determined spectro-photometrically using the Folin-Ciocalteu reagent (Włodarska et al., 2017). This method involves the spectrophotometric measurement of the color change from yellow to blue of the Folin-Ciocalteu reagent, due to its reaction with the hydroxyl groups of phenolic compounds.

Absorbance measurement was determined at 765 nm using a Biotek EpochTH microplate spectrophotometer
and Gen 5 software. Prior to the determination, the previously prepared tea infusion samples were centrifuged at 14,000 rpm for 5 min using a MiniSpin from the manufacturer Eppendorf. The total content of phenolic compounds was expressed in mg of gallic acid (GAE) per 100 ml of infusion, which was calculated based on the standard curve equation of gallic acid.

NIR measurement

A Bruker spectrophotometer (MPA/FT-NIR) was used to measure near-infrared (NIR) spectrain the range of 1250-4000 cm^{-1}. Each sample was measured 3 times.

The dried samples were measured using a solid reflectance attachment to record the NIR spectra in reflected light. Between each measurement, samples were mixed in order to obtained reliable results. The infusions were placed in glass cuvettes with an optical path length of 8 mm to record the NIR spectra in transmitted light.

The measurements were recorded using OPUS software, and presented in graphical form using The Unscrambler software from CAMO.

Data analysis

In order to group the samples according to their geographical origin, based on the near-infrared spectra obtained from the dried teas, the PCA analysis method was applied. Principal component analysis (PCA) is a multivariate technique that linearly transforms an original set of variables into a substantially smaller set of uncorrelated variables that represents most of the information in the original data set. The experimental data for PCA are arranged in two-way matrix, in which column vectors represent variables and row vectors represent “objects” of which the variables are measured.

The PCA analysis was carried out using The Unscrambler (CAMO Analytics) software.

The partial least squares (PLS) regression method was also used to investigate the correlation of NIR spectra of tea infusions with total phenolic compounds. The set of independent variables X were the NIR spectra and the set of dependent variables Y were TPC. The regression models were evaluated using the adjusted R^2 and the root mean-square error of estimation (RMSE) and root mean-square error of cross validation (RMSECV). The efficiency of the modeling was evaluated by the ratio of the relative percent deviation (RPD). The regression method was carried out using OPUS, and both the full range of the NIR spectrum and its selected regions were used for analysis, along with appropriate mathematical transformations.

Results and discussions

Phenolic content

Yao et al., reported that phenolic compounds are the main quality parameters for tea. Tea phenolic compounds, known as tea polyphenols, previously called tea tannins have been regarded as the quality parameters or indicators of tea (Yao et al., 2006).

Tea infusions were prepared from one portion of dried tea and brewed twice according to the recommendations of the producer. The results for total phenolic compounds (TPC) are shown in Figure 1.

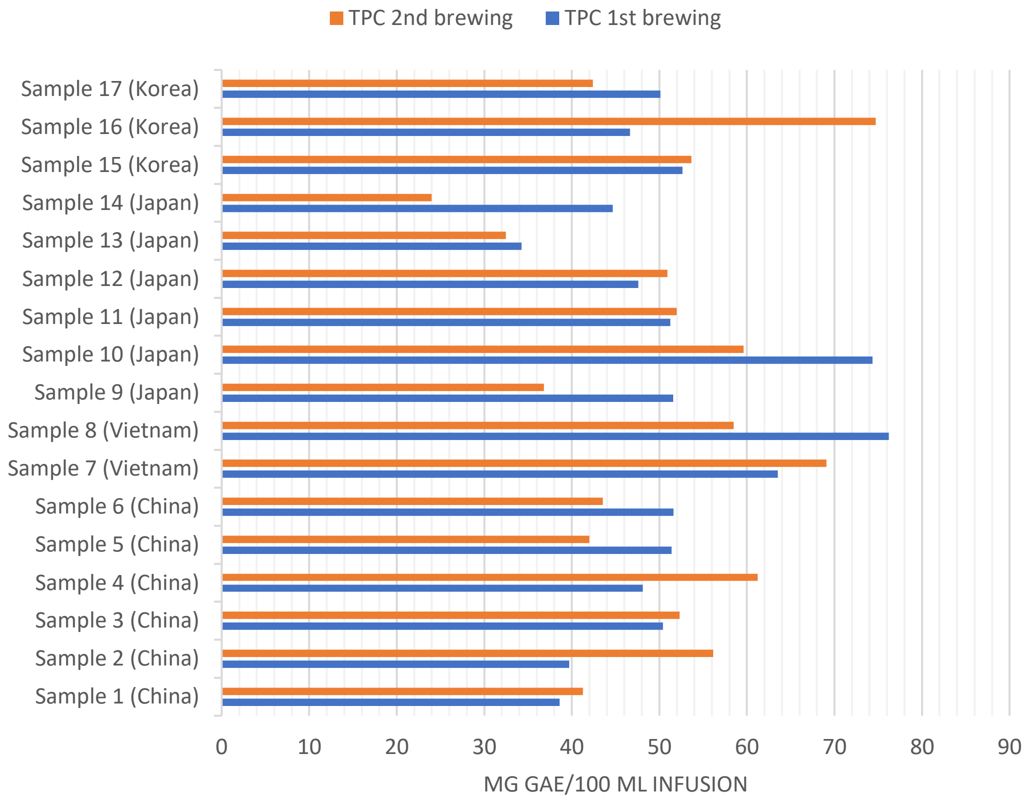


Fig. 1. Total content of phenolic compounds in infusions, determined using Folin-Ciocalteu reagent

Source: Own study.

The amount of TPC ranged from 34 to 76 mg GAE/100 ml infusion for the first brew, and from 24 to 75 mg GAE/100 ml infusion for the second brew. The highest amount of phenolic compounds for the first brew was shown by sample 8 (Vietnamese green tea), with a total phenolic compound content of 76.2 mg GAE/100 ml infusion. Sample 10 from Japan, contained slightly less with 74.34 mg GAE/100 ml infusion.

On the other hand, in the second brew, the highest total content of phenolic compounds, 74.42 mg GAE/100 ml of infusion, was found in sample 16, a tea from South Korea. The lowest amount of phenolic compounds was found in two teas from Japan, in the first brew it was sample 13 with a content of 34.27 mg GAE/100 ml of infusion, while in the second brew it was Hojicha tea (Sample 14) with a content of 23.97 mg GAE/100 ml of infusion.

Analyzing the obtained results, according to the geographical origin of the teas, it can be seen that samples from Vietnam were characterized by relatively high content of phenolic compounds, both in the first and in the second brew.

Spectral characteristics of tea samples

Figure 2 shows the raw spectra of all the dried tea samples measured over the entire near-infrared range of 12500-4000 cm^{-1}. All samples showed similarity in the shape of the spectra with no major differences.

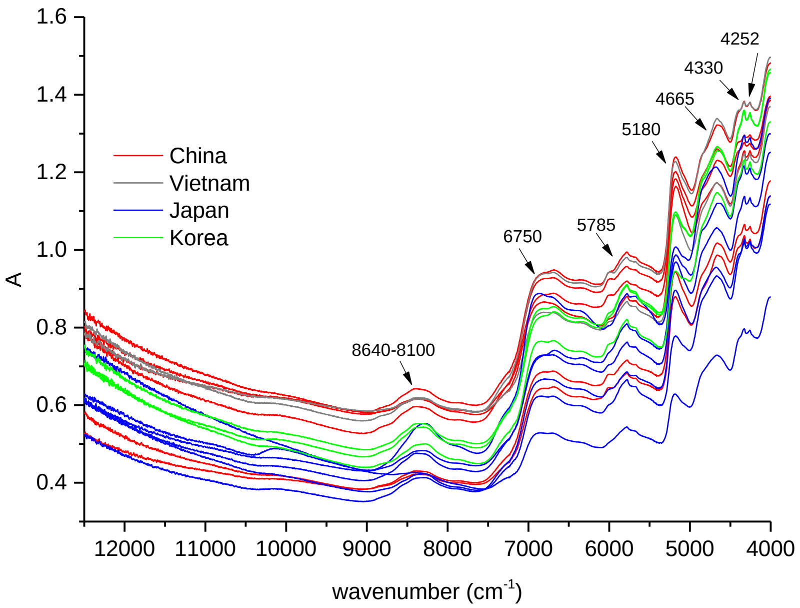


Fig. 2. Absorption spectra of all dry's tea samples in near-infrared region (12500-4000 cm^{-1})

Source: own study.

Green tea is a natural healthy product rich in polyphenolic compounds composed of a large number of hydrogenous bonds (i.e., C–H, O–H, and N–H) (Ridder et al., 2013). The most intense absorption bands are seen in the range of 9000-4000 cm^{-1}, the spectra of dried tea were characterized by seven bands with maximum absorption at: 8640-8100, 6750, 5785, 5180, 4665, 4330 and 4252 cm^{-1}.

The broad and weak peak observed at 8640-8100 cm^{-1} can be associated with the stretching of C–H, CH_2 and CH_3 groups, indicating the presence of polyphenols (Xu et al., 2018; Yan et al., 2022).The peak in the region of 6750 cm^{-1} may be due to the first overtone of O-H stretching from amino acids and caffeine, while the peak in the region of 5785 cm^{-1} may be responsible for the second overtone of C–H stretching in various groups (Fu et al., 2019). The peak around 5180 cm^{-1} can be explained as second overtone of C=O stretching bands, first overtone of C–H stretching bands in aromatic rings and combination of the base bands of O–H stretching and bending. The band at around 4665 cm^{-1} comes from C=C stretching vibrations, =C–H bands, and a combination of basic N–H stretching and bending bands. The bands at 4330 cm^{-1} and 4252 cm^{-1} can be attributed to a combination of C-H stretching and C-H bending in the phenyl or the second overtone of CH_2 bending, and these peaks may be relevant to tea polyphenols, catechin, and their derivatives (Fu et al., 2019; Yan et al., 2022).

PCA analysis

In order to investigate the possibility of grouping the samples according to their geographical origin based on the recorded NIR spectra, a PCA analysis was performed. The analysis was performed both for the whole range of the NIR spectrum, the results of which are shown in Figure 3, and for a selected range (from 7803 cm^{-1} to 4000 cm^{-1}), the results of which are shown in Figure 4.

Figure 3 shows a graphic representation of PCA of full NIR spectra. The first and the second main component (PC1 and PC2) describes 99% of total variation. PC1 describes 85% of total variability while the PC2 14%. Samples spread along the PC1 axis from negative to positive values, according to the origin. Teas from China (red color), Vietnam (grey color) and Korea were characterized (in most cases) by positive values of PC1. Two teas from China were clearly different from other tea samples from China presented in the PCA model. These were samples of teas named Dingu Gu Da Fang (Sample 1) and Long Jing (Sample 6). These samples are similar in terms of the way the leaves are processed, as they are pressed against the surface of the wok in the process of stopping oxidation to form a flat and elongated shape, which distinguishes them from other teas. Samples from South Korea (green color), are characterized by positive value of PC1 and PC2. Samples from Japan (blue color) were characterized (in most cases) by negative PC1 values and positive PC2 values. Among the teas from Japan, sample 14 stands out, which is a roasted tea consisting mainly of stems.

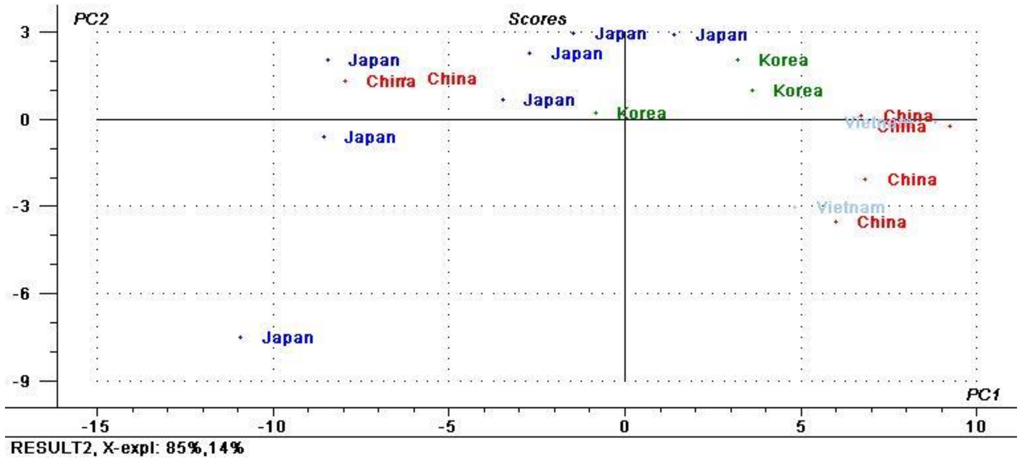


Fig. 3. PCA results of the NIR spectra of dried tea samples in the range 12500-4000 cm^{-1}

Source: own study.

