Gdynia Maritime University

Faculty of Management
and Quality Science

Sustainable Development and Innovations in Shaping Product Quality

Zrównoważony rozwój i innowacje w kształtowaniu jakości produktów

Edited by Millena Ruszkowska, Aleksandra Wilczyńska

Gdynia 2025

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SUSTAINABLE CONSUMPTION AS A FACTOR IN THE QUALITY OF LIFE – ANALYSIS OF SOCIAL, ECONOMIC, AND ENVIRONMENTAL ASPECTS IN SELECTED CITIES

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Abstract

Sustainable consumption is playing an increasingly important role in shaping the quality of life of city dwellers. This chapter aims to analyze sustainable consumption as a significant factor influencing the quality of life of residents of the largest cities in Poland: Warsaw, Krakow, Łódź, Wrocław, and Poznań. The study is based on a three-pillar approach – considering social, economic, and environmental aspects – using statistical data from the Central Statistical Office (GUS) for 2021–2024. The analysis includes indicators such as the availability of green areas, selective waste collection, use of public transport, level of environmental education, and the economic situation of residents. The results indicate that cities differ in the degree of advancement in implementing the principles of sustainable consumption, which translates into a diverse quality of life. Warsaw and Wrocław stand out with an integrated approach, combining technological innovation, social activity, and effective environmental policy. Łódź, on the other hand, lags, especially in waste management and environmental education. The study uses the total and partial utility method.

Keywords: quality of life, sustainable development, usability, indicators.

INTRODUCTION

Sustainable development is based on integrating three fundamental dimensions: social, economic, and environmental, which should remain in a state of mutual balance. Maintaining harmony between these spheres is a condition for the durability of socio-economic systems and ecosystems. Disturbances in one of these areas can generate negative consequences in other areas. According to this principle, the development of one component should not lead to the dysfunction of others [WCED 1987]. Some social and economic processes can contribute to the intensification of environmental degradation, which in the long term threatens the entire system's stability. In the context of consumerism, the disruption of this balance is obvious. An increase in the level of consumption – often motivated by social and economic factors, such as lifestyle, social status, or market development – can lead to excessive exploitation of natural resources, increased emissions of pollutants, and degradation of the natural environment. From the perspective of sustainable development, consumption patterns mustn't generate environmental and social costs that exceed economic benefits. Consumption should be directed towards efficiently using resources, reducing waste, and promoting responsible consumer choices [Jackson 2009]. Only then can economic development goals be reconciled with environmental protection and social well-being.

1. MATERIAL AND METHODS

Sustainable development at the local level is becoming a key area of public management, especially in the era of global climate, migration, and economic crises. The challenges above are related to monitoring and analyzing local development results, among others, due to the lack of uniform operational tools that would be flexible and comparable between units.

Total and partial utility and classifying indicators into stimulants and destimulants are well-known methods in multi-criteria analysis (e.g., TOPSIS method, Hellwig method) [Zeliaś 2002], allowing for reducing data complexity while maintaining their interpretative significance [Mierzejewska 2015].

Importantly, assigning indicators to one of these categories is not always unambiguous and requires considering the local context and the nature of the given phenomenon. In addition, the change in the value of a given indicator may be linear or non-linear, which implies the need to use one- or multidimensional analyses.

This study empirically verifies sustainable consumption as a significant determinant of the quality of life in cities. The study covered the five largest cities in Poland, and the analysis was based on six diagnostic indicators selected in terms of their representativeness for three dimensions of sustainable development: social, economic, and environmental.

Six indicators were analyzed: the number of clinics per 10,000 people, average monthly salary, number of apartments put into use, registered unemployment rate, area of green areas per 1 inhabitant, and the share of waste collected selectively. The first indicator concerns the number of clinics per 10,000 people. Access to health care is a fundamental dimension of the quality of life and human rights. The number of clinics per 10,000 residents reflects the availability of outpatient health services, which play an essential role in preventing and treating chronic diseases and rapid response to emergencies.

From the point of view of sustainable development, the appropriate location of clinics reduces the need for medical transport over longer distances, which reduces pollutant emissions and relieves the transport infrastructure. In addition, the local availability of health services supports the concept of the so-called 15-minute city – an urban structure in which basic needs can be met within a radius of a dozen or so minutes' walk or bike ride.

The registered unemployment rate is one of the key indicators determining the decrease in the quality of life. Lack of employment means limited income and a loss of meaning, belonging, and social security. Long-term unemployment results in social marginalization and can increase social costs (social assistance, health care, public safety).

From the point of view of sustainable consumption, employment stability allows for planning expenses in the long term and promotes responsible consumer choices. Work enables consumption, strengthens social capital, and supports the development of the local economy.

The area of green areas per 1 inhabitant is an indicator of environmental order. Green areas play a multifunctional role in the urban fabric: they improve air quality, counteract the effects of climate change, and perform recreational and integration functions. The area of greenery available to residents is an essential indicator of the quality of life, especially in cities.

Sustainable urban development assumes creating spaces conducive to physical activity, relaxation, and contact with nature. Well-designed urban greenery reduces temperatures during periods of heat (urban heat island effect), increases rainwater retention, and supports biodiversity. A high share of green areas also correlates with lower stress levels and better mental health of residents. Another indicator of environmental order is the percentage of waste collected selectively. This indicator reflects the waste management system's efficiency and society's ecological awareness level. A high share of waste collected selectively indicates implementing the principles of the circular economy (CE), which is the foundation of sustainable consumption.

Waste segregation enables recycling, limits the consumption of natural resources, and reduces the amount of waste that goes to landfills. This action does not require large financial outlays but significantly impacts the environment – primarily if a system of economic incentives, social education, and efficient municipal logistics supports it.

The chapter uses statistical data from the Central Statistical Office (GUS) database. The analysis confirms that the utility method is an effective tool for presenting research results in an accessible and comparable way. The essence of this conversion is using a mathematical equation that allows for reducing the different units of measurement of individual indicators and transforming them into absolute values ranging from 0 to 1 – interpreted as partial utilities. Then, thanks to the aggregation of these values, it is possible to obtain the total utility for each analyzed object (city) and transparently present complex data in the form of synthetic comparative indicators.

The key element of the analysis is to determine the function performed by a given indicator, i.e., whether it is a stimulant (S – an increase in its value is desirable), a destimulant (D – an increase in its value is unfavorable), or a nominative (intermediate values are the most optimal). The partial utility is the relative value of the analyzed city's sustainable development indicator compared to other cities' values. It is calculated according to the following formula:

$$U_{ij} = \frac{C_{ij} - C_j^0}{C_j^1 - C_j^0}$$

where:

- U_{ij} – partial utility for city i in relation to indicator j,

- C_{ij} – value of sustainable development indicator j for city *i*,
- $C^0{}_j$ – the lowest (for the sustainable development stimulator) or the highest (for the sustainable development destimulator) value of sustainable development indicator j among the analyzed cities,
- $C^1{}_j$ – the highest (for the sustainable development stimulator) or the lowest (for the sustainable development stimulator) value of sustainable development indicator j among the analyzed cities [Alpopi et al. 2011b].

The value of partial utility ranges from 0 to 1. A value of 0 means that a given city has achieved the lowest result among all analyzed units, while a value of 1 indicates that the city is a leader in relation to a given indicator. Total utility is calculated according to the formula [Alpopi et al. 2011a]:

$$UG_i = \sum_{j=1}^{n} U_{ij}$$

The total utility value assigned to a city is determined not only by the levels of partial utilities but also by the number of indicators included in the analysis. In a situation where a city achieves maximum values (1) for all indicators, its total utility corresponds to the sum of the number of these indicators.

1.1. Sustainable consumption

In the face of ongoing climate change, depletion of natural resources, and deepening socio-economic inequalities, sustainable development is gaining increasing importance in scientific, political, and social discourse. One of its key components is sustainable consumption, understood as a model of consumer behavior that reconciles the needs of the individual and society with environmental constraints and the need to maintain intergenerational balance.

Sustainable consumption assumes rational and responsible use of goods and services, waste reduction, selection of environmentally friendly products, and support for local and ethical forms of production. In practice, this means changing consumer habits and transforming entire production and distribution systems towards greater efficiency and justice.

Quality of life, defined multidimensionally – encompassing material, health, environmental, social, and psychological aspects – is closely related to the consumption model. Uncontrolled consumerism can contribute to the degradation of the natural environment, reduced quality of life, increased stress levels, and the disappearance of social bonds. In turn, sustainable consumption, based on conscious choices and concern for the common good, can help improve the well-being of individuals and build a more just and sustainable society.

Empirical studies indicate that people who prefer pro-ecological and responsible consumer attitudes are likelier to report higher levels of life satisfaction and a stronger sense of agency and meaning. Moreover, local communities promoting sustainable consumption models – e.g., through zero waste initiatives, regional markets, cooperatives, or the sharing economy – are characterized by a higher level of social cohesion and a better state of the environment.

Sustainable consumption should be an individual's choice and an element of public policy and local and global development strategies. Instruments such as ecological education, certification systems, ecological taxes, regulations on production and advertising, or supporting innovations in sustainable development can play an essential role in shaping more responsible consumer attitudes.

Including sustainable consumption in the socio-economic development agenda allows not only to counteract the adverse effects of environmental degradation but also to build a model of prosperity that is not based solely on economic growth but also on the quality of life, public health, and social balance.

1.2. Literature review

Sustainable consumption was clearly defined in the Agenda 21 document, adopted during the Earth Summit in Rio de Janeiro 1992. It points to the need to change consumption patterns that lead to overexploitation of natural resources and exceeding planetary boundaries [UNCED 1992]. In the scientific literature, sustainable consumption is defined as a process in which goods and services minimize environmental impact while ensuring social and economic well-being [Jackson 2005]

Authors such as Tukker et al. [2010] or Mont and Plepys [2008] emphasize that sustainable consumption is not limited to environmental aspects but also includes the social dimension – including issues of justice, equality in access to resources, and civic participation. Cohen [2005] notes that adopting responsible consumer practices depends mainly on the level of education, cultural values, and institutional support.

Research shows a positive correlation between pro-environmental consumer attitudes and subjective well-being in the context of quality of life. Brown and Kasser [2005] showed that people who prefer less materialistic life goals and avoid excessive consumption are more likely to experience a higher level of life satisfaction. Similar conclusions are presented by Hunecke et al. [2007], who noted that consumption by the principles of sustainable development can strengthen the sense of meaning, identity, and social responsibility. In Europe, it is worth pointing out the reports of the European Environment Agency [EEA 2020] and OECD studies [2011, 2020], which indicate that changing consumption patterns is one of the key conditions for improving the quality of life and achieving the Sustainable Development Goals (SDGs). At the same time, they emphasize structural challenges – such as the availability of alternative products, economic barriers, and lack of sufficient social awareness. The impact of public policies on consumer behavior is also increasingly raised in the literature. Thøgersen [2010] argues that effective transformation of consumption requires integrated regulatory, fiscal, and educational actions.

2. RESULTS

In this work, the total and partial utility was calculated for six selected indicators of environmental, social, and economic order, which undoubtedly indicate the quality of life in a given city. The list of these indicators is presented in Table 1.