Figure 4 shows the results of the principal components analysis for the selected NIR spectra (8746-12000 cm^{-1}). The first and second main component (PC1 and PC2) describes 99% of total variation. PC1 describes 95% of total variability while the PC2 4%. As can be seen in Figure 4, samples are divided into two main groups. First group includes China and Vietnam teas with the positive values of PC1 and PC2. Two teas differ from other tea samples for the same reason as previous. The second group include Japan and Korea samples which were characterized mostly by negative values of PC2. Among the teas from Japan, sample 14 stands out for the same reason as previous.

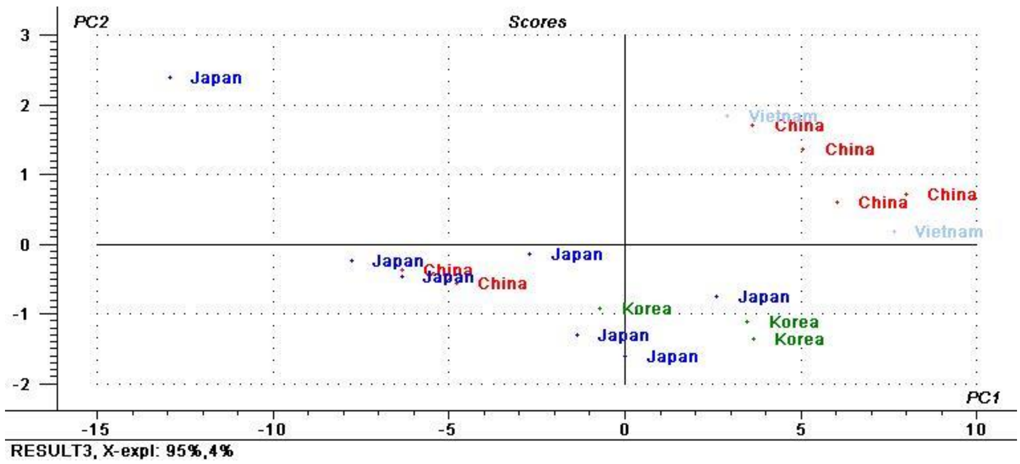


Fig. 4. PCA results of the NIR spectra of dried tea samples in the range 7803-4000 cm^{-1}

Source: own study.

PLS analysis

In order to investigate the possibility of determining the phenolic content by NIR spectrum, the PLS analysis was performed. Different ranges of spectra and their transformations, including multiplicative scatter correction (MSC), first derivative and first derivative with vector normalization, were used to build PLS models. PLS analysis was carried out on single and double brewed tea samples and on all infusions together.

Figure 5 shows the PLS regression model for tea infusions brewed for the first time. The best model was obtained for the range of 9403-5446 cm^{-1} and 4601-4246 cm^{-1} with the MSC transformation. An average correlation between the NIR spectra and the determined phenolic compounds was obtained, as evidenced by the R^2 parameter, which was 68.99 for the calibration model and 44.39 for the validation model. The error values were relatively low, the RMSEE value in the calibration model was 6.33, while the RMSECV in the validation model was 8.05. The RPD value was 1.8 for calibration, while for the validation model it was 1.34.

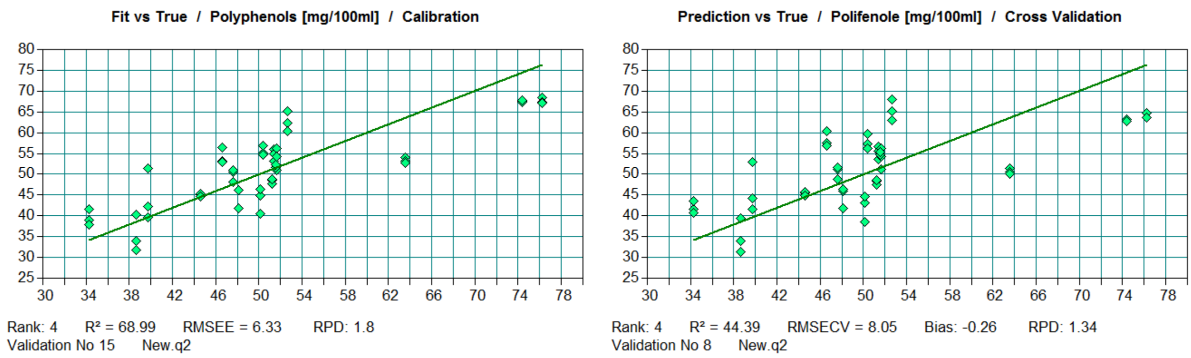


Fig. 5. Results of PLS regression analysis of tea infusions brewed for the first time, for the ranges 9403-5446 cm^{-1} and 4601-4246 cm^{-1} using the MSC transformation. Left – calibration model, right – validation model

Source: own study.

Figure 6 shows the results of PLS analysis made for tea infusions brewed for the second time. Model for the NIR spectra in the range of 6102-5446 cm^{-1} coupled with the first derivative transformation achieve the best fit. The results of the regression analysis show that a very good correlation of NIR spectra with the content of phenolic compounds was obtained. The R^2 for the calibration curve was 92.01 while for validation 84.79. The RMSE values were low – for the calibration 3.77 while for validation 4.94.

The models obtained were of good quality, as the value of the RPD index in the calibration model was 3.54 and for the validation model it was 2.56.

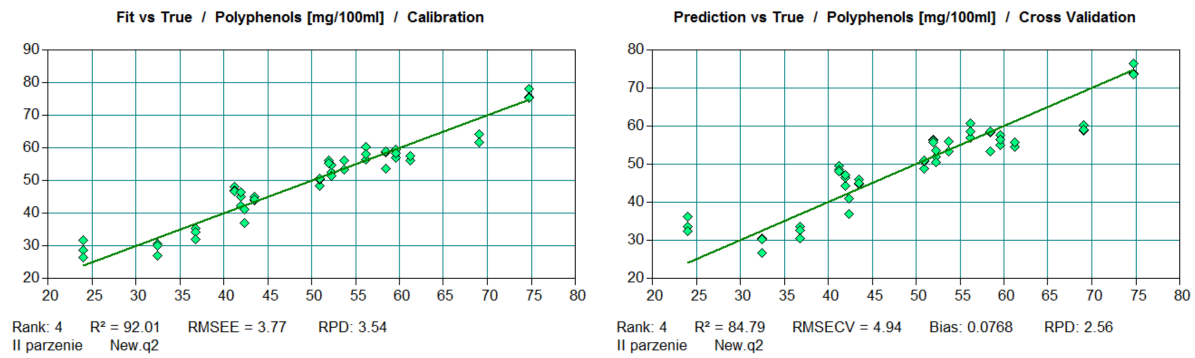


Fig. 6. Results of PLS regression analysis of tea infusions brewed for the second time, for the range 6102-5446 cm^{-1} using first derivative transformation. Left – calibration model, right – validation model

Source: own study.

Figure 7 shows the results of the PLS analysis of all the tea infusions. The model was built using NIR spectrum in the range of 8251-7498 cm^{-1} and 6102-5446 cm^{-1} coupled with the first derivative transformation and vector normalization.

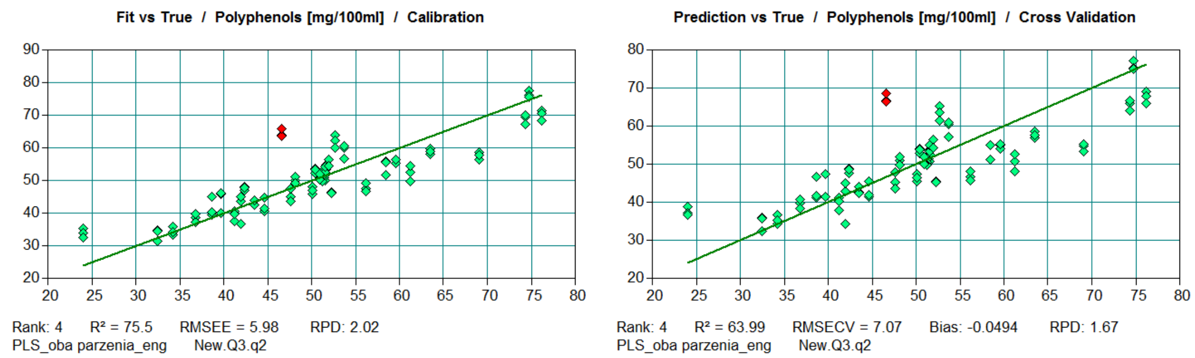


Fig. 7. Results of PLS regression analysis of all tea infusions, for the ranges 8251-7498 cm^{-1} and 6102-5446 cm^{-1} coupled with the first derivative transformation and vector normalization. Left – calibration model, right – validation model

Source: own study.

Based on the R^2 coefficient values, which were 75.5 for the calibration model and 63.9 for the validation model, it can be concluded that a good correlation of NIR spectra with total phenolic compounds was obtained. The error values were relatively low and were as follows: for the calibration model, the RMSEE error value was equal to 5.98, while for the validation model, the RMSECV error value was equal to 7.07. The quality of the model was good, as indicated by the RPD index value, which was 2.02 for the calibration model and 1.67 for the validation model.

To test the performance of the obtained model and its ability to predict the polyphenol content in the tea infusions, PLS analysis was carried out for the calibration and test set. The results are shown in Figure 8. The best model was for the range 6102-5446 cm^{-1} coupled with the first derivative transformation. For the test set validation R^2 parameter was 63.99 while RMSECV 7.07. These values indicate that model has a good potential for the TPC prediction.

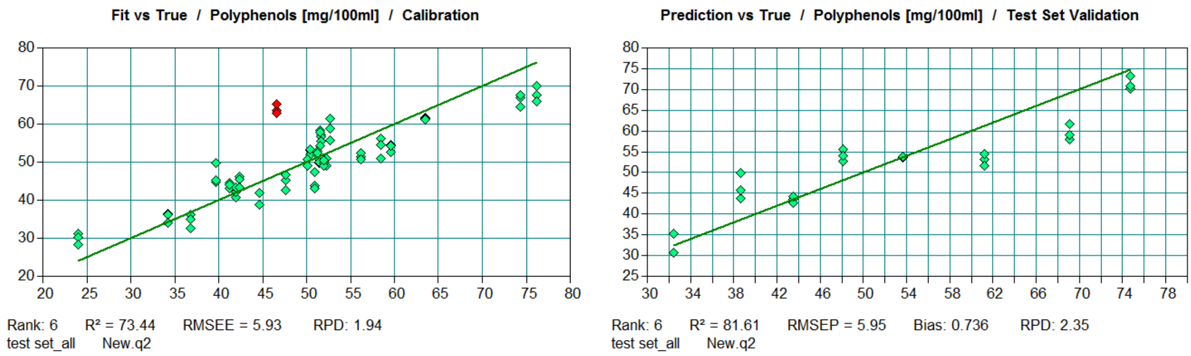


Fig. 8. Results of PLS regression analysis of all tea infusions, for the range 6102-5446 cm^{-1} coupled with the first derivative transformation. Left – calibration model, right – test set validation model

Source: own study.

Conclusions

Based on the NIR spectrum we could investigate the composition of the tea samples due to the characteristic bands and vibrations. The obtained regression results confirmed that it was possible to apply NIR spectra to predict the phenolic compounds of tea infusion samples. The good correlation between spectra and TPC was evidenced by the high values of the R^2 and the relatively low values of the mean squared errors. The quality of the model was determined by the RPD value, which was relatively high.

On the basis of the results obtained, it was proved that the NIR spectroscopy applied together with the chemometric analysis could be used as a green technology for quality assessment of tea samples. Such a solution is very important in the era of sustainable production due to better management of resources with a focus on reducing harmful reagents.

References

Andrés, S., Murray, I., Navajas, E.A., Fisher, A.V., Lambe, N.R., & Bünger, L. (2007). Prediction of sensory characteristics of lamb meat samples by near-infrared reflectance spectroscopy. *Meat Science*, *76*(3), 509-516. https://doi.org/10.1016/j.meatsci.2007.01.011

Basri, K.N., Hussain, M.N., Bakar, J., Sharif, Z., Khir, M.F.A., & Zoolfakar, A.S. (2017). Classification and quantification of palm oil adulteration via portable NIR spectroscopy. *Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy*, *173*, 335-342. https://doi.org/10.1016/j.saa.2016.09.028

Cozzolino, D., Murray, I., Chree, A., & Scaife, J.R. (2005). Multivariate determination of free fatty acids and moisture in fish oils by partial least-squares regression and near-infrared spectroscopy. *LWT – Food Science and Technology*, *38*(8), 821-828. https://doi.org/10.1016/j.lwt.2004.10.007

Dixit, Y., Casado-Gavalda, M. P., Cama-Moncunill, R., Cama-Moncunill, X., Markiewicz-Keszycka, M., Cullen, P.J., & Sullivan, C. (2017). Developments and challenges in online nir spectroscopy for meat processing. *Comprehensive Reviews in Food Science and Food Safety*, *16*(6), 1172-1187. https://doi.org/10.1111/1541-4337.12295

Fu, H., Hu, O., Xu, L., Fan, Y., Shi, Q., Guo, X., Lan, W., Yang, T., Xie, S., & She, Y. (2019). Simultaneous recognition of species, quality grades, and multivariate calibration of antioxidant activities for 12 famous green teas using mid- and near-infrared spectroscopy coupled with chemometrics. *Journal of Analytical Methods in Chemistry*, *2019*, 1-14. https://doi.org/10.1155/2019/4372395

Kumar, P.V.S., Basheer, S., Ravi, R., & Thakur, M.S. (2011). Comparative assessment of tea quality by various analytical and sensory methods with emphasis on tea polyphenols. *Journal of Food Science and Technology*, *48*(4), 440-446. https://doi.org/10.1007/s13197-010-0178-y

Mahesh, S., Jayas, D.S., Paliwal, J., & White, N.D.G. (2015). Comparison of Partial Least Squares Regression (PLSR) and Principal Components Regression (PCR) methods for protein and hardness predictions using the near-infrared (NIR) hyperspectral images of bulk samples of canadian wheat. *Food and Bioprocess Technology*, *8*(1), 31-40. https://doi.org/10.1007/s11947-014-1381-z

Ren, G., Zhang, X., Wu, R., Yin, L., Hu, W., & Zhang, Z. (2023). Rapid Characterization of Black Tea Taste Quality Using Miniature NIR Spectroscopy and Electronic Tongue Sensors. *Biosensors*, *13*(1), 92. https://www.mdpi.com/2079-6374/13/1/92

Ridder, L., Hooft, J.J.J., Verhoeven, S., De Vos, R., Bino, R., & Vervoort, J.J.M. (2013). Automatic Chemical Structure Annotation of an LC-MSn Based Metabolic Profile from Green Tea. *Analytical Chemistry*, *85*. https://doi.org/10.1021/ac400861a

Wang, Y., Cui, Q., Jin, S., Zhuo, C., Luo, Y., Yu, Y., Ning, J., & Zhang, Z. (2022). Tea Analyzer: A low-cost and portable tool for quality quantification of postharvest fresh tea leaves. *LWT*, *159*, 113248. https://doi.org/https://doi.org/10.1016/j.lwt.2022.113248

Wang, Y., Hu, X., Jin, G., Hou, Z., Ning, J., & Zhang, Z. (2019). Rapid prediction of chlorophylls and carotenoids content in tea leaves under different levels of nitrogen application based on hyperspectral imaging. *Journal of the Science of Food and Agriculture*, *99*(4), 1997-2004. https://doi.org/https://doi.org/10.1002/jsfa.9399

Włodarska, K., Pawlak-Lemańska, K., Górecki, T., & Sikorska, E. (2017). Classification of commercial apple juices based on multivariate analysis of their chemical profiles. *International Journal of Food Properties*, *20*(8), 1773-1785. https://doi.org/10.1080/10942912.2016.1219367

Woodcock, T., Fagan, C.C., O'Donnell, C.P., & Downey, G. (2008). Application of Near and Mid-Infrared Spectroscopy to Determine Cheese Quality and Authenticity. *Food and Bioprocess Technology*, *1*(2), 117-129. https://doi.org/10.1007/s11947-007-0033-y

Xu, J., Wang, M., Zhao, J., Wang, Y.-H., Tang, Q., & Khan, I.A. (2018). Yellow tea (Camellia sinensis L.), a promising Chinese tea: Processing, chemical constituents and health benefits. *Food Research International*, *107*, 567-577. https://doi.org/https://doi.org/10.1016/j.foodres.2018.01.063

Yan, X., Xie, Y., Chen, J., Yuan, T., Leng, T., Chen, Y., Xie, J., & Yu, Q. (2022). NIR Spectrometric Approach for Geographical Origin Identification and Taste Related Compounds Content Prediction of Lushan Yunwu Tea. *Foods*, *11*(19), 2976. https://www.mdpi.com/2304-8158/11/19/2976

Yao, L.H., Jiang, Y.M., Caffin, N., D'Arcy, B., Datta, N., Liu, X., Singanusong, R., & Xu, Y. (2006). Phenolic compounds in tea from Australian supermarkets. *Food Chemistry*, *96*(4), 614-620. https://doi.org/10.1016/-j.foodchem.2005.03.009

Zhu, M.-Z., Wen, B., Wu, H., Li, J., Lin, H., Li, Q., Li, Y., Huang, J., & Liu, Z. (2019). The Quality Control of Tea by Near-Infrared Reflectance (NIR) Spectroscopy and Chemometrics. *Journal of Spectroscopy*, *2019*, 8129648. https://doi.org/10.1155/2019/8129648

THE EFFECT OF THE BASE ON THE MECHANICAL PROPERTIES OF RUBBER

Aleksander Kowalak, Karolina Wiszumirska[1], Katarzyna Wybieralska*[2]

[1] *Department of Industrial Products and Packaging Quality, Institute of Quality Science, Poznań University of Economics and Business, Poznań, Poland*
[2] *Department of Technology and Instrumental Analysis, Institute of Quality Science, Poznań University of Economics and Business, Poznań, Poland*
**Corresponding Author e-mail: k.wybieralska@ue.poznan.pl*

DOI: 10.56091/CTQS.Innov-26

Abstract

A rubber compound is a mixture of synthetic or natural rubber, fillers, and other additives that modify its properties. The properties are introduced into the rubber by many factors, including the type of rubber, its amount, type of filler and additives. The selection of rubber varieties is crucial to obtain the desired product property.

The problem undertaken in the work was the analysis of the impact of the rubber base on the physical and mechanical properties of rubber mixtures, using these auxiliary substances in the original amount and the same method of production. In addition to the base under examination, four criteria are evaluated by the use of other rubbers (isoprene, butadiene-styrene) or changes in their properties.

Experiments done made it possible to determine the impact of the rubber base on the physical and mechanical properties of regulated rubber compounds. The tested components, thanks to the modification of the rubber base, can be improved in this category of exemplary assessment, and at the same time lose other features, such as: tear strength, hardness, effect reinforcement or application. It has been found that methods that should not be used as tire tread input for trucks or passenger cars have been changed, due to the excessive start that is found for this parameter.

Keywords: rubber, rubber compound, strength tests

Introduction

The rubber compound is one of the basic ingredients of many products that are used daily, such as car tires, medical products, sports equipment and more. This mixture is a mixture of synthetic or natural rubber, fillers and additives that modify its properties. The properties of the rubber compound are decisive for its quality and use, so it is important to understand how the composition affects its properties. The properties of a rubber compound depend on many factors, including the type of rubber, its amount, type of filler, and additives.

Choosing the right rubber compound is crucial to achieving the desired properties of the final product. For example, in the case of car tires, it is important that the compound is sufficiently flexible and resistant to abrasion, so as to ensure safe and comfortable driving of the vehicle. In the case of medical products, the rubber compound must be safe for the patient and have antibacterial properties and anti-allergic.

The subject of the research was the analysis of the impact of the rubber base on the physical and mechanical properties of rubber mixtures, using the same auxiliary substances in the same amount and the same method of preparation.

The research processes carried out made it possible to determine the impact of the type of rubber on the physical and chemical properties of the prepared rubber blends.

Rubber mixture

Rubber compounds, thanks to their properties, are an important component of many industrial products. The rubber or a combination of rubbers used in it, i.e., the rubber base, has a very large impact on the parameters and quality of the mixtures (Hasan et al., 2017). The rubber base determines the mechanical properties, such as flexibility, strength and abrasion resistance. Natural rubber is very flexible and durable, but is sensitive to weather conditions and unstable over time. Therefore, natural rubber is often used with synthetic rubber. Synthetic rubber, such as SBR, is more stable and resistant to external influences than natural rubber. Synthetic rubbers are often used in the production of rubber compounds because they are readily available and can be adapted to different needs (Arayapranee & Rempel, 2013; Pornprasit et al., 2016). Depending on the type of rubber used for the production of rubber compounds, different properties can be obtained. Therefore, the selection of the appropriate rubber base is crucial to obtain the desired properties of rubber compounds.

Preparation

Mixing rubber compounds is a complex task. Many ingredients are difficult to dose, and materials are delivered to the mixer in all possible forms, as rubber bales, oils, powders, hard resins, granulates, chips and even pastes. As it is quite costly to convert these raw materials into a powder form, discontinuous mixing with a kneader (or batch mixer) is still the most versatile and economical solution. Rubber mixtures should be characterized by appropriate plasticity (which facilitates the proper distribution of the mixture in the vulcanization form) and homogeneity, ensuring correct and uniform properties of the vulcanizates throughout their volume. An extremely important parameter during mixing is the temperature, which affects the properties of the rubber mixture. Namely, too high temperature leads to overheating of the mixture, a decrease in mixing efficiency and insufficient vulcanization of the rubber mixture, while too low temperature leads to insufficient plasticization of the rubber, which may result in improper mixing of the rubber mixture components. Difficulties in temperature control during mixing result from the high viscosity of the mixture and its ability to generate heat, which is associated with an increase in temperature in the mixers (Datta & Włoch, 2017; Limper, 2012).

This chapter will discuss the mechanisms of rubber mixing and a brief summary of the process of preparing rubber mixtures.

Viscosity reduction

Lowering the viscosity of the rubber is not a mixing mechanism per se, but is often necessary. The rubber is subjected to temperature (approx. 60˚) before initiating the mixing process. One of the elements that reduce the viscosity of rubber is the increase in temperature. The sensitivity of rubber viscosity to temperature changes depends to a large extent on the difference between the process temperature and the glass transition temperature. Other factors that reduce viscosity include:

- flow caused by unraveling of chains (reversible changes),
- flow caused by breaking chains (irreversible changes),
- increase in mixing speed.

The plasticizers used also have a huge impact on the change in the viscosity of the rubber:

- chemical plasticizers contribute to the acceleration of chain cleavage,
- physical plasticizers reduce viscosity without breaking the chains.

Framing of the components of the rubber mixture

The term incorporation is used rather loosely to describe the transition of a rubber compound from separated components to a cohesive and plastic mass. When only rubber and granular materials are involved, the transition is usually achieved in three overlaps stages:

- encapsulation – surrounding granular components by rubber,
- fragmentation,
- immobilization – bonding the rubber to other components.

A homogeneous mixture is obtained at the stage of fragmentation of the surrounded rubber formations and the loose component. Fragmentation takes place at the stage of shearing the mixture by the rotors of the mixer or between the rollers of the rolling mill. At the end of this process, the ingredients take the form of small balls in which the rubber is then immobilized. Because that the fillers used as components of rubber mixtures have a developed specific surface due to their internal air spaces, which are filled with rubber (Datta & Włoch, 2017).

Dispersing

Dispersion refers to the breaking up of the filler agglomerates in the rubber into finer particles. The speed of this process is influenced by both the viscosity and the size of the agglomerates. Complete dispersion of the filler in the rubber is very rarely achieved. The degree of disintegration of the filler agglomerates depends on the magnitude of the stresses and their size. The rule is simple, moderate stresses break large agglomerates into a pair of smaller ones, and high stresses are able to completely break them into particles. The breaking of particles takes place cyclically. New particles are separated and surround fragments of agglomerates. New stresses appear that break the particles until they completely disintegrate or the stresses are exhausted so that they are no longer sufficient for further breaking (Bieliński et al., 2007; Masłowski, 2013).