Table 1. Indicators of the cities studied

City	2021	2022	2023	2024
1. Clinics per 10 thousand people [facilities]				
Warszawa	8	8	9	9
Kraków	9	10	10	10
Łódź	10	11	11	11
Wrocław	9	9	9	10
Poznań	10	10	11	12
2. Average gross monthly wages				
Warszawa	7687.58	8540.11	9625.74	11128.16
Kraków	7203.41	8157.43	9223.73	10002.25

cont. Table 1

Łódź	6062.04	6629.23	7548.1	8126.16
Wrocław	6693.3	7391.95	8334.84	9123.16
Poznań	6662.69	7362.74	8303.38	9009.65
3. Number of apartments completed per 1.000 inhabitants				
Warszawa	10	8.3	8.6	8
Kraków	12.6	13.4	12	10.7
Łódź	7.4	8.8	7.9	8.5
Wrocław	16.4	13.4	12.1	9
Poznań	11.7	9.8	8.6	9.4
4. Registered unemployment rate [%]				
Warszawa	2	1.8	2	1.9
Kraków	2.9	2.5	2	2.2
Łódź	5.5	4.5	4.4	4.4
Wrocław	1.9	1.6	1.6	1.7
Poznań	1.6	1	1	1
5. Area of green areas per 1 inhabitant [m²]				
Warszawa	27.9	27.5	27.1	27.4
Kraków	46.9	46.5	49.5	49.5
Łódź	60.1	62	63.1	63.2
Wrocław	49.6	53.1	53.3	53.7
Poznań	81.2	81.1	82.6	82.6
6. Share of waste collected selectively [%]				
Warszawa	33.4	33.8	32.5	33
Kraków	47	48	48.7	49
Łódź	38.3	39.7	38.3	39.2
Wrocław	36.5	39.1	36.9	38.7
Poznań	39.7	39	39.8	39.9

Source: own study based on data from the Central Statistical Office.

The results of total and partial utility are included in Table 2, divided into individual cities with county rights.

Table 2. Value of total and partial utility in the cities studied

City	Clinics per 10 thousand people [facilities]	Average monthly gross wages	Number of apartments put into use per 1000 people unemployment rate [%]	Registered unemployment rate [%]	Area of green areas per 1 inhabitant [m²]	Share of waste collected selectively [%]
2021						
Poznań	1	0.37	0.48	1	1	0.46
Kraków	0.5	0.7	0.58	0.67	0.36	1
Wrocław	0.5	0.39	1	0.92	0.41	0.23
Warszawa	0	1	0.29	0.9	0	0
Łódź	1	0	0	0	0.6	0.36
2022						
Kraków	0.67	0.8	1	0.57	0.35	1
Poznań	0.67	0.38	0.29	1	1	0.37
Wrocław	0.33	0.4	1	0.83	0.48	0.37
Łódź	1	0	0.1	0	0.64	0.41
Warszawa	0	1	0	0.77	0	0
2023						
Kraków	0.5	0.81	0.98	0.71	0.4	1
Poznań	1	0.36	0.17	1	1	0.45
Wrocław	0	0.38	1	0.82	0.47	0.27
Łódź	1	0	0	0	0.65	0.36
Warszawa	0	1	0.17	0.71	0	0
2024						
Poznań	0,87	1	0.28	0.52	1	1
Kraków	1	0.33	0.6	1	0.65	0.4
Wrocław	0,28	0.33	0.31	0.37	0.74	0.48
Łódź	0,12	0.67	0	0.18	0	0.65
Warszawa	0	0	1	0	0.73	0

Source: own study.

3. DISCUSSION

The analysis selected years for which the most complete statistical data were available. All analyzed indicators related to sustainable consumption were defined as stimulants.

Table 2 contains six indicators, so the hypothetical highest total utility value is 6. The research showed that none of the cities studied reached the maximum value. Based on six indicators: availability of clinics, level of wages, the intensity of housing construction, unemployment rate, area of green areas, and share of waste collected selectively – partial and total utilities were determined for the five largest cities in Poland: Warszawa, Kraków, Łódź, Wrocław, and Poznań.

The cities differ in their level of sustainable development, and their ranking position changes depending on the year. Poznań and Kraków mainly achieved the highest total utility. In contrast, despite the highest wages, Warsaw maintained the lowest total utility values, which indicates a lack of balance between economic, social, and environmental aspects.

In most of the years analyzed (2021 and 2024), Poznań achieved the highest or very high total utility values, which results from:

- very low unemployment rate,
- high availability of green areas (over 80 m²/person),
- high level of healthcare (number of clinics per 10,000 residents).

Although wages in Poznań were average, the overall balance between the criteria allowed this city to lead.

Kraków systematically achieved excellent results in:

- number of apartments put into use (in 2021–2023, it was the leader),
- share of waste collected selectively (increase from 47% to 49%),
- moderate, stable unemployment rate.

The relatively small green area and the moderate number of clinics did not prevent it from obtaining high sustainability ratings.

Despite maintaining the highest gross wages in all years (e.g., PLN 11,281 in 2024), Warsaw was consistently at the end of the total utility ranking. This is due to:

- low share of segregated waste (approx. 33%),
- relatively low availability of urban greenery,
- poor availability of clinics (9 per 10,000 people – the least in 2024).

This shows that the economic boom does not compensate for deficits in other areas of sustainable development.

Łódź stands out positively in terms of:

- green area (over 63 m^2/person),
- relatively good availability of clinics.

Unfortunately, the low quality of the labor market (the highest unemployment) and the lowest wages in all analyzed years significantly lowered the overall assessment of the city's sustainability.

Wrocław occupied middle positions in all analyzed years. It did not dominate in any category, but it did not record very low results either:

- stable housing development,
- low unemployment rate,
- average environmental quality.

This city can be described as 'medium-balanced' in each dimension.

However, it is worth paying attention to the scope of analyses conducted based on sustainable development indicators. The selection of indicators is often determined by the availability of data and the authors' discretion. The analysis results indicate that sustainable consumption is an essential and measurable factor that influences the quality of life of city residents. The study included six indicators from social, economic, and environmental areas, which were normalized and aggregated using the partial and total utility method. This allowed for a synthetic comparison of the level of consumption sustainability in the five largest cities in Poland: Warszawa, Kraków, Łódź, Wrocław, and Poznań in 2021-2024. By the concept of a three-dimensional approach to sustainable development [Brundtland Report 1987; Sachs 2015], the obtained results confirm that the dominance of one of the dimensions (e.g., economic) does not directly translate into high quality of life if the other aspects – social and environmental – are neglected. An example of such a phenomenon is Warsaw, which, despite the highest income of its residents, maintains the lowest level of total utility, mainly due to low environmental quality and limited availability of public services.

On the other hand, Poznań and Kraków achieve high values of total utility due to the relative balance between economic, social, and environmental consumption. Poznań stands out for the best availability of green areas and health services, as well as the lowest unemployment, suggesting that the city's policy supports responsible use of resources and access to basic public services. Kraków, despite the average availability of greenery, compensates for this deficiency through the dynamic development of housing and waste management, making it an example of urban consumption oriented towards efficiency and regeneration.

In the context of Łódź, strong environmental foundations of sustainable development were observed (e.g., high green area per capita). However, the social and economic lack of support (high unemployment, low wages) reduces the total quality of life. This means that environmental policies, although important, are not sufficient without a simultaneous improvement in the socio-economic situation of residents.

Sustainable consumption in cities should therefore be considered holistically while considering all three pillars of sustainable development. Using multi-criteria tools, such as utility analysis, enables an objective assessment of the level of consumption sustainability and identifies areas requiring intervention.

Moreover, differences in results between years show that cities are dynamic systems, and the effects of urban policy are visible only in the longer term. This suggests the need to monitor progress continuously, using multidimensional and dynamic models of assessing the quality of life, adapted to local conditions.

The results of partial and total utility analysis indicate that the quality of life in cities largely depends on the degree of integration of social, economic, and environmental policies. On this basis, the following recommendations for public policy at the local and national levels can be formulated:

- Cities with a dominant economic profile (e.g., Warsaw) show a low quality of life if a deficit of activities in the environmental and social area accompanies this. It is recommended that strategies be implemented to balance infrastructure investments with improving the quality of green spaces, access to health services, and the efficiency of selective waste collection.
- High quality of life results not only from income level but also from how local resources are used. Public policies should support ecological education, resource--saving programs (e.g., energy, water, space), and encourage residents to make responsible consumption choices.
- Cities such as Poznań and Łódź achieve high rates of access to green areas, which translates into a positive impact on the well-being of residents. It is recommended that environmental components (greenery, air quality, water retention) be included in urban planning and revitalization strategies.

- Traditional indicators (e.g., GDP, unemployment rate) do not reflect a comprehensive picture of consumption sustainability. It is recommended to use complex tools for assessing the quality of life, such as utility analysis or multi--criteria decision models, which allow for ongoing diagnosis of deficiencies and imbalances.
- Sustainable consumption should become integral to local and regional development strategies. This can be achieved through: local sustainable development programmes, ecological public procurement criteria, green budgeting, and social participation.

CONCLUSIONS

The analysis aimed to determine the level of sustainable consumption as a factor shaping the quality of life of the residents of the five largest cities in Poland in 2021–2024. Taking into account a set of six social, economic, and environmental indicators, the study showed how various factors affect the sustainability of urban consumption and how these differences translate into a synthetic assessment of urban well-being.

The use of the partial and total utility method proved particularly valuable because:

- it allows the transformation of indicators expressed in different units into a uniform scale,
- it allows for the aggregation of diverse aspects of urban life in the form of a single synthetic measure,
- it allows monitoring changes over time and identifying areas requiring intervention.

Thus, this method can be an effective diagnostic tool for public decision-makers, urban planners, and researchers of regional development.

The analysis results revealed that cities that balance economic, social, and environmental consumption achieve the highest quality of life. Poznań was identified as the city with the most harmonious development, while Warsaw, despite its economic dominance, reveals weaknesses in the social and environmental dimensions, which lowers its overall assessment. Sustainable consumption turned out to be not only a theoretical concept but also a measurable and comparable component of the quality of life that can be used to assess the effectiveness of city policies. It was also shown that the lack of balance between the pillars of sustainable development leads to a deterioration in the well-being of residents, regardless of the level of income or the scale of infrastructure investments.

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CURRENT TRENDS AND FLAVOR DIVERSIFICATION IN BEER PRODUCTION IN POLAND

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Abstract

The study investigates flavor diversification as a strategic instrument in the Polish beer sector, emphasizing the contrast between mainstream and craft breweries. While large producers adopt novel combinations, lower-risk approaches, craft breweries pursue bold, unconventional flavors driven by brewer creativity. A systematic classification (fruit, floral, herbal, prebiotic, and experimental beers) illustrates Poland's expanding sensory landscape. The findings confirm that flavor innovation supports product differentiation and strengthens market positioning, reflecting evolving consumer expectations. The article further proposes research on the influence of brewer personality on innovation and new product development, offering valuable insights for both industry and academia.

Keywords: beer flavor diversification, craft beer, innovation, consumer preferences, Polish beer market.

INTRODUCTION

Beer remains one of the most widely consumed alcoholic beverages globally, with a long-standing cultural, social, and economic significance [Colen & Swinnen 2016; Ualema 2024]. Despite regional differences in consumption habits, beer continues to hold a dominant position in the alcoholic beverage market in many countries. According to recent industry reports, global beer production and consumption have shown dynamic trends, shaped by demographic shifts, income level, health-conscious behaviors, and evolving consumer preferences including the need of non-alcoholic beverages (NOLO trend) [Colen & Swinnen 2016; Waehning & Wells 2024]. These factors have not only influenced the volume of beer consumed but also contributed to substantial changes in the types of beer being produced and offered on the market. In Poland, beer consumption has fluctuated over the past several years: from 37.223 million hl in 2017, declined during COVID-19 to 34.689 million hl in 2020 and in 2023 32.270 million hl [European Beer Trends Statistics Report 2024]. According to the study among consumers, taste and product availability in retail outlets emerged as the most critical factors influencing purchasing decisions for non-alcoholic beers [Gliszczyńska-Świgło et al. 2025].