Distribution

Distribution is a continuation of fragmentation and leads to the completion of the mixing process. It is convenient to separate the spreading process into two types of macro and micro:

- macro-distribution – the stage of distributing ingredients over longer distances (e.g., antioxidants, whose mass fraction is much lower than that of fillers, the distribution of antioxidants has a very large impact on the vulcanizate's aging resistance),
- micro-distribution – a stage involving the distribution of the remaining filler agglomerates in the mixture and follows the dispersion process (dispersion of the filler affects the final mechanical properties of the product) (Funt, 2009; Limper, 2012).

Implementation of the process of preparing rubber mixtures

In the industrial implementation of the process of preparing rubber mixtures, the so-called mixing cycles:

- made with mixers,
- characterized by fixed parameters, such as: mixing temperature, mixing time, rotational speed, and degree of conversion.

Implementation of the mixing process in the tire industry:

a) one batch of the mixture usually goes through 2 to 8 mixing cycles,

b) one mixing cycle usually lasts several minutes,

c) there are three basic mixing cycles:

- pre-mix cycle – mixing all components of the rubber mixture except for the vulcanizing agent,
- mixing cycle – Increasing the dispersion of ingredients already present in the mixture (no new raw materials are added),
- final cycle – a cycle in which a vulcanizing agent is added and mixing takes place at 119˚C, which cannot be exceeded because it will result in the vulcanization of the rubber mixture.

Physico-mechanical properties of rubber compounds

Five rubber compounds have been prepared for the needs of this work by the Polish company KABAT TIRE, which dates back to the first half of the 80's. The company has a professional laboratory, which ensures the quality of the rubber products offered.

The aim of the research was to check the mechanical properties and comparative analysis of rubber mixtures differing from each other in the rubber base. The scope of the research included:

- density,
- determination of tensile strength properties,
- determination of tear strength,
- hardness marking,
- marking of abrasion.

Materials and methods

The research material was rubber mixtures. The base compound (NB-1), on the basis of which the four variants of the compounds (NB-2/3/4/5) were prepared, is a compound intended for use on the front of the tread of truck tires (Jurkowska and Jurkowski, 1975).

The remaining four mixtures are modifications of the reference mixture, the modifications consisted of changing the rubber base by using other rubbers or changing their proportions:

a) in the NB-2 mixture, the change consists of reversing the proportions of the rubbers used,

b) in the NB-3 mixture natural rubber has been replaced with isoprene rubber,

c) in the NB-4 mixture, the butadiene rubber was replaced with styrene butadiene rubber,

d) in the NB-5 mixture natural rubber has been replaced with isoprene rubber, and butadiene rubber with styrene butadiene rubber.

Formulation and preparation of the mixture

Test material 1: Truck tire tread compound (NB-1). Research Material 2-5: Modified Blends (NB-2/3/4/5) The recipes for all five mixes are shown in Table 1. The method of preparing the mixtures, called the regime, was as follows:

Cycle I: preheating the mixer to 70 ^oC, loading the rubbers and mixing, adding zinc white and anti-aging agents, adding soot and oil, discharging and measuring the temperature.

Cycle II: loading the mixture into the rolling mill, after heating, adding the vulcanizing system, rolling until uniform consistency, cutting the sides, rolling the mixture and passing it through the rolling mill three times.

Table 1. Recipes of the tested mixtures (in grams)

Raw material name	NB-1	NB-2	NB-3	NB-4	NB-5
Cycle I					
Natural rubber	70.00	30.00	—	70.00	—
Butadiene rubber	30.00	70.00	30.00	—	—
Isoprene rubber	—	—	70.00	—	70.00
Styrene butadiene rubber	—	—	—	30.00	30.00
Naphthenic oil	12.50	12.50	12.50	12.50	12.50
Soot N330	55.00	55.00	55.00	55.00	55.00
zinc white	4.00	4.00	4.00	4.00	4.00
Stearin	1.50	1.50	1.50	1.50	1.50
TMQ antioxidant	1.00	1.00	1.00	1.00	1.00
6-PPD antiozonant	1.00	1.00	1.00	1.00	1.00
paraffin wax	1.00	1.00	1.00	1.00	1.00
Sum	**176.00**	**176.00**	**176.00**	**176.00**	**176.00**
Cycle II					
Mixture after the first cycle	176.00	176.00	176.00	176.00	176.00
Sulfur	2.20	2.20	2.20	2.20	2.20
CBS	0.70	0.70	0.70	0.70	0.70
Sum	**178.90**	**178.90**	**178.90**	**178.90**	**178.90**

CBS – vulcanization accelerator

Source: own study based on (Jurkowska and Jurkowski, 1975).

Determination of tensile strength properties for rubber was carried out on the basis of the requirements of the PN-ISO 37:2007 standard. Paddle-shaped samples of the required sizes were prepared for the tests (Fig. 1).

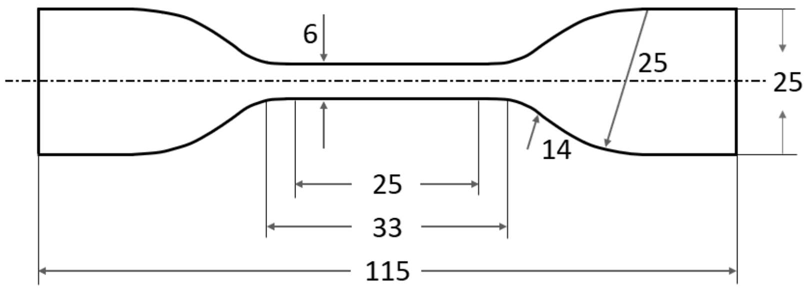


Fig. 1. Type 1 oar (mm)

Source: own study based on (PN-ISO 37:2007).

The tests were performed in three repetitions. Prior to testing, the samples were conditioned for at least 16 hours at 23˚C±2˚C and 50%±5% relative humidity. The tests were performed on an Alpha Technology testing machine, model T2000, with Alpha Technologies software, equipped with a 5000 N testing head with pneumatic jaws.

The following parameters were determined in the test: tensile strength, elongation at break and elongation at specified elongation.

Tear strength test

The determination of tear strength for rubber was carried out on the basis of the requirements of the PN-ISO 34-1:2007 standard.

Arch samples with a notch were prepared for the tests, the dimensions of which are shown in Fig. 2. The tests were carried out in five repetitions. Prior to testing, the samples were conditioned for at least 16 hours at 23˚C±2˚C and 50%±5% relative humidity. The tests were carried out on an Alpha Technology testing machine, model T2000, with Alpha Technologies software, equipped with a 5000 N force heads, with pneumatic jaws.

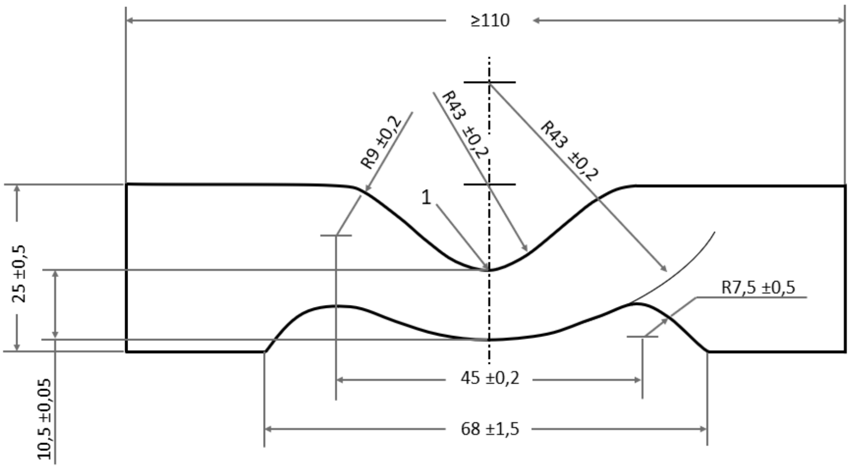


Fig. 2. Curved tear strength test piece (mm)

Source: own study based on (PN-ISO 34-1:2007)

Shore hardness determination

Shore hardness determination for rubber was carried out on the basis of the requirements of ISO 48-4:2018. Disc-shaped samples of the required sizes were prepared for the tests (Fig. 3).

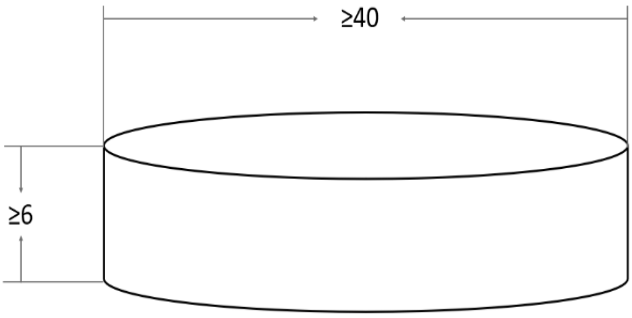


Fig. 3. Rebound hardness and flexibility test specimen (mm)

Source: own study based on (ISO-48-4:2018).

The tests were performed in five repetitions. Prior to testing, the samples were conditioned for at least 16 hours at 23˚C±2˚C and 50%±5% relative humidity. The hardness score was determined as the median of the sub-scores. The tests were performed with a Shore type A hardness tester.

Determination of abrasion using the Shopper-Schlobach apparatus

Resistance to abrasive wear was carried out on the basis of the requirements of the PN-ISO 4679:2007 standard. Cylindrical samples with a diameter of 16 mm and a height of 10 mm were prepared for the tests. The tests were performed in ten repetitions. Prior to testing, the samples were conditioned for at least 16 hours at 23˚C±2˚C and 50%±5% relative humidity.

The test determined the relative volume loss and the abrasion resistance index.

Research results

Determination of tensile strength properties

The results of strength tests for the analyzed mixtures are presented in Tables 2-6.

Table 2. Tensile properties of the NB-1 mix

no.	d [mm]	P_p [mm^2]	TS [MPa]	E_b [%]	S_5 [MPa]	S_{15} [MPa]	S_{100} [MPa]	S_{200} [MPa]	S_{300} [MPa]
Sample 1	2.162	12.970	22.676	452.900	0.419	0.756	2.690	7.271	13.349
Sample 2	2.154	12.926	23.213	441.900	0.463	0.815	2.952	7.791	14.271
Sample 3	2.183	13.100	23.404	461.500	0.522	0.830	2.943	7.831	13.860
Median	—	—	**23.098 ± 0.377**	**452.100 ± 9.824**	**0.463 ± 0.052**	**0.800 ± 0.039**	**2.862 ± 0.149**	**7.631 ± 0.312**	**13.827 ± 0.462**

d – thickness, P_p – cross-sectional area, TS – tensile strength, E_b – elongation at break, S_e – stress at a given elongation, %.

Source: own study.

Table 3. Tensile properties of the NB-2 mix

no.	d [mm]	P_p [mm^2]	TS [MPa]	E_b [%]	S_5 [MPa]	S_{15} [MPa]	S_{100} [MPa]	S_{200} [MPa]	S_{300} [MPa]
Sample 1	2.197	13.184	20.722	510.700	0.431	0.781	2.424	5.813	10.552
Sample 2	2.179	13.072	18.222	436.000	0.556	0.881	2.550	6.152	11.198
Sample 3	2.193	13.162	21.237	494.600	0.571	0.891	2.546	6.164	11.200
Median	—	—	**20.060 ± 1.613**	**480.433 ± 39.313**	**0.519 ± 0.077**	**0.851 ± 0.061**	**2.507 ± 0.072**	**6.043 ± 0.199**	**10.983 ± 0.374**

d – thickness, P_p – cross-sectional area, TS – tensile strength, E_b – elongation at break, S_e – stress at a given elongation, %.

Source: own study.

Table 4. Tensile properties of the NB-3 mix

no.	d [mm]	P_p [mm^2]	TS [MPa]	E_b [%]	S_5 [MPa]	S_{15} [MPa]	S_{100} [MPa]	S_{200} [MPa]	S_{300} [MPa]
Sample 1	2.195	13.170	20.722	510.700	0.431	0.781	2.424	5.813	10.552
Sample 2	2.198	13.188	23.130	549.400	0.332	0.645	1.887	5.017	9.756
Sample 3	2.192	13.154	24.320	572.400	0.466	0.692	1.977	5.233	9.937
Median	—	—	**22.724 ± 1.833**	**544.167 ± 31.181**	**0.410 ± 0.070**	**0.706 ± 0.069**	**2.098 ± 0.288**	**5.354 ± 0.412**	**10.082 ± 0.417**

d – thickness, P_p – cross-sectional area, TS – tensile strength, E_b – elongation at break, S_e – stress at a given elongation, %.