Among these changes, one of the most notable developments is the increasing diversification of beer styles and flavor profiles. As selected consumers seek more personalized and sensory-rich experiences, breweries have responded by novel beer categories [Cela et al. 2025; Jager et al. 2021; Steinbach et al. 2023]. This movement has accelerated particularly within the craft beer segment but is also visible among mainstream producers aiming to capture new market niches.

While beer has traditionally been associated with relatively stable taste categories, the contemporary market reveals a striking diversification in flavor offerings. This raises questions about how breweries adapt their product strategies to evolving consumer expectations and whether novel ingredients are one of the key drivers of competitive advantage in the beer sector. This study investigates the role of flavor diversification in shaping product differentiation and market positioning.

The main objective of this article is to analyze the role of flavor diversification in the beer market, with particular emphasis on the Polish context. The study aims to examine how breweries respond to changing consumer preferences through flavor innovation and how such strategies contribute to product differentiation and competitive positioning.

1. BEER CATEGORIES AND TRADITIONAL STYLES

Beer is a fermented alcoholic beverage typically produced from four basic ingredients: water, malted grains (most commonly barley), hops, and yeast. Despite the simplicity of its composition, beer exhibits remarkable diversity in styles, brewing methods, and sensory characteristics [Baiano 2021]. At the broadest level, beers are traditionally categorized into two main types based on the type of yeast and fermentation process: ales and lagers.

Ales are brewed with top-fermenting yeast (*Saccharomyces cerevisiae*) at warmer temperatures (typically 15–24°C). This results in faster fermentation and more pronounced fruity and estery flavors. Common ale styles include India Pale Ale (IPA), Pale Ale, Stout, Porter, and Belgian Ale [Baiano 2021].

Lagers, by contrast, are brewed with bottom-fermenting yeast (*Saccharomyces pastorianus*) at lower temperatures (typically 7–13°C), leading to slower fermentation and cleaner, crisper taste profiles. The most well-known lager styles include Pilsner, Helles, Dunkel, and Bock [Baiano 2021].

A third, smaller category gaining recognition is spontaneously fermented beers, such as Belgian Lambics, which rely on wild yeasts and bacteria naturally present in the environment [Baiano 2021].

Over time, this classical division has been enriched by hybrid styles and flavor--infused variants, especially in the craft beer movement. The rise of flavored beers – incorporating fruits, spices, herbs, coffee, chocolate, or even lactose – has significantly expanded traditional boundaries, catering to changing consumer tastes and opening up new market segments [Jaeger et al. 2021].

In order to provide a structured and internationally recognized framework for evaluating beer diversity, especially in the context of flavor, the Beer Judge Certification Program [BJCP 2021] has developed a comprehensive classification system. The BJCP 2021 Guidelines divide beer styles into 34 main categories, each containing one or more specific substyles, based on sensory attributes rather than geographical or historical criteria [BJCP 2021].

This system distinguishes beers primarily by fermentation type (ale, lager, or wild/mixed), strength, color, flavor dominance, and regional origin. For instance, lagers are divided into categories such as Standard American Beer, International Lager, Czech Lager, or Dark European Lager, while ales include Pale American Ale, British Bitter, IPA, or Strong Belgian Ale. Additionally, the guidelines cover hybrid and specialty categories, including fruit beers, spice/herb/vegetable beers, smoked beers, and experimental beers [BJCP 2021].

Importantly, each beer style in the BJCP framework is described using a standardized format that includes attributes such as aroma, appearance, flavor, mouthfeel, characteristic ingredients, and vital statistics (e.g., ABV, IBU, SRM). This makes it a useful tool not only for beer competitions and judge training but also for academic research, sensory analysis, and market segmentation. As the BJCP notes, these guidelines are not meant to constrain innovation rigidly but rather to describe current brewing practices and help in evaluating beer according to shared, sensory-based expectations [BJCP 2021].

2. THE CASE OF KOMPANIA PIWOWARSKA

The product portfolio of Kompania Piwowarska, one of the largest beer producers in Poland, clearly reflects the increasing diversification of the domestic beer market in terms of flavors, styles, and alcohol content. The company continues to provide a stable assortment of traditional beers (such as Żubr, Tyskie Gronie, or Kozel Ležák) (Table 1) and systematically increases the share of its portfolio allocated to flavored, alcohol-free, and enriched beer products.

Table 1. The overview of Kompania Piwowarska products

Kompania piwowarska	
Brand	**Products**
Pilsner Urquell Żubr Wojak, Dębowe Dojrzałe Mocne Peroni Nastro Azzurro	
Tyskie	Tyskie Gronie (Jasne Pełne) – 5.2% alcohol Tyskie 0.0% – 0.0% Tyskie Edycja Klasyczna – 4.8% alcohol Tyskie Pilzner – 4.9% alcohol Tyskie z Tanka – 5.2% alcohol
Lech	Lech Premium – 5.0% alcohol Lech Pils – 5.5% alcohol Lech Lime & Mint – 4.0% Lech Apple & Lemongrass – 4.0% alcohol Lech Cherry & Plum – 4.0% alcohol Lech Free 0.0% – 0.0% alcohol Lech 0.0 Hydrate Lychee Lemon – 0.0% alcohol Lech 0.0 Fit Low Sugar Grapefruit – 0.0% alcohol Lech 0.0 Active Mango Lemon – 0.0% alcohol Lech Free 0.0% Lime Mint – 0.0% alcohol Lech Free 0.0% Watermelon Mint – 0.0% alcohol Lech Free 0.0% Yuzu Pomelo – 0.0% alcohol

cont. Table 1

	Lech Free 0.0% Blackberry Cherry – 0.0% alcohol Lech Free 0.0% Dragon Fruit Grape – 0.0% alcohol Lech Free 0.0% Citrus Sour – 0.0% alcohol Lech Free 0.0% Passion Fruit Melon – 0.0% alcohol Lech Free 0.0% Dark Fruit Sour – 0.0% alcohol Lech Free 0.0% Blueberry Strawberry – 0.0% alcohol Lech Free 0.0% Apple & Lemongrass – 0.0% alcohol
Ksiażece	Książęce IPA – 5.4% alcohol Książęce Cherry Ale – 4.1% alcohol Książęce Porter – 8.0% alcohol Książęce Złote Pszeniczne – 4.9% alcohol Książęce Czerwony Lager – 4.9% alcohol Książęce Ciemne Łagodne – 4.1% alcohol Książęce Lager – 5.0% alcohol Książęce IPA bezalkoholowe – 0.0% alcohol Książęce Złote Pszeniczne bezalkoholowe – 0.0% alcohol
HARDMADE	HARDMADE Cherry Choco – 4.5% alcohol HARDMADE Blackberry Vanilla – 4.5% alcohol HARDMADE Exotic Kumkwat – 4.5% alcohol HARDMADE Yuzu Lemon – 4.5% alcohol HARDMADE Cool Passion Fruit – 4.5% alcohol HARDMADE Creamy Mango – 0.0% alcohol HARDMADE 0,0% Citrus IceTea Crush – 0.0% alcohol
Captain Jack	Captain Jack Original – 6.0% alcohol Captain Jack Exotic Daiquiri – 6.0% alcohol Captain Jack On the Beach – 6.0% alcohol Captain Jack Mango Daiquiri – 6.0% alcohol Captain Jack Tropical Sunrise – 6.0% alcohol Captain Jack Blue Lagoon – 6.0% alcohol Captain Jack Caribbean Sour – no data Captain Jack Party Lime – no data Captain Jack Mojito – no data
Kozel	Kozel Ležák – 4.6% alcohol Kozel Černý – 3.8% alcohol Kozel Bilý Lehký – 3.5% alcohol Kozel 0.0% – 0.0% alcohol

Source: own study based on Kompania Piwowarska website https://www.kp.pl/ accessed June 2025.

Particularly striking is the Lech Free 0.0% line, which includes at least twelve unique fruit-based or exotic flavor variants, such as:

- Yuzu & Pomelo, Dragon Fruit & Grape, Blueberry & Strawberry, and Passion Fruit & Melon representing a clear orientation toward tropical and less conventional fruit pairings,

- Apple & Lemongrass, Lime & Mint, and Citrus Sour appealing to health--conscious and refreshment-seeking consumers,
- Variants like Hydrate Lychee Lemon or Fit Low Sugar Grapefruit which suggest added functionality (e.g., hydration, low sugar content) and mimic isotonic or wellness drinks.

In addition to alcohol-free options, the hardmade sub-brand offers flavored alcoholic beverages with dessert-like or exotic profiles, including Cherry Choco, Blackberry Vanilla, and Exotic Kumkwat. These products are on the border of beer and ready-to-drink cocktails, often aimed at younger audiences or occasions where beer alone may not suffice. The Captain Jack line further supports this trend by blending beer with cocktail inspirations (e.g. Mojito, Blue Lagoon, Daiquiri, On the Beach), thus contributing to experiential and themed drinking occasions.

Meanwhile, the Książęce line combines traditional styles (Porter, Lager, Pszeniczne) with more contemporary entries such as Cherry Ale or alcohol-free IPA, indicating an attempt to combine craft cues with mass-market accessibility.

Taken together, these products illustrate the current strategic segmentation of the mass beer market in Poland:

- from classic beer drinkers to adventurous flavor seekers,
- from alcohol-focused consumers to those seeking non-alcoholic or functional alternatives,
- from traditional formats to hybrid, cocktail-inspired beverages.

What becomes apparent is that while many of these flavored beers and variants follow global flavor trends, only some demonstrate true product innovation. Many offerings could be classified as novel products, involving the new fruit combinations rather than introducing new brewing techniques or formats.

3. CRAFT BREWERIES

In contrast to mass-market brewing, the Polish craft beer market become a dynamic and experimental field in which flavor innovation, diversity of styles, and sensory sophistication play a central role. Since the early 2010s, a growing number of independent breweries, such as PINTA, Browar Stu Mostów, Nepomucen, Funky Fluid, AleBrowar or Trzech Kumpli, have introduced hundreds of limited-edition beers that often defy conventional classification.

Craft breweries have already introduced bold and unconventional flavor combinations, including:

- Heavily hopped IPAs with New World varieties offering tropical, citrusy, or resinous notes.
- Pastry stouts with additions such as cocoa nibs, vanilla, salted caramel, coconut, peanut butter, or even cake and brownie infusions.
- Fruited sours and smoothie-style beers, often using large quantities of puréed fruit (e.g., mango, maracuja, raspberry, blackcurrant) and lactose.
- Barrel-aged beers, matured in whisky, rum, or wine barrels, developing complex oxidative, oaky, or spirit-like profiles (e.g., Dwie Wieże Winowajca – Saison Red Wine Barrel Aged).
- Spice-infused and herbal e.g., with chili, thyme, ginger, cardamom, or even coffee and tea e.g., Into the Void (Coffee Rye Stout) – Browar Nepomucen & Browar Golem.
- Flower beers e.g., Rose petals, lavender e.g., Piwo z Żuka Lavender, Brewer Hoplala – PSZEróżnie bywa.

These offerings often fall into the BJCP's Specialty Beer, Experimental Beer, or Mixed Fermentation categories, showcasing sensory innovation as a distinguishing feature of Polish craft brewing.

3.1. Functional and conceptual variants

Beyond flavor, some craft breweries have also ventured into functional innovation, often produced in the form of alcoholic and non-alcoholic:

- Low-alcohol or session IPAs, hazy pale ales, or non-alcoholic craft beers (e.g., PINTA Mini Maxi, Funky Fluid Free series).
- Beers with added electrolytes and/or probiotics (e.g., Browar Piotrków: Iguana Metabolizm BIO) represent an intersection between the craft beer segment and functional beverages. These beers not only offer unique sensory profiles but also communicate added health or wellness benefits, targeting consumers interested in 'better-for-you' products and aligning with broader trends in functional food and drink innovation [Ali & Ali 2022].