Source: own study.

Table 5. Tensile properties of the NB-4 mix

no.	d [mm]	P_p [mm^2]	TS [MPa]	E_b [%]	S_5 [MPa]	S_{15} [MPa]	S_{100} [MPa]	S_{200} [MPa]	S_{300} [MPa]
Sample 1	2.032	12.192	24.990	476.500	0.683	0.893	2.986	8.102	14.257
Sample 2	2.118	12.708	23.833	454.200	0.690	0.913	3.082	8.243	14.326
Sample 3	2.193	13.160	24.249	465.500	0.485	0.849	2.772	7.651	13.855
Median	—	—	**24.357 ± 0.586**	**465.500 ± 11.150**	**0.619 ± 0.116**	**0.885 ± 0.033**	**2.947 ± 0.159**	**7.999 ± 0.309**	**14.146 ± 0.254**

d – thickness, P_p – cross-sectional area, TS – tensile strength, E_b – elongation at break, S_e – stress at a given elongation, %.

Source: own study.

Table 6. Tensile properties of the NB-5 mix

no.	d [mm]	P_p [mm^2]	TS [MPa]	E_b [%]	S_5 [MPa]	S_{15} [MPa]	S_{100} [MPa]	S_{200} [MPa]	S_{300} [MPa]
Sample 1	2.020	12.124	22.994	551.30	0.587	0.771	2.021	5.038	9.377
Sample 2	2.093	12.558	23.635	559.10	0.586	0.764	2.035	5.221	9.675
Sample 3	2.083	14.498	23.538	560.70	0.578	0.765	2.019	5.148	9.492
Median	—	—	**23.389 ± 0.346**	**557.033 ± 5.029**	**0.584 ± 0.005**	**0.767 ± 0.004**	**2.025 ± 0.009**	**5.136 ± 0.092**	**9.515 ± 0.150**

d – thickness, P_p – cross-sectional area, TS – tensile strength, E_b – elongation at break, S_e – stress at a given elongation, %.

Source: own study.

The obtained results allow for a comparative analysis of the determined parameters, i.e., tensile strength, elongation at break and stress at a given elongation. It can be seen that the mixtures are characterized by their individual categories, in which they obtained better values than the reference compound intended for the tread face of truck tires (NB-1), but also lost some properties in relation to this mixture.

Tear strength test

The results of tear strength tests for the analyzed mixtures are presented in tables 7-11.

Table 7. Tear strength of the NB-1 mix

no.	median thickness [mm]	T_s [kN/m]
Sample 1	2.197	87.57
Sample 2	2.195	81.39
Sample 3	2.192	54.98
Sample 4	2.195	80.42
Sample 5	2.197	73.13
Median	—	**75.50±12.56**

Ts – tear strength.

Source: own study.

Table 8. Tear strength of the NB-2 mix

no.	median thickness [mm]	T_s [kN/m]
Sample 1	2.191	76.53
Sample 2	2.192	44.96
Sample 3	2.135	41.02
Sample 4	2.196	45.72
Sample 5	2.197	41.94
Median	—	**50.03±14.94**

Source: own study.

Table 9. Tear strength of the NB-3 mix

no.	median thickness [mm]	T_s [kN/m]
Sample 1	2.073	73.67
Sample 2	2.191	85.24
Sample 3	2.181	50.51
Sample 4	2.144	47.39
Sample 5	2.198	74.20
Median	—	**66.20±16.45**

Source: own study.

Table 10. Tear strength of the NB-4 mix

no.	median thickness [mm]	T_s [kN/m]
Sample 1	2.098	51.71
Sample 2	2.173	90.58
Sample 3	2.207	91.60
Sample 4	2.198	63.45
Sample 5	2.203	61.22
Median	—	**71.71±18.23**

Source: own study.

Table 11. Tear strength of the NB-5 mix

no.	median thickness [mm]	T_s [kN/m]
Sample 1	2.141	67.92
Sample 2	2.080	83.11
Sample 3	2.038	54.73
Sample 4	2.144	52.16
Sample 5	2.132	77.72
Median	—	**67.13±13.66**

Source: own study.

The conducted study allows us to conclude that the best parameters are characterized by the reference mixture NB-1, characterized by noticeably higher strength to tearing than the rest of the tested mixtures. The worst parameters in this test were obtained by the NB-2 mixture, achieving a value of tear strength lower by more than 55% than the reference mix.

Shore hardness determination

The hardness measurement results for all tested mixtures are presented in Table 12. Analyzing the results, it can be seen that the hardness results obtained by the NB-1/2/4 mixtures represent close values, only the NB-3 mixture performed unfavorably in this determination, it obtained a noticeably lower value (10% lower hardness compared to the reference mixture NB -1).

Table 12. Shore hardness analysis (˚ShA)

Rubber type	Sample hardness (˚ShA)					
	1	2	3	4	5	Average
NB-1 mix	58.5	58.8	57.8	57.5	58.7	58.3±0.6
NB-2 mix	58.7	58.4	58.6	58.1	58.1	58.4±0.3
NB-3 mix	53.0	52.1	52.2	52.5	52.6	52.5±0.4
NB-4 mix	57.3	57.8	57.1	57.0	57.9	57.4±0.4
NB-5 mix	54.4	54.6	55.3	54.5	54.2	54.6±0.4

Source: own study.

Determination of abrasion using the Shopper-Schlobach apparatus

The results obtained during the determination of abrasion for all tested mixtures are presented in Table 13. Thanks to the carried out determination of abrasion, it is possible to compare the influence of the rubber base on the relative volume loss and abrasion resistance index of the tested rubber mixtures. The NB-1 mixture as a reference mixture obtained 100% ARI, as the rest of the mixtures are analyzed on its basis.

Table 13. Abrasion

Rubber type	Density [g/cm^3]	Weight loss [g]	ΔV [mm^3]	ARI [%]
NB-1	1.099	0.075	0.182	100.00
NB-2	1.098	0.040	0.097	187.67
NB-3	1.096	0.069	0.168	108.99
NB-4	1.105	0.114	0.275	65.43
NB-5	1.099	0.105	0.255	71.33

ΔV – relative volume loss; ARI – abrasion resistance index.

Source: own study.

Conclusions

The research allows us to determine how the selection of rubbers in a rubber mixture affects its physical and mechanical properties. The reference mix was NB-1 intended for the front of the tread of truck tires. The remaining blends differed only in the rubbers used or their proportions. The paper analyzes the impact of rubbers on the obtained parameters for the tested rubber mixtures.

1) Tear strength – the parameters of most mixtures oscillate around a value close to 23.5 MPa, only the NB-2 mixture, in which the proportions of the rubbers used were reversed relative to the reference mixture (NB-1), obtained a result over 10% worse than the other tested mixtures.

2) Elongation at break – each modified mixture obtained a higher value than the reference mixture NB-1. Only the NB-4 mixture obtained a similar result (greater than 2%) than the NB-1 mixture. This is due to the dominance of natural rubber in the rubber base of these blends, which is responsible for flexibility.

3) Stress at specified elongation – mixtures containing natural rubber obtained significantly higher stress values at each of the tested elongation degrees. The greatest stress occurred in the following mixtures NB-4 and NB-1, characterized by a 70% share of NR in the rubber base, the third place was taken by the mixture NB-2 with 30% NR in the rubber base. The stress of the NB-3 and NB 5 blends, which contained only a blend of synthetic rubbers, was almost 25% lower than the average strain of the blends containing natural rubber.

4) Tear strength – the highest was obtained by the reference mixture NB-1. The results obtained during this assay vary greatly. All the mixtures were characterized by noticeably lower strength values than the reference mixture. The NB-2 mixture fared the worst during this test, obtaining a worse result by over 55% from the reference mix.

5) Hardness – mixtures based on NR are characterized by the highest hardness values in the performed determination. The highest hardness is characterized by the NB-1 reference compound, whose base consists of 70% NR and 30% butadiene rubber, followed by the NB-2 mixture, in which the proportions of these rubbers have been changed. The third in terms of hardness is the NB-4 compound, whose base consists of 70% NR and 30% SBR. The lowest values of hardness were noted in succession for the mixtures NB-3 and NB-5, where the difference in the average hardness of the mixtures with NR and the average hardness of the mixtures based entirely on synthetic rubber does not exceed 7%.

6) Abrasion (the reference mixture is the NB-10 mixture) – the best results in both cases, i.e., relative volume loss and abrasion resistance index, were achieved by the NB-2 mixture (over 87%). The results similar to the reference mixture were obtained by the NB-3 mixture (about 9% higher abrasion resistance). The NB-4 and NB-5 mixtures obtained comparable results (approx. 35% and approx. 29%, respectively, worse abrasive properties compared to the reference mixture).

The mixtures, thanks to the modification of the rubber base, obtained better results in a given category in relation to the reference mixture (NB-1), but they lose other important properties, such as: tear strength, hardness, abrasion resistance, or flexibility. However, some differences are not so significant as to disqualify the potential use of these mixtures for the production of other products, e.g., tires for wheelbarrows or trolleys. The NB-2 compound could be used in the production of tires for prams, thanks to its abrasive properties. The NB-4 compound could be used as a rubber cover, thanks to its strength and flexibility. Nevertheless, none of the modified compounds should be used as the front of the tread of truck or passenger car tires due to excessive losses of key properties for this product.

References

Arayapranee, W., & Rempel, G.L. (2013). Effects of polarity on the filler-rubber interaction properties of silica filled grafted natural rubber composites. *Journal of Polymer Science,* 279529.

Bieliński, D. M., Dobrowolski, O. & Ślusarski, L. (2007). Dyspersja napełniacza w mieszance gumowej. *Polimery* V. 52, (7-8), 546-555. Wydawnictwo Sieć Badawcza Łukasiewicz – Instytut Chemii Przemysłowej.

Datta, J. & Włoch ,M. (2017). Inżynieria elastomerów, 7-55. Wydawnictwo Politechniki Gdańskiej.

Funt, J. (2009). Mixing of Rubber. iSmithers Rapra Publishing.

Hasan, A., Rochmadi, Sulistyo, H., & Honggokusumo, S. (2017). Rubber mixing process and its relationship with bound rubber and crosslink density. *IOP Conference Series: Materials Science and Engineering*, *213*, 012048. https://doi.org/10.1088/1757-899X/213/1/012048

Jurkowska, B., & Jurkowski, B. (1975). Produkcja opon i dętek rozdział 2, 3. Wydawnictwo Naukowo-Techniczne.

Limper, A. (2012). Mixing of Rubber Compounds rozdział 2, 6. Wydawnictwo Hans Publishsers, Munich.

Masłowski, M. (2013). Ocena stopnia dyspersji nanonapełniaczy w kompozytach polimerowych. Politechnika Łódzka Instytut Technologii Polimerów i Barwników.

Pornprasit, R., Pornprasit, P., Boonma, P., & Natwichai, J. (2016). Determination of the mechanical properties of rubber by FT-NIR. *Journal of Spectroscopy*, 4024783.

PERCEPTION OF FOOD WASTE PROBLEMS IN THE CONTEXT OF SUSTAINABLE CONSUMPTION

Jerzy Żuchowski*[1], Magdalena Paździor[1]

[1] Department of Management and Product Quality, Faculty of Chemical Engineering and Commodity Sciences, Kazimierz Pulaski University of Technology and Humanities in Radom, Radom, Poland
**Corresponding Author e-mail: j.zuchowski@uthrad.pl*

DOI: 10.56091/CTQS.Innov-27

Abstract

Preventing food waste is key to achieving one of the sustainable development goals, i.e., halving the amount of food waste per EU inhabitant at retail and consumer levels by 2030. The scale of household waste is directly influenced by individual consumers.

The aim of the study was to analyse the consumers' perception of the problem of food waste. The research covered the dimension of food waste, taking into account the problem of its measurement and reporting at the level of individual households. Existing data, i.e., formal and commercial reports and statistics, were researched. It was assumed to show the current state of consumer interest in the issues of food waste and sustainable consumption. The research was interpretive.

The paper presents that reducing the scale of food waste is conditioned by consumer attitudes. It was found that there is a trend of increasing consumer awareness regarding the impact of their lives on the environment and their role in reducing waste. Consumer interest in the problem of food waste has also been demonstrated. It was pointed out that there is still a need to popularize the issue of minimizing food waste and to promote this problem in Poland in order to pursue sustainable consumption.