- Beers with addition of adaptogens (ashwagandha, ginseng) or superfoods (matcha, spirulina), e.g., Piwo Bo Beer Gruit z Ashwagandhą Browar Bóbr, Funky Fluid GREEN Kiwi Mango Pear Spirulina 3,8 %.
- Gluten-free beer (e.g., Browar Maryenztadt, Piwo Bezglutenowy West Coast IPA or Piwo OWSIANY STOUT BEZGLUTENOWY), address the needs of consumers with gluten intolerance or those who choose gluten-free diets for lifestyle reasons [Newberry et al. 2017]. These beers require specialized brewing techniques and ingredient substitutions (e.g., using alternative grains).
- Hybrid formats such as beer-wine blends (grape ales) or beers co-fermented with fruit and wild yeast strains.
- Organic products (e.g., Lager Cieszyński BIO Browar Zamkowy Cieszyn, AleBrowar Organic) developed by using certified organic raw materials and avoiding artificial additives, for environmentally conscious consumers who value transparency and ecological stewardship in their purchasing decisions [Czernyszewicz et al. 2022].

Equally important is the narrative and visual identity of these beers. Craft labels often include artistic design, satirical names, and stories that reflect local identity, social issues, or cultural references. This emotional and cultural positioning may be one of the key parts of the product experience, creating value beyond taste alone.

3.2. Innovation vs. novelty

While the craft segment is widely perceived as the most innovative in the industry, it is not free from 'novelty fatigue'. With the high turnover of new releases (so-called 'one-offs'), some critics argue that breweries increasingly rely on shocking ingredients or extreme flavors at the expense of balance, drinkability, or coherence. Nonetheless, the craft segment remains a laboratory for experimentation, pushing the boundaries of what beer can be and shaping consumer expectations even beyond niche markets. One of directions that can lead to new flavor effects is selecting yeast strains, Saccharomyces and non-Saccharomyces yeasts [Iorizzo et al. 2021; Maust et al. 2025].

An important characteristic of the craft segment is its limited release strategy, which often involves producing certain beer variants only once or in extremely small batches. Many breweries introduce unique recipes as single-batch experiments, never repeating them in future cycles. Others follow a seasonal approach, creating beers tied to specific times of the year, such as summer fruit sours, autumn pumpkin ales, or winter spice-infused stouts. This approach may indicate freshness, creativity, and exclusivity, appealing to consumers who seek new sensory experiences and appreciate the ephemeral, 'here and now' nature of such offerings [Salanță 2020].

To better illustrate the strategic and sensory differences between mainstream and craft beer producers, Table 2 provides a comparative overview of key aspects such as product development approach, flavor philosophy, use of ingredients, and market positioning. This comparison underlines how large-scale breweries focus on consistency and broad appeal, whereas craft breweries emphasize creativity, sensory diversity, and niche market engagement. The table that describes the Polish market well may serve as a framework for understanding how each segment addresses consumer expectations and competition dynamics.

Table 2. Key differences between mainstream and craft breweries

Aspect	Mainstream Beer (e.g., Kompania Piwowarska)	Craft Beer (e.g., PINTA, Nepomucen)
Product development strategy	Market-driven, portfolio optimization	Creative, brewer-led experimentation
Flavor profile	Mild, familiar, low-risk flavors	Bold, intense, complex, unconventional
Use of ingredients	Standardized, cost-efficient, artificial flavorings allowed	Natural, high-quality, experimental adjuncts
Alcohol content variation	Moderate variation (classic, radler, 0.0%)	Wide range of alcohol from 0.0% to >10%
Innovation level	Novel combinations or trend-following	High, often radical or category-breaking
Frequency of new releases	Occasional seasonal variants	Weekly/monthly limited editions
Label design and branding	Consistent, conservative branding	Artistic, humorous, niche storytelling
Consumer target group	Mass-market consumers, loyalty-based	Explorative, experience-seeking consumer
Distribution channels	Retail chains, supermarkets, HORECA	Specialist stores, taprooms, HORECA, online
Market positioning	Accessible, everyday consumption	Premium, artisanal, expressive
Price	Low to moderate	Moderate to high

Source: based on: Buiattis 2021; Durán-Sánchez et al. 2022.

4. FUTURE RESEARCH DIRECTIONS

While this study focuses on flavor diversification as a strategic tool in the beer market, future research could explore additional factors influencing innovation dynamics within breweries. One particularly promising direction involves investigating the role of the brewer's personality and individual creative disposition in shaping product portfolios and driving novelty.

Breweries, especially in the craft segment, often rely on the personal vision, risk tolerance, and creative identity of individual brewers or founders. Understanding how traits such as openness to experience, entrepreneurial mindset, or cultural orientation influence the willingness to experiment and introduce unconventional flavors could provide valuable insights for both academia and industry.

Such research might include qualitative approaches (e.g., in-depth interviews or case studies with head brewers) as well as psychometric analyses to connect personality profiles with innovation outcomes. Ultimately, exploring this human factor could deepen our understanding of how new trends emerge in the beer market and how individual creativity translates into tangible market differentiation.

CONCLUSIONS

The study objective underscores the strategic significance of flavor, which extends beyond its role as a mere sensory attribute. In the context of the increasingly saturated and highly competitive beer market-particularly in Poland-flavor diversification enables breweries to address changing consumer expectations, strengthen brand identity, and explore new market segments. By incorporating both mainstream and craft beer categories, the present study aims to elucidate the potential of flavor-driven innovations to shape product portfolios and influence market dynamics. The resulting insights may serve as a reference for producers, marketers, and policymakers engaged in the development and regulation of the beer sector.

Looking ahead, it is anticipated that the beer market will continue to evolve towards increased availability of non-alcoholic and low-alcohol alternatives, alongside the emergence of functional beers enriched with probiotics, adaptogens, or other bioactive components perceived as 'better-for-you' ingredients. These tendencies are consistent with the growing consumer interest in health, wellness, and individualized consumption experiences.

Nevertheless, several limitations of this study must be acknowledged. The analysis focuses primarily on the Polish beer market, which may restrict the generalizability of the findings to other cultural and regional contexts. Furthermore, the study relies predominantly on qualitative data and descriptive market observations, without the inclusion of quantitative sensory evaluations or large-scale consumer perception studies. Lastly, the scope of the research is confined to a selected number of breweries and product lines, which may not comprehensively capture the full spectrum of flavor innovation practices currently present in the market. Future investigations may address these limitations by expanding the geographical scope, incorporating quantitative consumer studies, and employing experimental methodologies to validate and extend the present research.

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POTENTIAL OF SEA BUCKTHORN FRUIT EXTRACTS AS A SUSTAINABLE METHOD OF *FUSARIUM* FUNGI CONTROL IN AGRICULTURE

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Abstract

Ensuring an adequate level of food security is currently becoming one of the most important global challenges, especially in the face of constantly increasing population. Agriculture plays a key role in meeting the demand for food, providing various types of raw materials and products for the entire food sector. Unfortunately, the presence of pests in agricultural crops, such as mycotoxigenic filamentous fungi, can result in significant losses in the number of crops as well as a decrease in their quality and safety. To limit the occurrence of pests in agricultural crops, due to environmental aspects plant extracts, exhibiting antagonistic activity against selected plant pathogens, are becoming increasingly important. The aim of this study was to assess the fungistatic properties of common sea buckthorn fruits extracts against selected *Fusarium* fungi. In addition, the amount of total phenolic compounds in tested extracts were estimated. The obtained results indicate that the effectiveness of the extracts against the tested *Fusarium* fungi species was varied and depended mainly on fungi species and the type of solvent used for extraction. The conducted experiment indicate that the tested extracts have a high potential to inhibit the growth of selected fungi of the *Fusarium* genus and may constitute an alternative solution in sustainable pathogen control in agriculture.

Keywords: sustainable agriculture, biological plant control, pest management, plant extracts.

INTRODUCTION

According to literature data, the vast majority of crop diseases are caused by various types of fungi and fungus-like pathogens, which has a direct impact on the increased risk of food security [Tian et al. 2020]. Filamentous fungi of the genus Fusarium can be classified as one of the most important plant pathogens that infect many agricultural crops, including those of the most economic importance such as wheat, maize, and rice [Ekwomadu & Mwanza 2023]. In addition, Fusarium fungi may pose a direct threat to the health and life of consumers and farm animals due to their ability to synthesize toxic secondary metabolites – mycotoxins [Ferreira et. al, 2018]. It is therefore necessary to constantly monitor and control these plant pathogens to ensure the appropriate quantity and quality of agricultural produce. Commonly used for this purpose chemical plant protection products, especially in conventional agriculture, carry many health, and environmental hazards. Excessive use of agricultural chemicals contributes to, among others, a reduction in biodiversity, soil degradation, and water pollution [Głodowska & Gałązka 2017], while according to the World Health Organization, the presence of pesticides in the food chain results in 1.5 million poisonings worldwide, responsible for many illnesses and diseases [Makles & Domański 2008]. In the face of these challenges, sustainable development is playing an increasingly important role – an idea that has been reflected in legal regulations and development strategies implemented at various levels – from local to international [Żmija 2014]. Sustainable agriculture is one of the key pillars of the EU's Common Agricultural Policy (CAP) and is in line with the assumptions of the European Green Deal and the 'From Farm to Fork' strategy [Gwiazdowska et al. 2024a]. In this context, integrated plant protection is becoming increasingly important, including crop rotation, sowing pathogen-resistant varieties, responsible and balanced fertilization, and the use of appropriate agrotechnical treatments such as biological agents [Pruszyński et al. 2012]. In biological plant protection, great potential is seen in various types of substances of plant origin, which are characterized by broad antimicrobial activity and do not have a harmful effect on the natural environment [Boukaew et al. 2017; Ferreira et al. 2018; Sumalan et. al. 2019]. Considering the global challenges related to the protection of agricultural crops and the further development of biopreparations for the biological control of plant pathogens, in this work an attempt was made to estimate the fungistatic activity of sea buckthorn fruit extracts.

1. MATERIAL AND METHODS

1.1. Materials

1.1.1. Plant material

The research material consisted of frozen sea buckthorn fruit (*Hippophae rhamnoide*s L.) from Cajdex Sp. z o. o. sp. k. purchased in a local wholesale store. Various extract variants were obtained from appropriately prepared plant material and used in further research.

1.1.2. Plant extracts

Sea buckthorn fruit extracts were obtained using two extraction methods: in a Soxhlet apparatus and an ultrasonic bath. Different chemical reagents were used both for the extraction and the dissolution of the extracts. As a result, eight variants of extracts were obtained, which were analysed for fungistatic activity against selected *Fusarium* fungi and total number of polyphenolic compounds.

1.1.3. Microorganisms

Four species of the *Fusarium* fungi were selected as indicator microorganisms: *F. oxysporum* KZF 20, *F. poae* KZF 181, *F. graminearum* KZF1 and *F. culmorum* KZF 5. The selected filamentous fungi came from the collection of the Department of Natural Sciences and Quality at the Poznań University of Economics and Business. Before each use, the indicator microorganisms were cultivated on a PDA (Potato Dextrose Agar, BioMaxima, Poland) medium at 23-25°C for approx. 5–7 days until the mycelium matured.

1.1.4. Chemicals

Two solvents were used to obtain extracts from sea buckthorn fruit: hexane and methanol (Chempur, Poland). Additionally, depending on the extract variant, the residue after extraction was dissolved in methanol or dimethyl sulfoxide (DMSO, Sigma Aldrich, Germany). To total polyphenolic content determination the Folin--Ciocalteu reagent (Sigma Aldrich, Germany) and 20% sodium carbonate solution (POCH, Poland) were used. The obtained results were compared to the gallic acid (GA, Sigma Aldrich, Germany), which was used to prepare a calibration curve.