Keywords: food waste, sustainable consumption, consumers, waste

Introduction

The problem of reducing the waste of goods in the aspect of food waste is a key area of activities aimed at maximizing the effect of sustainable consumption. It is also related to the implementation of one of the Sustainable Development Goals (SDG), i.e., responsible consumption and production. The transformation of the food chain in the European Union (EU) towards sustainable food systems involves its participants in the implementation of the strategic goal, i.e., making Europe the first climate-neutral continent. The framework for achieving this goal by 2050 is contained in the European Green Deal (EGD). Environmental, health, social and economic benefits are expected from the implementation of the EGD strategy.

The period after the pandemic is to direct EU residents to a sustainable path (Commission for Environmental Cooperation, 2019). Under Sustainable Development Goal 12.3, the European Commission has committed to halving the amount of food waste per capita in the EU by 2030 at the retail and consumer level (*UN General Assembly Resolution 70/1 , 2015*). In relation to this task, Member States implement a unified methodology for measuring and reporting food waste. The EU Commission has also set legally binding food waste reduction targets across the entire EU (Commission Delegated Decision (EU) 2019/1597 of 3rd May 2019).

Actions taken up to reduce food loss and waste are critical to achieving an optimal level of sustainability and it is a task for all stakeholders (Stenmarck et al., 2016). Producing some of the food that is thrown away consumes resources such as water, energy and is responsible for 8% of global greenhouse gas emissions (O'Connor, 2019). The result is unjustified exploitation of natural resources, climate change and economic consequences (Gniadek et al., 2018). Despite the intensification and implementation for several years of formal activities aimed at implementing the sustainable development strategy in the context of food waste, publicity in the public space and popularization of this issue among consumers, the problem of achieving the level of sustainable consumption is still valid (Żuchowski & Żuchowska-Grzywacz, 2018).

In order to meet these issues, the authors adopted the aim of the work to analyse, on the basis of open access reports and statistics, the interest of consumers in the problems of food waste. Trends were analysed regarding the degree of consumer interest in Poland and around the world, proper estimation of the level of waste in the context of strategies supporting sustainable development and consumer attitudes to this issue, taking into account the pandemic period. The work is characterized by a new approach to the analyzed issue, because in previous publications there is practically no assessment of consumers' / internet users' perception and interest in the problem of food waste and sustainable consumption based on informal data sources, including published commercial reports and statistics.

Sustainable consumption in the food chain and the European Green Deal strategy

Food waste at household level in the supply chain

The Food and Agriculture of the United Nations Organization (FAO) has defined waste in the food chain as Food Loss & Waste (FLW). The measure of the implementation of Goal 12 of sustainable development (responsible consumption and production in the context of Goal 12.3) are two indicators: food losses, related to supply – Food Losses Index (FLI) and food waste, related to demand – Food Waste Index (FWI). According to FAO data, the FWI index is responsible for 65% of FLW, of which 53% is generated by households (Food and Agriculture Organization, 2019a).

According to BIG InfoMonitor research, the statistical Polish consumer who wastes food is a man aged 18-24 who lives in a big city. According to these data, consumers aged 65-75 perform best (Biuro Informacji Gospodarczej InfoMonitor, 2020). Food waste at the household level can be caused by a number of factors. The authors Blair & Sobal (2006, 63-74) recognized, for example, luxury consumption as synonymous with food waste, leading to both adverse effects on consumer health and simultaneous excessive use of resources.

Food waste at the household level can be caused by a number of factors. According to the Public Opinion Research Center (CBOS), food waste may result from consumers' ignorance about food storage conditions, as well as the possibility of reusing meal residues (Public Opinion Research Center, 2016). Research carried out by the Commission for Environmental Cooperation in relation to food waste indicates similar reasons for this undesirable phenomenon as in the CBOS study (Commission for Environmental Cooperation, 2019). The published research on the causes of food waste by consumers also shows that the phenomenon is dictated by their attitudes, but it can also be an effect that is partly independent of consumers (random reasons), i.e., events, for example of natural origin (e.g., power outages) (Karaczun, 2018). It should be recognized that the pandemic period was also such an unpredictable factor.

Unified measurement of household food waste in the circular economy package

The problem of the lack of a universal method of measuring food waste has been analysed both at the scientific and institutional level (Paździor & Żuchowski, 2020). Formal attempts were made to unify it and popularize solutions aimed at reducing waste. For example, Organization of FAO in the implementation of the Sustainable Development Goal (SDG) 12.3.1. has made available an online database of constantly updated data on both food loss and food waste – The Food Loss and Waste database (Food and Agriculture Organization, 2019b). The provisions of The Circular Economy Package (CEP) address the issue of unifying the monitoring and reporting of food waste levels within the EU. In order to meet the task of unifying the measurement of food waste, in 2019 a common measurement methodology was established, in which measurement in households was included among the stages of the supply chain (Commission Delegated Decision (EU) 2019/1597 of 3rd May 2019, art. 1. point 1). Based on a common definition of food waste, the methodology aims to ensure consistent monitoring of food waste levels across the EU. It was indicated that the classification of food waste should be referred to the EU statistical classification of economic activities "NACE Rev. 2" (Regulation (EC) No 1893/2006), and in the case of "households", the measurements should be referred to section 8 point 1.2 in Annex I to Regulation (EC) No 2150/2002, i.e., waste generated in households (Regulation (EC) No. 2150/2002).

Materials and methods

Empirical studies of existing data, such as formal and commercial documents, reports and statistics in open access, were carried out in the work. Desk research of source data was chosen as the research method, aimed directly at the implementation of the research goal. The subject of the research was the scale and interest of consumers in the problem of food waste at the level of individual households, taking into account the period of the pandemic. It was assumed that reflection on the actual state of affairs in this area would broaden the cognitive perspective for assessing and improving actual activities, including the EGD strategy and the European sustainable food system.

Results and Discussion

Indicator 12.3.1 Global Food Loss and Waste – data and impact of Covid-19

The year 2020 was the first reporting year for the harmonized monitoring of food waste levels in accordance with Commission Delegated Decision (EU) 2019/1597 3. (Commission Delegated Decision (EU) 2019/1597 of 3rd May 2019). It was also the first year of the pandemic. In 2020, an average of 127 kilograms of food waste per EU inhabitant was generated from various sources in the food supply chain. Households were responsible for generating 53% of food waste. On average, a Polish citizen generated 106 kilograms of wasted food in 2020, which gave us 16th place (out of 24 countries surveyed) (Eurostat, 2023). Table 1 compares the level of food waste from selected sectors and the food supply in the European Union in 2020.

Table 1. Comparison of food waste quantities from selected sectors and food supply quantities in the European Union, 2020 [kilograms per inhabitant]

Food waste amounts for selected sectors	Estimated consumed food	Food supply quantity, FAO
91	788	879

Source: (Eurostat, 2023).

Table 1 shows that generated food waste can account for 10% of the food delivered to consumers in the EU in the supply and consumption sectors. In establishing these figures, Eurostat estimated the amount of food placed on the market based on 2019 FAO data on the amount of supply given in kilograms per capita and compared it with the amounts of food waste in the supply and consumption sectors.

Figure 1 shows the percentage of food loss for European regions in 2016-2022 according to FAO statistics. It should be noted, however, that in individual European sub-regions, unfortunately, there are no homogeneous sources of information, and for Eastern Europe statistical data is incomplete both in terms of the number of data and the number of countries represented in all sectors.

According to the UN, in 2019, 17% of food intended for consumption was wasted in households, retail stores, restaurants and other food service establishments, a situation worsened by the pandemic (United Nations Environment Programme, 2021b). Figure 2 shows progress made by countries towards reducing food loss (2016-2020).

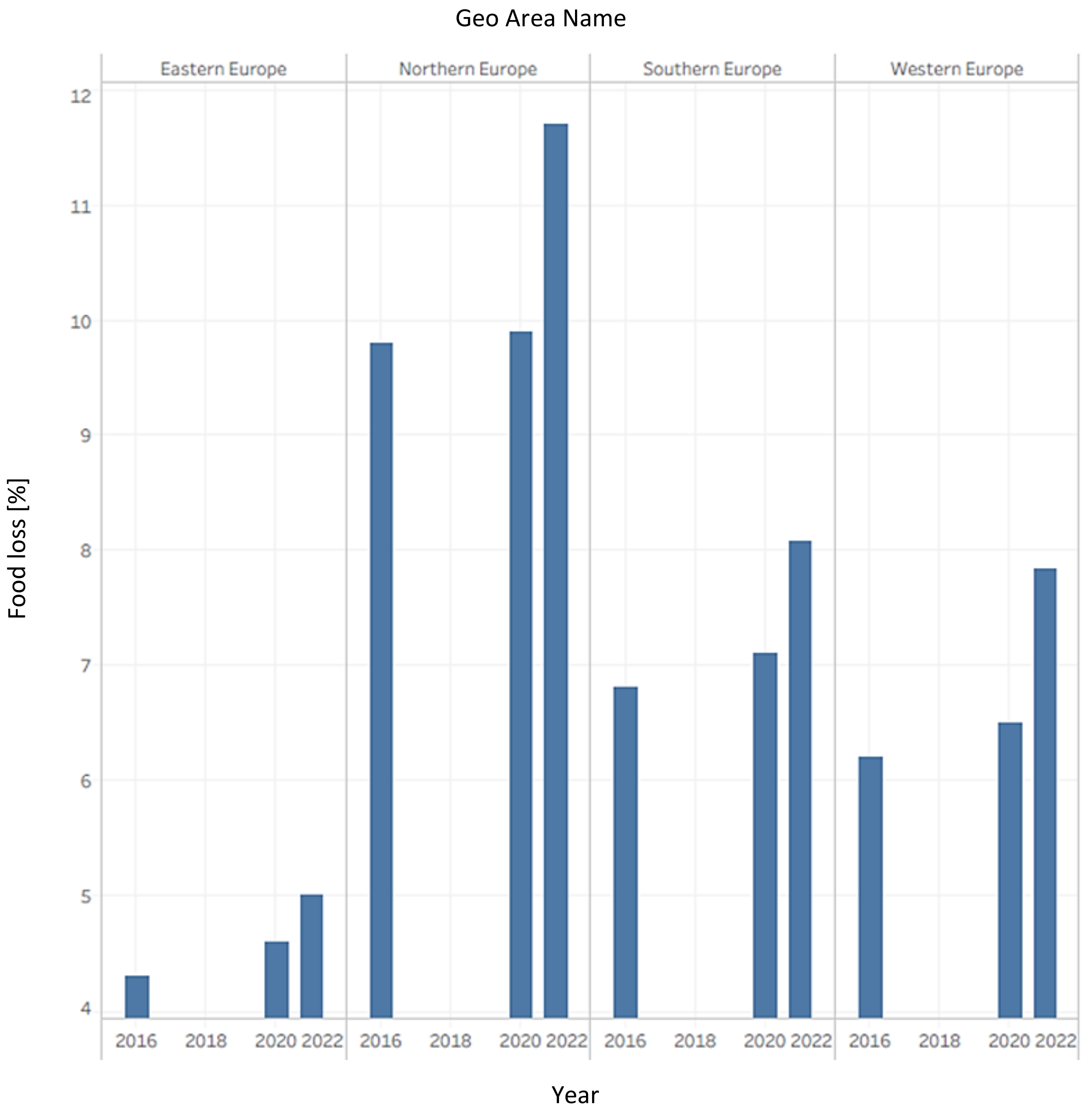


Fig. 1. Food loss in percent by European regions in 2016-2022

Source: (Food and Agriculture Organization, 2022).

Fig. 2. Progress made by countries towards reducing food loss (2016-2020)

Source: (Food and Agriculture Organization, 2022).

Consumers towards stockpiling and food waste

The evolution of consumer perception of the problem of waste of goods and their impact on the natural environment is indicated by a comparison of CBOS research from 2009-2020 (Table 2). From the declarations of consumers, there was an increasing trend of declarations for the answer "Yes" to the assessment of the impact of their lives on the environment. Estimated data on food waste in households are presented in Table 3.

Table 2. The opinion of consumers concerning the impact of their lifestyles on the environment

Question Does Your lifestyle influence the condition of the natural environment?	Indications of respondents [%]				
	2009	2011	2014	2016	2020
No, it does not.	24	18	23	16	17
Yes, it does.	71	79	74	81	81
Hard to say.	5	3	3	3	2

Source: own study based on (Public Opinion Research Center, 2020).

Table 3 compares the values for selected countries from each of the four European regions. European countries with a medium and high level of trust were included due to the method of diagnosis and limitations in obtaining real information (United Nations Environment Programme, 2021a).

Table 3. Household food waste estimates (from measured data points or extrapolation) for each country

Region Europe	Confidence in estimate	M49 code[1] Country	Country Household food waste estimate [kg/capita/year]	Household food waste estimate [tonnes/year]
Eastern	Medium	348 Hungary	94	908 669
		616 Poland	56	2 119 455
		643 Russian Federation	33	4 868 564
Northern	Medium	233 Estonia	78	102 743
		246 Finland	65	361 937
		372 Ireland	55	267 073
	High	208 Denmark	81	469 449
		578 Norway	79	423 857
		752 Sweden	81	812 948
		826 United Kingdom	77	5 199 825
Southern	Medium	300 Greece	142	1 483 996
		380 Italy	67	4 059 806
		470 Malta	129	56 812
		705 Slovenia	34	71 107
		724 Spain	77	3 613 954
Western	Medium	56 Belgium	50	576 036
		250 France	85	5 522 358
		442 Luxembourg	90	55 126
	High	40 Austria	39	349 249
		276 Germany	75	6 263 775
		528 Netherlands	50	854 855
		756 Switzerland	72	616 037

Source: own study based on (United Nations Environment Programme, 2021a).

The data in Table 3 indicate that most of the countries with a high level of confidence in measuring food waste at the household level are located in the western and northern regions of Europe. From this group of countries, the highest estimated food losses in households (kg/capita/year) were diagnosed in Sweden and Denmark, and the lowest in Austria. However, this inference is limited due to heterogeneous sources and methods of measuring waste at the household level. Poland was classified as a country with an average level of trust in the sources of estimating food waste by consumers (United Nations Environment Programme, 2021b). Therefore, food losses recorded in this period for Poland (Table 3) should be taken with some reserve.

The period of the pandemic was a random and crisis situation, when buying food in stock could result from, among others, the need to protect oneself in the event of illness or possible restrictions on the availability of products. According to the study "Poles shopping during the COVID-19 pandemic" from October 2020 conducted by the BioStat® Research and Development Centre (number of 1000 respondents), half of the respondents did not see the need to make larger purchases due to the increasing number of detected coronavirus infections, while at the same time almost every third respondent intended to make more food purchases in advance. Thus, a picture is drawn of consumers who, on the one hand, limit excessive purchases, and on the other hand, in a crisis situation, value their own food security (BioStat® Research and Development Centre, 2020).

Food management and shopping trends during the pandemic were also the subject of consumer research from September 2020 conducted by the SW Research agency on a sample of 1,032 Poles. On the basis of these studies, it was found that 47% of the respondents declared buying food in advance. Comparing the responses to similar earlier studies by this agency, it was found that the number of people who tried to prevent spoilage or waste of food products increased by 12% (50% before the pandemic vs 62% during) (SW Research, 2020). In turn, according to CBOS research from the turn of September and October 2020 regarding the pro-ecological behaviour of consumers related to avoiding food waste – the statement: "you buy as much food as you need, you do not waste food" in total " definitely” and “rather yes” were confirmed by 93% of respondents (definitely yes 56%, rather yes 37%) (Public Opinion Research Center, 2020).

The cited results of commercial research confirm the view expressed by researchers Stępień and Dobrowolski (2017, 305-316) that reducing the problem of food waste is related to and results from the attitudes and awareness of households. Therefore, this stage of the food chain is as important as the others and crucial for the implementation of the EGD strategy, in the context of minimizing food waste and indirectly the waste of resources.

Food waste – consumers' interest in the subject

In order to reduce food waste at the household level, according to the Supreme Audit Office (NIK), it is necessary, among others, to building social awareness of the need to counteract this phenomenon, using an information campaign on its scale and negative social, environmental and economic effects (Supreme Audit Office, 2021). Bearing in mind the results of the NIK audit and the importance of the problem of wasting food and resources in economic, ecological and ethical terms, the interest of Polish consumers in the problem of waste was verified on the basis of search trends in a popular Internet search engine for the term: "waste of food" and related phrases.

Thanks to a publicly available tool, the search trend for a given term was checked, understood as the level of its popularity in time and geographical terms. Figure 3 presents the results for the phrase: "food waste" for Poland in the last year (as of May 19, 2023). The interest in the slogan in particular regions of Poland was also shown (Fig. 4). It should be emphasized that the charts of the cited tool do not show the number of searches for a phrase. The data is presented on a scale of 0-100 and determined for the analysed period in relation to the day on which Internet users in a given time and region most often searched for a given term. This score is marked as 100. The other days are assigned numbers from 0 to 100 proportionally to the highest score.

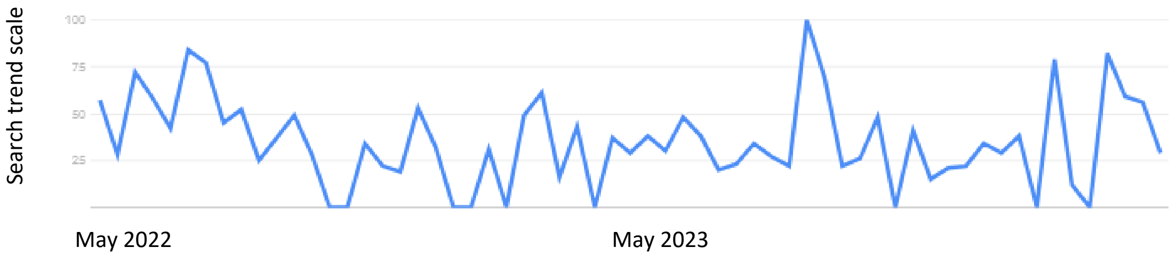


Fig. 3. Internet search trend for: food waste in Poland, in the last year (as of May 19th, 2023)

Source: (Google Trends, 2023a).

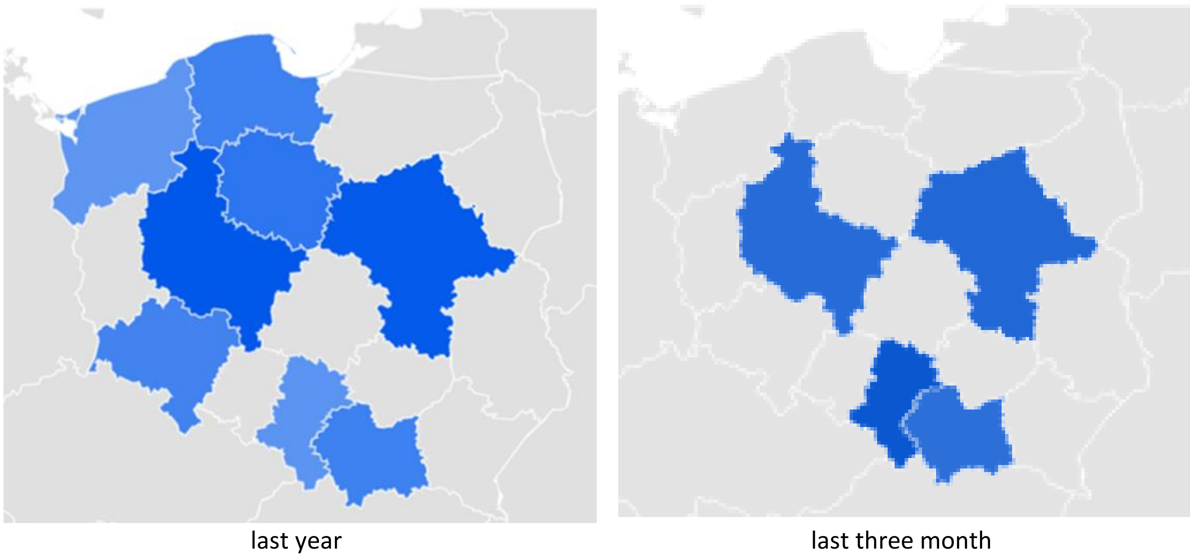


Fig. 4. The interest in the slogan: food waste in particular regions of Poland (as of May 19th, 2023)

Source: Google Trends, 2023a.

In the last five years in Poland, the period with the highest search level for the phrase "food waste" was May 17th-23rd, 2020, and then April 24th-30th, 2023 (Google Trends, 2023a). The greatest interest in the topic of food waste over the last year was represented by the inhabitants of the Wielkopolskie and Mazowieckie voivodeships, and the time of the greatest popularity of this slogan was September 18th-24th, 2022. In general, it can be observed that consumers have shown interest in this phrase. It can be assumed that therefore they were interested in the problem and perhaps in practical actions aimed at reducing food waste. Figure 5 shows a comparative breakdown of interest in terms of time for thematically related phrases for the problem of food waste. In addition, in order to show the diversity of consumer attitudes depending on the region of the EU, data on the trend of interest in these terms for Poland and Germany from the last 12 months were compared. Germany was selected for comparison, because according to data from 2020, this country is at the top of the list of fresh food waste production (nearly 11 million tons of wasted food vs. Poland – approx. 4 million) (European Commission, 2022).

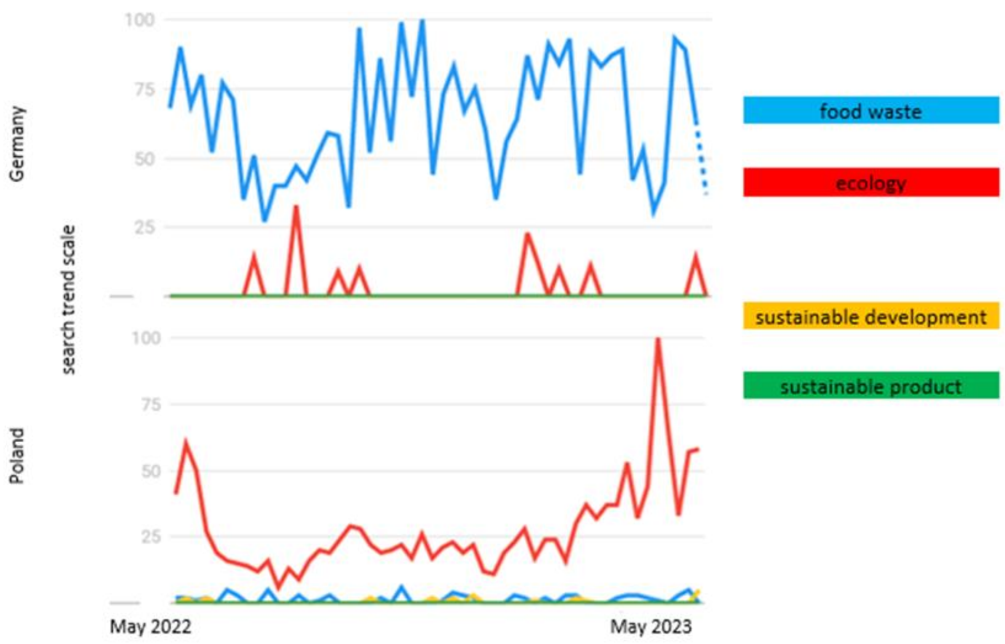


Fig. 5. Internet search trend for: food waste, ecology, sustainable development and sustainable product in Poland and Germany, in the last year (as of May 19th, 2023)

Source: (Google Trends, 2023b).

Based on the graphs in Figure 5. it was noticed that in Poland, among Internet users – consumers, the phrase "ecology" was more popular than "food waste". This is completely the opposite of the trend in Germany. In both countries, the scant interest and popularity of searches for "sustainable development" and "sustainable product" is noteworthy, i.e., practically zero compared to the amount of searches for "food waste" and "ecology". This fact may indicate insufficient popularization of these issues and the need to intensify the promotion of the issues of sustainable consumption and production as well as the purchase of sustainable products.

Bearing in mind the identified diversification of interest in the analysed passwords among consumers – Internet users from different regions, the popularity of the analysed passwords was verified globally. In order to examine the difference in the perception of key passwords for environmentally responsible behaviour by Polish Internet users, the trend of searching for phrases: "food waste" and "ecology" at the same time (last year) in global terms – the whole world – was examined (Fig. 6.). Figure 6 shows a map of the world shaded in proportion to the popularity of a given password. The intensity of grey corresponds to the percentage of searches.