1.2. Methods

1.2.1. Preparation of plant material for extraction

Before starting the extraction process, frozen sea buckthorn fruit was freeze-dried to evaporate water bound to the plant material. Freeze-drying was performed using a CHRIST ALPHA 1-2 LO freeze-dryer under reduced pressure at –70°C. Then, the freeze-dried fruit was crushed using a laboratory mill A11 basic (IKA Poland Sp. z o. o.). The prepared material was placed in sterile containers and stored at –20°C.

1.2.2. Ultrasonic bath extraction

The extraction process in an Elmasonic P ultrasonic bath was carried out based on the modified methodology described by Hossain et al. [2012]. First, 10 g of mechanically crushed sea buckthorn fruit was weighed into glass flasks with a capacity of 200 cm^3 and poured with 50 cm^3 of methanol or hexane, depending on the extract variant. Then, the prepared samples were subjected to extraction in an ultrasonic bath, performing three cycles of 15 minutes each, at a frequency of 50 kHz and a temperature of 35°C. After each cycle, another portion of the solvent in a volume of 50 cm^3 was added to the flasks, reaching at the end 150 cm^3 of the extraction mixture. After extraction, all samples were filtered on Büchner funnel, using increased pressure to accelerate filtration.

1.2.3. Soxhlet extraction

The Soxhlet extraction was carried out according to the methodology described by Karami et al. [2015] with some modifications. 10 g of mechanically crushed freeze-dried sea buckthorn fruit were weighed into extraction thimbles and then placed in the Soxhlet apparatus. The apparatus was connected to a reflux condenser and a round-bottomed flask containing 250 cm^3 of the selected solvent – methanol or hexane. The flask was placed in a water bath to brought solvents to boiling temperature: methanol to 64.7°C and hexane to 68.7°C, which ensured the correct extraction process. The extraction was carried out for 4 hours, assuming that the extraction mixture had completely flowed from the Soxhlet apparatus to the round-bottomed flask at least once. After extraction, all samples were filtered on Büchner funnel, using increased pressure to accelerate filtration.

1.2.4. Preparation of final extracts

After filtration, the extracts were transferred to previously weighed round--bottom flasks, and then the extraction solvent was evaporated using a Buechi Rotavapor R-114 rotary evaporator. After evaporation, the flasks with the extract residue were cooled and re-weighed, which allowed for determining the mass of the extracts obtained. On this basis, the appropriate amount of solvent was calculated, necessary to prepare solutions with a concentration of 64 mg/ml. In the case of hexane extracts, in which the extract could not be fully dissolved at a concentration of 64 mg/ml, the concentration was reduced to 32 mg/ml to ensure the homogeneity of the solutions. The extracts were dissolved in dimethyl sulfoxide (DMSO) or methanol, depending on the extract variant.

1.2.5. Determination of fungistatic activity of extracts

The fungistatic activity of sea buckthorn fruit extracts against indicator filamentous fungi was assessed by serial dilution on 96-well titration plates, according to the procedure described by Gwiazdowska et al. [2022]. In the first stage, a series of two-fold dilutions of extracts were prepared in PDB (Potato Dextrose Broth, BioMaxima, Poland) medium in a volume ratio of 80:80 µl. Then, 80 µl of inoculum was added to the prepared wells, which was prepared from mature cultures of selected *Fusarium* species by suspending hyphae and spores in PDB medium. The density of the suspension was determined hemocytometrically using a Thoma chamber. Then, the titration plates were incubated for 7 days at 23–25°C. Fungistatic activity was analysed for extract concentrations ranging from 16 to 1 mg/ml. Pure PDB medium and solvents (methanol and DMSO) at concentrations from 50/25 to 6.25% were used as controls. After incubation, 100 µl of suspension was taken from each well and plated on PDA medium in Petri dishes. The plates were incubated for another 7 days at 23–25°C. Based on the visual assessment of fungal growth compared to the control samples, the fungistatic activity of the extract concentrations tested was determined, as well as the minimum inhibitory concentration (MIC) and the minimum fungicidal concentration (MFC).

1.2.6. Determination of total polyphenolic content

The total polyphenolic content (TPC) of the tested sea buckthorn extracts was tested based on the methodology described by Szutowska et al. [2020].

Before starting the tests, 1 cm^3 of each tested extracts were added to Eppendorf tubes and centrifuged in an Eppendorf MiniSpin® Plus centrifuge (5 min., 8000 rpm). After centrifugation 10 µl of the centrifuged samples were applied to a 48-well titration plate. Then, to each well 50 µl of Folin-Ciocalteu reagent was added and left for 3 minutes in the dark place. Next, each well was supplemented with 150 µl of freshly prepared 20% sodium carbonate solution as well as 790 µl of distilled water and left for 2 hours in the dark place. The absorbance measurement was performed using an EPOCH2 microplate reader (BioTek) at a wavelength of 765 nm. The results were related to a previously prepared standard curve for gallic acid, and the TPC in the tested extracts was expressed as mg of gallic acid per 1 gram of extract (mg GAE/g E).

1.2.7. Statistical analysis

The results of the total polyphenolic compounds were presented as arithmetic means with standard deviation, calculated based on six parallel repetitions. To determine significant differences between the obtained data, one-way analysis of variance (ANOVA) was performed using Tukey's test at a significance level of $p < 0.05$. Calculations and statistical analyses were performed using Microsoft Excel® and IBM SPSS Statistic 29 (PS IMAGO PRO 10.0).

2. RESULTS

2.1. Description of the obtained sea buckthorn fruit extracts

The extracts prepared for the study differed both in the extraction method and the used solvents. A total of eight extract variants were obtained, four of which were prepared by extraction in an ultrasonic bath (designated as UHM, UHD, UMM, UMD), and another four using a Soxhlet apparatus (designated as SHM, SHD, SMM, SMD). Hexane and methanol (MeOH) were used as extraction solvents, while the solvent used to prepare the final solutions was methanol or dimethyl sulfoxide (DMSO). The complete list of extracts is presented in Table 1.

Table 1. Summary and description of the obtained from sea buckthorn fruit extracts

Extract code	Extraction solvent	Dissolve solvent	Final extract concentration [mg/ml]
Ultrasonic bath extraction			
UHM	Hexane	MeOH	32
UHD	Hexane	DMSO	32
UMM	MeOH	MeOH	64
UMD	MeOH	DMSO	64
Soxhlet extraction			
SHM	Hexane	MeOH	32
SHD	Hexane	DMSO	32
SMM	MeOH	MeOH	64
SMD	MeOH	DMSO	64

Source: own study.

2.2. Total phenolic content in the tested extracts from sea buckthorn fruit

The performed analyses indicated that the tested sea buckthorn fruit extracts exhibit potential in terms of fungistatic activity against selected *Fusarium* fungi, but their effectiveness depended mainly on the type of indicator microorganisms as well as on the variant of the tested extract. The highest sensitivity to the effects of the tested extracts was demonstrated by *F. graminearum*, while the least sensitive were *F. culmorum* and *F. poae*. The serial dilution method used to determine fungistatic activity allowed for determining the minimum inhibitory concentration (MIC) and minimal fungicidal concentration (MFC) of the tested sea buckthorn fruit extracts against selected *Fusarium* fungi. Determining the MIC and MFC values turned out to be crucial in determining the antagonistic activity of the tested extracts due to the strong effect of the solvents themselves on the growth of fungi. The results of the experiments are presented in Table 2 and partial in Figures 1–2.

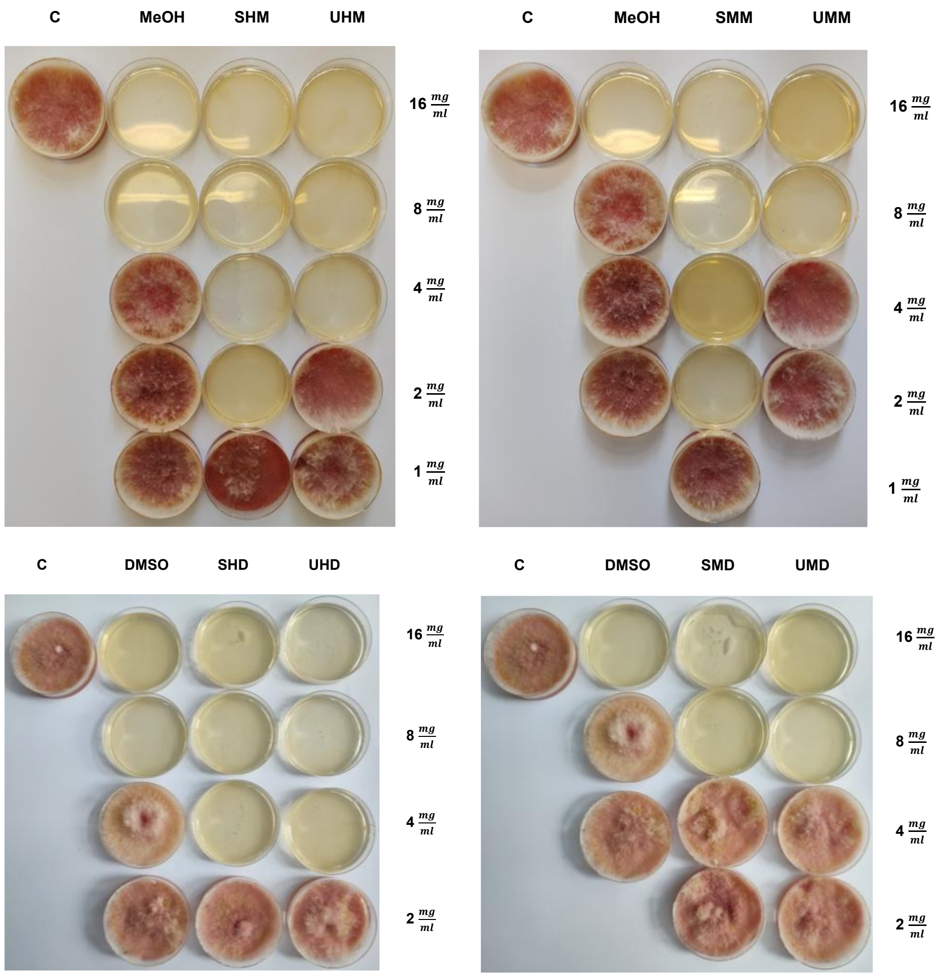
Table 2. Minimum inhibitory concentration (MIC) minimum fungicidal concentration (MFC) of sea buckthorn fruit extracts against selected *Fusarium* fungi

Tested extract*	MIC/MFC [mg/ml]			
	F. oxysporum	*F. poae*	*F. graminearum*	*F. culmorum*
UHD	>16	>16	4	>16
SHD	>16	>16	4	>16
UMD	>16	>16	8	>16
SMD	>16	>16	8	>16
UHM	>16	>16	4	>16
SHM	>16	>16	2	>16
UMM	4	4	8	8
SMM	4	>16	2	8

* UHD – hexane extract from ultrasonic bath, soluble in DMSO; SHD – hexane extract from Soxhlet apparatus, soluble in DMSO; UMD – methanol extract from ultrasonic bath, soluble in DMSO; SMD – methanol extract from Soxhlet apparatus, soluble in DMSO; UHM – hexane extract from ultrasonic bath, soluble in MeOH; SHM – hexane extract from Soxhlet apparatus, soluble in MeOH; UMM – methanol extract from ultrasonic bath, soluble in MeOH; SMM – methanol extract from Soxhlet apparatus, soluble in MeOH.

Source: own study.

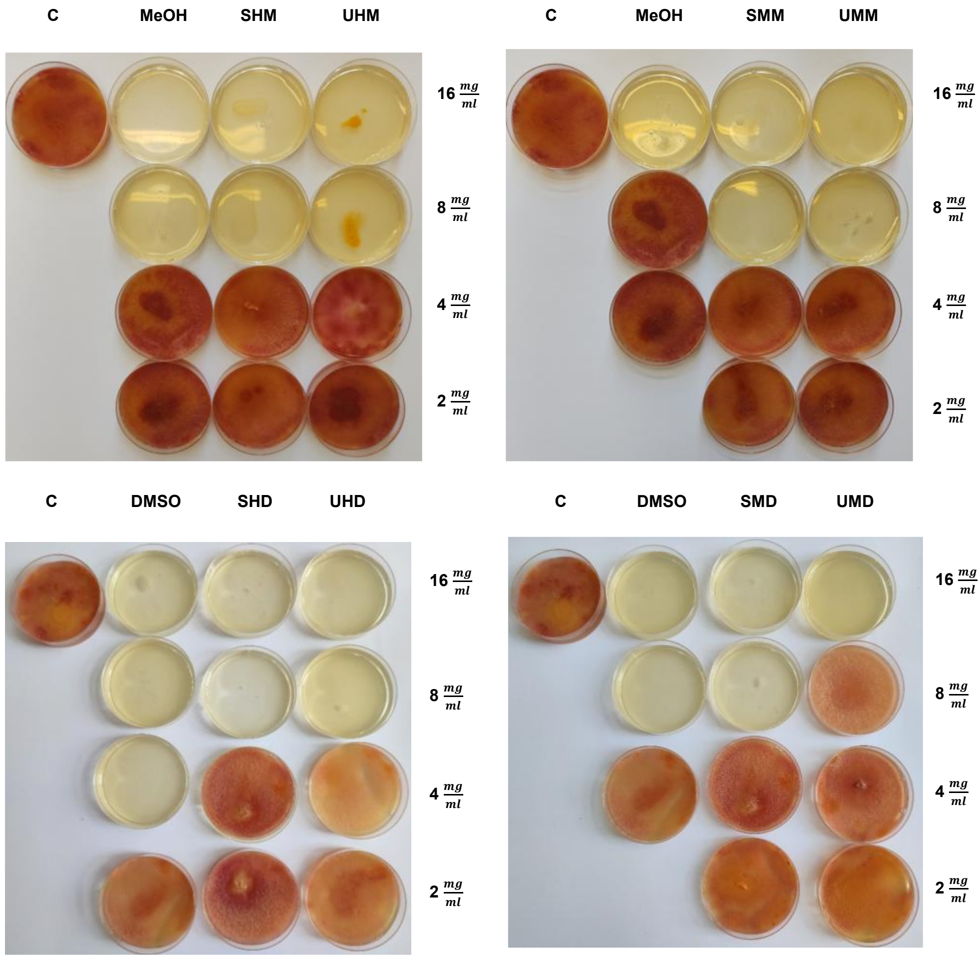
Analysing the obtained results, it can be observed that for most of the tested extracts, it was not possible to determine the MIC/MFC value in the tested concentration range. Only for *F. graminearum*, for all extract variants, MIC/MFC values were determined, in the concentration ranged 2–8 mg/ml, depending on the extract. The variants extracted and dissolved in methanol were definitely the most effective, regardless of the used extraction method. In the case of the extract obtained in an ultrasonic bath (UMM), it was possible to determine the MIC/MFC value for all selected *Fusarium* fungi at the concentration of 4 and 8 mg/ml, respectively for *F. oxysporum* and *F. poae* and *F. graminearum* and *F. culmorum*. In turn, for the extract obtained in the Soxhlet apparatus (SMM), the MIC/MFC values were 4 mg/ml for *F. oxysporum*, 8 mg/ml for *F. culmorum* and 2 mg/ml for *F. graminearum*, whereas for *F. poae* the MIC/MFC value could not be determined for this variant of extract. The results obtained for *F. graminearum* allowed for a preliminary analysis of the effect of the extraction conditions fungistatic activity of the obtaining extracts. In this case, based on the MIC/MFC values, it can be observed that for extracts dissolved in DMSO, hexane extracts obtained both in the Soxhlet apparatus and in an ultrasonic bath were more effective. In the case of extracts dissolved in methanol, the extraction method in the Soxhlet apparatus allowed for obtaining extracts with higher antagonistic efficacy against *F. graminearum*. However, that for full conclusions in the context of the effect of extraction conditions on the antifungal properties of the tested solutions, further analyses should be performed.



* C – control; UHD – hexane extract from ultrasonic bath, soluble in DMSO; SHD – hexane extract from Soxhlet apparatus, soluble in DMSO; UMD – methanol extract from ultrasonic bath, soluble in DMSO; SMD – methanol extract from Soxhlet apparatus, soluble in DMSO; UHM – hexane extract from ultrasonic bath, soluble in MeOH; SHM – hexane extract from Soxhlet apparatus, soluble in MeOH; UMM – methanol extract from ultrasonic bath, soluble in MeOH; SMM – methanol extract from Soxhlet apparatus, soluble in MeOH.

Figure 1. Fungistatic activity of sea buckthorn fruit extracts against *F. graminearum*

Source: own study.



* C – control; UHD – hexane extract from ultrasonic bath, soluble in DMSO; SHD – hexane extract from Soxhlet apparatus, soluble in DMSO; UMD – methanol extract from ultrasonic bath, soluble in DMSO; SMD – methanol extract from Soxhlet apparatus, soluble in DMSO; UHM – hexane extract from ultrasonic bath, soluble in MeOH; SHM – hexane extract from Soxhlet apparatus, soluble in MeOH; UMM – methanol extract from ultrasonic bath, soluble in MeOH; SMM – methanol extract from Soxhlet apparatus, soluble in MeOH.

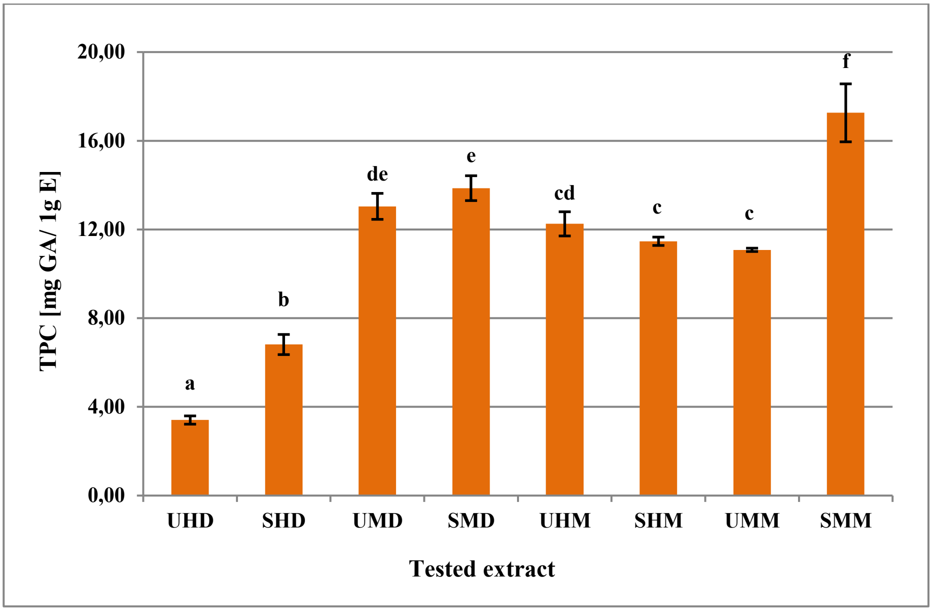
Figure 2. Fungistatic activity of sea buckthorn fruit extracts against *F. culmorum*

Source: own study.

2.3. Total phenolic content in the tested extracts from sea buckthorn fruit

The determination of the total content of polyphenolic compounds (TPC) in the tested extracts was carried out based on the Folin-Ciocalteu reagent method. The experiment was aimed at a preliminary, demonstrative analysis of bioactive components in the prepared extracts. Based on the obtained results, it can be stated that the tested sea buckthorn fruit extracts contained low or moderate amounts of phenolic compounds. The lowest TPC content was noted for hexane extracts dissolved in DMSO: 3.35 and 6.69 mg GA/g extract, respectively, for UHD and SHD extracts, while the highest TPC content was noted for the SMM extract (17.26 mg GA/g extract). In the remaining extracts the total number of phenolic compounds ranged from 11.08 to 13.68 mg GA/g extract. The effect of the conditions of obtaining extracts on TPC values can be observed only within the variants dissolved in each solvent (DMSO or MeOH). In the case of extracts dissolved in DMSO, a significantly higher content of phenolic compounds was noted in methanol extracts compared to hexane extracts. For hexane extracts, a significant difference was also observed depending on the used extraction method (higher TPC value in the extract obtained in the Soxhlet apparatus). In the case of extracts dissolved in methanol, the significantly highest TPC value was noted for the extract obtained in the Soxhlet apparatus (SMM), while the remaining variants were characterized by the content of polyphenolic compounds at a statistically similar level.

Comparing the results obtained in this experiment to the results of fungistatic activity, it can be stated that the content of phenolic compounds has a small effect on the antifungal activity of the tested extracts. It is therefore highly probable that another group of compounds is responsible for the antagonistic activity of the tested sea buckthorn fruit extracts against selected *Fusarium* fungi, although full conclusions would require an extended analysis of the extract composition.



* UHD – hexane extract from ultrasonic bath, soluble in DMSO; SHD – hexane extract from Soxhlet apparatus, soluble in DMSO; UMD – methanol extract from ultrasonic bath, soluble in DMSO; SMD – methanol extract from Soxhlet apparatus, soluble in DMSO; UHM – hexane extract from ultrasonic bath, soluble in MeOH; SHM – hexane extract from Soxhlet apparatus, soluble in MeOH; UMM – methanol extract from ultrasonic bath, soluble in MeOH; SMM – methanol extract from Soxhlet apparatus, soluble in MeOH.

Figure 3. Total phenolic content (TPC) in the tested sea buckthorn fruit extracts

Source: own study.

3. DISCUSSION

In this study, the fungistatic activity of eight variants of sea buckthorn fruit extracts against selected species of *Fusarium* filamentous fungi (*F. oxysporum*, *F. poae*, *F. graminearum* and *F. culmorum*) as well as the total content of polyphenolic compounds (TPC) was assessed. The results of the conducted studies indicate that the effectiveness of the extracts against the indicator fungi was diverse and depended mainly on the fungal species, type of solvent or extraction method. The highest fungistatic activity was noted for extracts where methanol was used for extraction and dissolution of the extracts (UMM and SMM). For these variants, MIC/MFC values in the range of 2-8 mg/ml were determined for all used filamentous fungi. In the case of the remaining variants of the tested extracts, no antagonistic effect was observed in the tested concentration range (MIC/MFC >16 mg/ml) against most of the selected indicator microorganisms. The exception was *F. graminearum*, which exhibit sensitivity to all tested extracts. On the other hand, the greatest resistance to the tested extracts was characteristic for *F. culmorum* and *F. poae*. This effect resulted mainly from the strong inhibitory effect of the solvents (MeOH and DMSO) on the growth of indicator microorganisms.