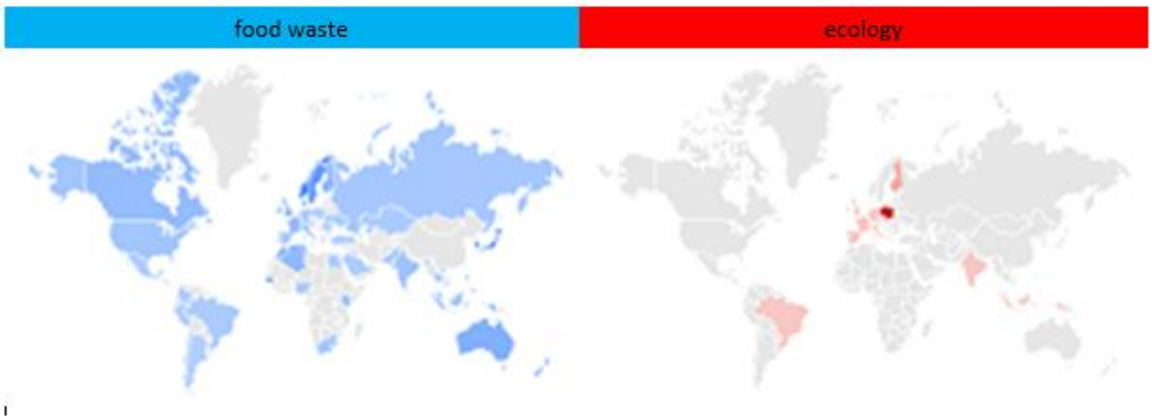


Fig. 6. Global Internet search trend for: food waste and ecology, in the last year (as of May 19th, 2023), (the color intensity indicates the popularity of the slogan)

Source: (Trends Google, 2023c).

Based on the data in Figure 6, it can be seen that Poland is marked on the map as a country for which the phrase "ecology" was clearly more popular among Internet users than "food waste". The highest interest of Internet users in the slogan "food waste" was found in the Scandinavian countries, i.e., Norway and Sweden, and the slogan "ecology" in Poland. Of course, bearing in mind the limitations in the data collection methodology of the quoted tool, the indicated trend should be verified with further research. Nevertheless, the indicated data structure can be considered as confirming the need to popularize the importance of the problem of food waste in Poland. However, one should also consider the issue of the level of distinguishing between the analysed phrases by Poles and thus their semantic range. In addition, it can be expected that for Polish consumers, perhaps ecology is the overarching slogan and a synonym for the other analysed keywords. For these reasons (among others), the observed correlations require further research, but also informative activities to be undertaken in parallel. Nevertheless, the fact of distinguishing Poland's dissimilarity from other countries may lead to the conclusion that the perception of the analysed problem by Polish consumers is different. It can also be assumed that it is necessary to intensify the popularization and information campaign in the field of food waste and the European Green Deal strategy and the need to effectively implement responsible consumption attitudes into consumer behaviour.

Conclusions

Food waste generated in the supply and consumption sectors is a significant problem in the context of negative social, environmental and economic impacts, which is why achieving the level of sustainable consumption is important and still relevant. The implementation of unified measurement of the amount of food wasted on the EU scale will help, in the long term, to realistically assess the scale of the phenomenon and, consequently, to take effective preventive measures in the context of implementing strategies supporting sustainable development.

Changes in the perception and interest of consumers in the problems of food waste have been noticed. The analysis of available statistics and reports showed that the number of consumers declaring counteracting food waste has been increasing in recent years, but they are still divided on the issue of buying food in reserve. However, there is a picture of a consumer who is aware of its impact on the environment. It should be noted, however, that the pandemic worsened the situation and resulted in progress in reducing the scale of food waste.

The analysis of available statistics and reports showed that:

- there is a trend of increasing consumer awareness of the impact of their lifestyle on the environment;
- the group of consumers declaring counteracting food waste is growing;
- consumers are still divided when it comes to buying food for storage;
- despite the implementation of a unified measurement of food waste, there is still a problem of estimating food losses at the household level;
- the pandemic period contributed to the regression of consumers' pro-ecological attitudes regarding food waste;
- consumers show varying interest in the problem of food waste;
- the greatest interest in the problem was observed among consumers/Internet users from Scandinavian countries.
- Polish consumers/Internet users showed greater interest in the slogan: ecology than food waste.

The analysis of the interest of Polish consumers in the problem of food waste on the basis of Internet search trends indicated the need to popularize it and to take actions in the field of building awareness regarding the need to counteract this phenomenon. Bearing in mind the implementation of the EGD strategy and the European sustainable food system, it should be stated that the awareness and practical actions of consumers must constantly be directed at minimizing the negative impact and maximizing the positive contribution. Such perception of the problem is crucial in making individual purchasing decisions consistent with the strategic pursuit of full sustainability of consumption in the context of food waste.

References

BioStat® Research and Development Centre. (2020). *Polacy na zakupach podczas pandemii Covid-19* [Brochure]. https://www.biostat.com.pl/img/UserFiles/raporty-rynkowe/pazdziernik20/Zakupy/raport_koronawirus_Polacy%20na%20zakupach%20podczas%20pandemii%20COVID-19.pdf

Biuro Informacji Gospodarczej InfoMonitor. (2020). *Ponad połowa Polaków traci na nieprzemyślanych zakupach, głównie z powodu żywności* [Brochure]. https://media.bik.pl/informacje-prasowe/490653/ponad-polowa-polakow-traci-na-nieprzemyslanych-zakupach-glownie-z-powodu-zywnosci

Blair, D., & Sobal, J. (2006). Luxus consumption: Wasting food resources through overeating. *Agriculture and Human Values*, *23*(1), 63-74. https://doi.org/10.1007/s10460-004-5869-4

Commission Delegated Decision (EU) 2019/1597 of 3 May 2019 supplementing Directive 2008/98/EC of the European Parliament and of the Council as regards a common methodology and minimum quality requirements for the uniform measurement of levels of food waste (Text with EEA relevance) OJ L 248, 27.9.2019 (European Union). https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32019D1597

Commission for Environmental Cooperation. (2019). *Why and How to Measure Food Loss and Waste: A Practical Guide* [Brochure]. http://www.cec.org/files/documents/publications/11869-why-and-how-measure-food-loss-and-waste-practical-guide-version-20-en.pdf

European Commission. (2020). *A Farm to Fork Strategy for a fair, healthy and environmentally-friendly food system.* Commission to the European Parliament, The Council, The European Economic and Social Committee and the Committee of the Regions. https://eur-lex.europa.eu/resource.html?uri=cellar:ea0f9f73-9ab2-11ea-9d2d-01aa75ed71a1.0001.02/DOC_1&format=PDF

European Commission. (2022). *Odpady Żywnościowe Pakiet informacyjny.* Europejski Panel Obywatelski Odpady Żywnościowe. https://commission.europa.eu/system/files/2022-12/COFE5_Next%20Generation_PL_NEW.pdf

Eurostat. (2023). *Food waste and food waste prevention – estimates.* https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Food_waste_and_food_waste_prevention_-_estimates

Food and Agriculture Organization. (2019a). *Sustainable food systems. Concept and framework* [Brochure]. https://www.fao.org/3/ca2079en/CA2079EN.pdf

Food and Agriculture Organization. (2019b). *Moving forward on food loss and waste reduction* [Brochure]. http://www.fao.org/3/ca6030en/ca6030en.pdf

Food and Agriculture Organization. (2022). *Indicators. In: Sustainable Development Goals.* Food and Agriculture Organization. www.fao.org/sustainable-development-goals/indicators/en

Gniadek, J., Grzeszak, J., Kłosiewicz-Górecka, U., Kukołowicz, P., Marczewski, K., & Ważniewski, P. (2019). Marnotrawstwo żywności – skala, skutki, przeciwdziałanie. *Tygodnik Gospodarczy, Polski Instytut Ekonomiczny*, 29, 4-5. https://pie.net.pl/wp-content/uploads/2019/08/Tygodnik_PIE_29-19.pdf

Google Trends. (2023a). *Temat: Marnotrawstwo żywności*. https://trends.google.com/trends/explore?geo=PL&q=%2Fm%2F026c0vb&hl=pl

Google Trends. (2023b). *Temat: Marnotrawstwo żywności, ekologia, zrównoważony rozwój, zrównoważony produkt.*https://trends.google.com/trends/explore?geo=PL&q=marnotrawstwo%20%C5%BCywno%C5%9Bci,ekologia,zr%C3%B3wnowa%C5%BCony%20rozw%C3%B3j,zr%C3%B3wnowa%C5%BCony%20produkt

Google Trends. (2023c). *Podział według regionu – porównanie: marnotrawstwo żywności, ekologia* https://-trends.google.pl/trends/explore?q=%2Fm%2F026c0vb,ekologia&hl=pl

Karaczun, Z. (Ed.). (2018). *Wpływ marnowania żywności na zmianę klimatu*. Polski Klub Ekologiczny Okręg Mazowiecki.

O'Connor, C. (2019, October 18). *SDG 12.3 and the Food Waste Index International Workshop on Food Loss and Waste Prevention* [Conference presentation]. International Workshop on Food Loss and Waste Prevention South East and East Asia, UNU, Tokyo, Japan. https://www.macsg20.org/fileadmin/macs/Activities/S1_1_O_Connor-_SDG_12.3_and_the_Food_Waste_Index.pdf

Paździor, M., & Żuchowski, J. (2020). Marnowanie żywności w obrocie towarowym. In A. Pałka (Ed.), *Food quality development* (pp. 183-196). Wydawnictwo Uniwersytetu Morskiego w Gdyni.

Public Opinion Research Center. (2016). *Deklaracje Polaków dotyczące marnowania żywności, Komunikat z badań nr 115/2016* [Brochure]. https://www.cbos.pl/SPISKOM.POL/2016/K_115_16.PDF

Public Opinion Research Center. (2020). *Świadomość ekologiczna Polaków. Komunikat z badań* [Brochure]. https://www.cbos.pl/SPISKOM.POL/2020/K_163_20.PDF

Regulation (EC) No 1893/2006 of the European Parliament and of the Council of 20 December 2006 establishing the statistical classification of economic activities NACE Revision 2 and amending Council Regulation (EEC) No 3037/90 as well as certain EC Regulations on specific statistical domains OJ L 393, 30.12.2006 (European Union). https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=celex%3A32006R1893

Regulation (EC) No 2150/2002 of the European Parliament and of the Council of 25 November 2002 on waste statistics OJ L 332,9.12.2002 (European Union). https://eur-lex.europa.eu/eli/reg/2002/2150/oj

Stenmarck, A., Jensen, C., Quested, T., Moates, G., Buksti, M., Cseh, B., Juul, S., Parry, A., Politano, A., Redlingshofer, B., Scherhaufer, S., Silvennoinen, K., Soethoudt, J. M., Zübert, C., & Östergren, K. (2016). *Estimates of European food waste levels* (Report No: D1.8 EU). IVL Swedish Environmental Research Institute. https://edepot.wur.nl/378674

Stępień, S., & Dobrowolski, D. (2017). Straty i marnotrawstwo w łańcuchu dostaw żywności – propedeutyka problemu. *Progress in Economic Sciences*, 4, 305-316. https://doi.org/10.14595/PES/04/022

Supreme Audit Office. (2021). *Informacja o wynikach kontroli: Przeciwdziałanie marnowaniu żywności* [Brochure]. https://www.nik.gov.pl/plik/id,25262,vp,28013.pdf

SW Research. (2020). *Gospodarowanie żywnością w trakcie pandemii.* https://swresearch. pl/reports

UN General Assembly Resolution 70/1 (2015). Transforming our world: the 2030 Agenda for Sustainable Development A/RES/70/1.https://www.un.org/en/development/desa/population/migration/generalassembly/-docs/globalcompact/A_RES_70_1_E.pdf

United Nations Environment Programme. (2021a). *Food Waste Index Report 2021.* Job No: ROW/2366/BA. United Nations Environment Programme, Kenya. https://www.unep.org/resources/report/unep-food-waste-index-report-2021

United Nations Environment Programme. (2021b). *Food Waste Index Report 2021. Appendix.* United Nations Environment Programme, Kenya. https://wedocs.unep.org/bitstream/handle/20.500.11822/35356/FWA.pdf

Żuchowski, J., & Żuchowska-Grzywacz, M. (Eds.). (2018). *Kierunek na zrównoważony produkt. Aspekty towaroznawcze*. Wydawnictwo Naukowe Instytutu Technologii i Eksploatacji – PIB.