It is worth mentioning that the search for new methods of control phytopathogens is in line with current trends related to sustainable agriculture, which is also reflected in numerous scientific studies in this area. For example, Hara, Szparaga and Czerwińska [2018] demonstrated the fungistatic effect of peppermint oils (*Menthapiperita* L.) against the fungi *F. oxysporum*, *F. poae*, *F. culmorum*, *F. graminearum*, and *F. solani*. In another experiment, essential oils obtained from hop cones (*Humulus lupus* L.) were tested, but they showed moderate effectiveness in inhibiting the development and growth of *F. oxysporum* and *F. culmorum*. In contrast to hop cone oil, ETJA thyme oil completely inhibited the growth both above-mentioned species of filamentous fungi, even at the lowest tested concentration (0.25%), which indicates its high effectiveness and potential in controlling fungal pests [Rył 2023]. The fungistatic effectiveness of plant extracts was also described by Małkusz et al. [2022]. In their work, the authors determined the efficacy of *F. oxysporum* growth inhibition for extracts from four plants of the *Apiaceae* family – cumin, caraway, fennel, and anise. Anise and cumin extract completely inhibited the growth of the fungus at each tested concentration (0.5%, 1.0%, 1.5%, and 2.0%), while fennel and caraway extracts were effective in the concentration range of 1.0-2.0%. The different efficacy of these preparations depended on the different chemical composition of individual plants [Małkusz et al. 2022]. Currently, in the scope of research on the fungistatic activity of plant substances, a trend can be observed towards the effectiveness of extracts obtained using methods with low impact on the natural environment. One example may be extracts obtained by extraction in supercritical CO_2 (including oregano or *Glechoma hederacea*), which exhibit the potential to inhibit the growth of fungi of the genus *Fusarium* [Gwiazdowska et al. 2022 and 2024b]. In the literature, the antimicrobial properties of substances obtained from sea buckthorn are also described. Extracts from various parts of sea buckthorn are characterized by antifungal properties against both yeasts such as *Pichia jadini* and *Candida albicans* [Jeong et al. 2010] and filamentous fungi including *Penicillium*, *Aspergillus*, *Fusarium* or *Botrytis*

[Popescu et al. 2022]. The antimicrobial effect of sea buckthorn is primarily due to the presence of numerous bioactive compounds contained in this plant, in particular polyphenolic compounds [Uośko & Biel 2017]. These are some of the most biologically active compounds in sea buckthorn fruits and leaves, and their content ranges from 120 to 550 mg per 100 g of fruit. The most common phenolic compounds identified in sea buckthorn fruit include gallic acid, rutin, quercetin, and kaempferol. Sea buckthorn fruit is also a rich source of vitamins such as C, E, K, and D, as well as vitamins from the group B [Ulanowska et al. 2018]. Vitamin C is by far the most abundant, with a content ranging from 87.45 to 2500 mg/100 g, depending on the country of origin and assay method. Furthermore, other biologically active compounds are also found in sea buckthorn fruit, including organic acids, essential oils, carotenoids, and phytosterols [Piłat & Zadernowski 2016]. In the sea buckthorn fruit extracts tested in this study, the content of phenolic compounds, depending on the variant, ranged from 3.35 to 17.26 mg GAE/g of extract. However, it should be noted that for a full characterization of the polyphenolic compound profile in the tested extracts, further analyses should be performed using more accurate analytical methods.

CONCLUSIONS

The conducted studies indicated that the two variants of sea buckthorn fruit extracts (SMM and UMM) exhibit potential in the context of their use in biological plant protection against fungi of the genus *Fusarium*. It was also confirmed that both the extraction method and solvent can affect on biological activity of exanimated extracts. The observations indicate that the tested extracts may constitute an interesting alternative to chemical plant protection products, which is in line with contemporary trends in sustainable agriculture. For full conclusion it is necessary to conduct further research into the fungistatic activity of sea buckthorn fruit extracts, including optimizing the extraction process and conducting studies in greenhouse or field conditions. However, it would be necessary to replace methanol with another, non-toxic solvent (e.g., ethanol) in the field studies.

ACKNOWLEDGEMENTS

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TOWARDS CIRCULAR CRAFT BREWING: INTEGRATIVE STRATEGIES FOR WASTE MANAGEMENT, ENERGY EFFICIENCY, AND SUSTAINABLE PACKAGING

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Abstract

This review presents circular economy (CE) strategies used in craft brewing. A special focus was placed on waste management, energy efficiency, and sustainable packaging. Waste valorization options, such as biochar production, biorefineries, and compound extraction, offer environmental benefits but face economic and technical barriers. Heat recovery, combined heat and power systems and renewables reduce emissions but are often costly for small breweries. Sustainable packaging shows potential but is limited by supply chain and consumer factors. Circular economy goals can be achieved in craft breweries; however, there are required integrated approaches, regional collaboration, and supportive policies to enhance sustainability and competitiveness in this sector.

Keywords: circular economy, craft breweries, waste valorization, sustainable packaging, industrial symbiosis.

INTRODUCTION

The global craft brewing sector has experienced remarkable growth over the past two decades. Small breweries have become an important part of local economies and cultural identities. They not only contribute to employment and regional development but also influence consumer preferences through innovation, quality, and authenticity. However, as this industry expands, more attention is paid to environmental impact, particularly concerning energy consumption, waste generation, and packaging practices. Craft breweries often operate with lower efficiency due to their smaller scale and limited resources, which can exacerbate sustainability challenges compared to large-scale industrial breweries.

One of the most significant environmental issues in brewing is the volume of waste generated during production stages. Brewers' spent grains (BSG), spent hops, yeast, and processed wastewater comprise most waste streams [Purchase 2023; Sperandio et al. 2017]. Managing these by-products is especially difficult in rural areas, where infrastructure for recycling and reuse is limited and logistics often increase operational costs.

Energy use represents a second primary concern. Beer brewing, wort boiling, and mashing require precise temperature control during fermentation and maturation, are very energy-intensive, increasing both greenhouse gas emissions and production costs [Dai et al. 2023; Salazar Tijerino et al. 2023].

Packaging choices further add to the sector's environmental footprint. Although glass bottles and aluminium cans continue to dominate the market, the environmental costs associated with producing and transporting these packages have led to growing interest in alternative solutions, such as reusable drums, recycled PET, and biodegradable secondary packaging [Norris et al. 2024; Wojnarowska et al. 2025]. However, implementing these solutions is often impeded by economic constraints, logistics, and consumer factors.

In this context, a closed-loop economy (CE) framework offers a practical and integrated approach to reducing the environmental impact of craft brewing. Through its focus on resource efficiency, waste valorization, and closed-loop systems, CE can support small breweries in fulfilling environmental obligations [Cimini & Moresi 2021; Rawalgaonkar et al. 2023]. Large breweries have already implemented CE solutions, such as anaerobic digestion or glass recovery systems. How these principles can be adapted and introduced into small and medium-sized breweries remains insufficiently explored.

Developing closed-loop systems and CE practices drives craft breweries to reduce environmental pressures and generate new value streams [Cimini & Moresi 2021; Rawalgaonkar et al. 2023]. While some large-scale breweries have adopted CE principles through solutions such as anaerobic digestion or glass recovery schemes, much less is known about how these approaches can be adapted to the specific conditions of small and medium-sized craft breweries.

Although the literature on sustainability in brewing is expanding, most studies focus on specific themes, such as energy consumption, waste recovery, or packaging. Analyses that consider the interaction between these dimensions remain scarce. Furthermore, the feasibility, scalability, and potential of technologies such as biorefineries, heat recovery systems, smart manufacturing, and their synergies in the craft segment are still insufficiently examined.

Our study addresses that gap by offering a comprehensive review of circular economy strategies in craft brewing. It focuses on three key domains: waste management, energy consumption, and packaging. This paper aims to (1) identify main sustainability challenges faced by craft breweries, (2) assess the practical relevance and effectiveness of both established and emerging CE practices, and (3) propose recommendations for stakeholders seeking to improve environmental performance in this growing sector.

1. MATERIALS AND METHODS

We applied a traditional (narrative) review method and structured it into four phases: design, execution, analysis, and writing [Snyder, 2019; Templier & Paré 2015]. We have based our research on peer-reviewed literature from Scopus and Web of Science, publications from 2000 to 2025 to capture early developments and recent advances in circular economy and sustainability in brewing. We used selected book chapters, conference papers, and review articles identified through snowballing as an additional source.

2. RESULTS

2.1. Waste management in craft breweries

Craft breweries generate significant amounts of waste, with environmental and economic impacts. The main waste streams are solid residues, i.e., brewer's spent grains (BSG) (about 85%), spent hops and yeast, liquid residues, i.e., process wastewater, and gaseous residues, i.e., carbon dioxide released during fermentation

[Purchase 2023; Sperandio et al. 2017]. Traditionally, BSG has been used as a fodder, a cost-effective and low-cost reuse pathway [Cimini & Moresi 2021]. However, due to limitations, such as a lack of animals or long distances, alternative uses of BSG need to be identified [Cuenca-Nevárez et al. 2025].

An increasingly popular solution is the conversion of BSG into biocarbon through a pyro-gasification process. This process will reduce the carbon footprint of BSG after disposal, and the carbon footprint of BSG after disposal will be reduced from about 3.0 to 1.18 kg CO_2e per kilogram of grain consumed [Newman et al. 2025]. The resulting biocarbon can be used as a soil amendment, contributing to long-term carbon sequestration.

Another promising strategy is to develop biorefineries that convert BSG into specialty flour. Colpo et al. [2022a] demonstrated that such facilities can achieve economic and financial viability under favorable market conditions and foster industrial symbiosis by linking breweries with the food sector.

Although spent hops and yeast represent smaller waste streams, they contain high-value compounds. Obtained polyphenols, essential oils, and acids in microwave-assisted extraction and supercritical fluid processing can be used in functional foods, nutraceuticals, cosmetics, and pharmaceuticals [Silva et al. 2023]. However, craft breweries have limited possibilities to implement such technologies, because of the high capital and operating costs involved

As for liquid waste, particularly process wastewater generated during cleaning operations, e.g., rinsing fermentation tanks, storage vessels, and packaging lines [Purchase 2023; Sperandio et al. 2017], its variable composition and high organic load require adequate treatment before discharge, especially in breweries located outside of municipal sewage networks.

Wastewater in large breweries is anaerobically digested (AD) with recovered biogas [Rawalgaonkar et al. 2023]. Although the AD process is effective, only breweries that produce more than 50,000 barrels per year can afford it, which makes it impractical for most craft breweries. Combining trickling filters with constructed wetlands is a proposed solution for small-scale systems. For instance, Dąbrowski and Karolinczak [2019] proved that such hybrid installations can significantly reduce chemical oxygen demand and total suspended solids to the level that allows for fulfilling environmental discharge standards.

Apart from end-of-pipe solutions, reducing waste generation at its source by implementing process optimization and lean manufacturing tools, such as Standard

Work, 5S, Poka Yoke, and Systematic Layout Planning, might also improve breweries' sustainability. Flores-Perez et al. [2023] reported that using lean practices in a Peruvian craft brewery, it was possible to reduce beer losses from 5,029 to 2,370 liters and increase overall process efficiency from 76.14% to 82.17%. These strategies require low investment and can deliver measurable benefits quickly.

Despite promising solutions, such as biochar production or advanced wastewater treatment, they typically require substantial upfront investment, which often exceeds the financial capabilities of small-scale operations [Colpo et al. 2022a]. In addition, regional disparities further constrain adoption. Breweries located in areas without agricultural demand for BSG or lacking industrial composting facilities have fewer viable circular options [Cuenca-Nevárez et al. 2025].

Knowledge and culture-related factors also play a role. Colpo et al. [2022b] and Rawalgaonkar et al. [2023] noted that small breweries are unfamiliar with valorization beyond traditional uses as a fodder. Adherence to established practices may sometimes discourage experimentation with more innovative or circular approaches.

Nevertheless, several strategies illustrate how circular economy principles can be meaningfully applied to brewery waste streams. From a CE perspective, the most effective solutions are those that close material loops and generate additional value from by-products such as special flour, convert organic residues into biochar, or form local partnerships with farms and food manufacturers. Extracting high-value compounds from spent hops and yeast allies with CE goals is rare in the craft segment due to cost and scale limitations.

2.2. Energy management in craft breweries

Energy consumption is a key operational and environmental issue in craft brewing. Small breweries are less energy efficient than large ones due to limited infrastructure and lack of economies of scale [Salazar Tijerino et al., 2023]. The most energy-intensive processes in breweries include: wort boiling, mashing, fermentation, maturation, and cleaning.

Wort boiling requires a significant heat input (up to 30% of a brewery's total energy consumption [Schreiber et al. 2012]) for evaporation, sterilization, and removal of volatile compounds such as dimethyl sulfide [Dai et al. 2023]. To reduce this burden, low-temperature stress cooking and rotating cone evaporators can be used [Dai et al. 2023].

Mashing also requires a significant amount of energy, mainly to heat water and maintain stable temperatures that promote the enzymatic conversion of starch [Tschoeke et al. 2019]. Fermentation and ripening still require significant energy for cooling. Stable temperatures ensure product quality, especially in warmer climates, when cooling is needed [Salazar Tijerino et al. 2023].

Several technologies have been explored to improve energy performance in craft brewing. Combined heat and power (CHP) systems generate electricity and usable heat from a single fuel source, and they can effectively reduce energy costs and emissions [Dai et al. 2023]. However, this solution needs a high capital investment, which is limited in small-scale operations.

Heat recovery, particularly in capturing thermal energy from wort boiling and redirecting it to preheat water or support cleaning processes, is another strategy to be considered. These systems can reduce brewhouse energy use by around 5% and contribute to lower CO_2 emissions [Raffa et al. 2022].

Renewable energy options, especially photovoltaic (PV) systems with battery storage, might be installed in breweries to decrease reliance on grid electricity. Under favorable conditions, dual-tracking PV setups can reduce daily operational costs by more than half [Kusakana 2021]. Nonetheless, challenges remain, including variable energy supply and substantial initial installation costs [Conduah et al. 2019].

Predictive modeling and smart manufacturing, such as artificial neural networks [Conduah et al., 2025], in breweries can be used to optimize load management, identify bottlenecks, improve process control, and save energy [Nimbalkar et al. 2020].

2.3. Sustainable packaging in craft breweries

Packaging significantly influences the environmental performance of craft breweries, contributing to resource use, greenhouse gas emissions, and post--consumer waste. Still, glass bottles and aluminum cans dominate the sector, but increasing environmental awareness and tightening regulatory frameworks have triggered interest in more sustainable alternatives.

Assessing the environmental impact of conventional packaging is a necessary starting point. Glass bottles, while often perceived as premium by consumers, require substantial energy to produce and generate high transport-related emissions, mainly when distributed over long distances [Wojnarowska et al. 2025]. Glass is theoretically recyclable. However, the environmental benefit depends on the proportion of recycled cullet used and the collection and reuse system. Similarly, aluminum cans are lighter and more easily recyclable than glass bottles, but their production is energy-intensive [Cimini & Moresi, 2021].

Transport further increases the environmental burden of packaging. Wojnarowska et al. [2025] showed that shortening transport distances in glass bottle reuse schemes can significantly improve environmental outcomes, underlining the role of regional supply chains in packaging sustainability.

Several alternative solutions have been developed to reduce impacts and align with CE principles. Stainless steel kegs offer one of the most efficient options, combining long service life with high reuse potential. Compared to single-use glass bottles, they significantly lower emissions and energy use per beer unit [Cimini & Moresi 2021]. However, their use is mainly confined to on-premises sales, since large-scale collection and cleaning remain logistically challenging for off-site distribution.

Recycled PET is also gaining attention as a circular alternative to virgin plastic. When managed to produce food-grade flakes, PET packaging can reduce environmental impact and avoid downcycling [Cimini & Moresi, 2021]. Nevertheless, broader adoption is still limited by issues related to consumer perception, material performance, and regulatory standards.

Craft breweries have experimented with biodegradable secondary packaging, including compostable holders for can multipacks. Such solutions have improved consumer perceptions of brand sustainability [Norris et al. 2024]. Bioplastics, like polylactic acid or starch-based composites, have also been tested, although their environmental benefits depend heavily on the availability of industrial composting infrastructure [Michaliszyn-Gabryś et al. 2022].

Despite their potential, the uptake of packaging innovations is shaped by economic constraints, supply chain limitations, and consumer acceptance. Among alternatives, glue-pack holders and keel clip systems are proposed solutions that reduce plastic use in multipacks. These designs lower material input and improve recyclability compared to conventional Pak-Tech holders, strengthening sustainability messaging [Norris et al. 2024].

Despite promising technological solutions, craft breweries encounter several barriers to integrating sustainable packaging (Table 1).

Table 1. Barriers to integrating sustainable packaging in craft breweries and recommended actions to overcome them

Barrier	Action
Economic feasibility	Facilitate access to targeted financial support for small and medium-sized breweries through grants, preferential loans, or tax relief mechanisms. Support should focus on investments in packaging line adaptation and material procurement to reduce the entry barrier to circular packaging solutions
Supply chain limitations:	Support the development of regional supply chains for circular packaging materials by fostering partnerships between breweries, material suppliers, and recycling or composting facilities. Public procurement policies and local incentives can help stimulate demand and stabilize prices for recycled and compostable inputs
Consumer acceptance	Develop communication strategies that emphasize circular packaging formats' environmental performance and safety without compromising perceived product quality. Messaging should be supported by visual cues, third-party certifications, and alignment with brand identity to build consumer trust and acceptance
Infrastructure dependencies	Expand local waste management infrastructure to include industrial composting or anaerobic digestion facilities capable of processing biodegradable packaging. Regional planning should align infrastructure development with packaging innovation to ensure environmental benefits are fully realized

Source: own study.

Despite existing barriers, packaging remains a critical area where CE principles can be effectively implemented to enhance sustainability. The packaging domain offers substantial potential for alignment with circular economy principles through:

- Using recycled content, designing for reuse, and selecting materials compatible with local recycling or composting systems (material circularity).
- Minimizing packaging material volume and weight while maintaining functionality and product protection (design for environment).
- Developing regional reuse schemes (e.g., bottle deposit and return systems), facilitating closed-loop packaging cycles (collaborative systems).

Emerging practices, such as the integration of packaging choices into territorial marketing strategies, further illustrate how circular packaging can support brand differentiation and local economic resilience [García-Chamizo et al. 2025].

The analysis shows that waste management, energy use, and packaging are linked areas where circular synergies can be realized. For example, using brewer's spent grains to produce pellets or biochar contributes to waste reduction and energy recovery [Newman et al. 2025; Sperandio et al. 2017]. Likewise, anaerobic digestion of wastewater and organic residues supports waste treatment and generate renewable energy [Rawalgaonkar et al. 2023]. Despite this potential, such integrated approaches remain rare in small and medium-sized craft breweries due to high investment costs and technical complexity [Colpo et al. 2022c].

Packaging choices can also affect other environmental outcomes. Reducing material use or improving recyclability lowers packaging-related impacts and can indirectly reduce energy use in distribution [Wojnarowska et al. 2025].

Economic feasibility emerges as a dominant barrier across all domains. Many of the most promising technologies for waste valorization (e.g., biorefineries, compound extraction), energy management (e.g., combined heat and power systems, photovoltaic arrays with storage), and packaging (e.g., biodegradable materials, regional bottle return schemes) involve substantial upfront investment [Cimini & Moresi 2021; Raffa et al. 2022]. For small breweries operating with narrow margins, these costs can be unaffordable without external support.

Limited technical capacity and infrastructure persist as key barriers to implementing CE solutions. Advanced systems such as anaerobic digestion, heat recovery, or sustainable packaging often require expert knowledge, dedicated equipment, and access to supporting infrastructure [Dąbrowski & Karolinczak 2019; Michaliszyn-Gabryś et al. 2022].

Small breweries rely on established practices and are often unaware of newer valorization strategies [Colpo et al. 2022b; Rawalgaonkar et al. 2023]. In addition, consumer preferences, such as a strong association of beer with glass bottles, can discourage the use of more sustainable but less familiar packaging formats [Norris et al. 2024].

Despite these barriers, several factors provide a foundation for advancing CE practices in craft brewing:

- There is growing interest among consumers in products with authentic environmental credentials. Breweries that successfully integrate CE practices into their brand narrative can enhance market differentiation and loyalty [García--Chamizo et al. 2025].

- Industrial symbiosis, where breweries partner with local farms, food producers, or other industries to share resources and by-products, offers a practical route to circularity without requiring individual breweries to internalize all functions [Purchase 2023; Rechsteiner et al. 2025].
- Regulatory frameworks and financial incentives can help overcome economic barriers. Examples include subsidies for renewable energy installations, grants for process innovation, and extended producer responsibility schemes that promote circular packaging systems [Cimini & Moresi 2021].
- While large-scale technologies may be out of reach, lean manufacturing techniques, simple heat recovery loops, and process scheduling to align with off-peak energy tariffs represent accessible strategies with meaningful impacts [Flores-Perez et al. 2023].

These findings are consistent with previous research showing uneven adoption of circular economy practices in the brewing sector [Mainardis et al. 2024]. Large breweries are generally better equipped to implement integrated solutions, benefiting from economies of scale and access to infrastructure, while smaller craft operations face more complex constraints [Rawalgaonkar et al. 2023].

At the same time, this review highlights untapped potential within the craft segment. Existing studies often address waste, energy, and packaging in isolation. In contrast, our analysis points to the value of integrated strategies, such as linking waste valorization with onsite energy recovery or aligning packaging with local reuse systems. A systems-based perspective is essential to fully realize the environmental and economic benefits of CE approaches.

Based on the synthesis of current practices and barriers, several recommendations emerge in Table 2.

Table 2. Practical implications and recommendations

Area	Description
Prioritize accessible circular solutions	Craft breweries can begin with low-cost interventions, such as lean manufacturing, simple heat recovery, and better insulation, before moving toward more capital-intensive technologies
Strengthen local collaborations	Partnering with farms, food producers, or regional recycling initiatives can enable circularity without requiring breweries to invest in all necessary infrastructure

cont. Table 2

Leverage sustainability as a brand asset	Clear communication about circular practices (e.g., use of biochar, regional packaging reuse) can enhance consumer engagement and willingness to pay
Advocate for supportive policy frameworks	The sector should work collectively to promote policies that facilitate CE adoption, such as incentives for renewable energy and infrastructure development for waste valorization and circular packaging

Source: own study.

CONCLUSIONS

This review demonstrates that circular economy strategies can offer viable responses to the environmental challenges facing the craft brewing sector, particularly in waste management, energy use, and packaging. Many small breweries are already implementing low-cost interventions, including lean manufacturing, simple heat recovery solutions, and the local reuse of spent grain. However, the integration of more advanced CE practices remains limited.

The results confirm that financial and infrastructure constraints are the most tenacious obstacles. Many potentially promising technologies require significant capital investments, access to sophisticated equipment and technical knowledge, which are often lacking at the local level. At the same time, specific consumer preferences and cultural habits continue to discourage the adoption of alternative packaging formats, even when these offer environmental benefits.

Despite these limitations, the sector shows potential for incremental progress. Regional collaboration, partnerships with farms or waste processors, and the strategic use of sustainability as a brand asset can help small breweries expand their circular practices without taking on the full burden of new infrastructure. Combining waste, energy, and packaging management activities, rather than considering them as separate challenges, has the potential to lead to more coherent and effective results.

Future research should go beyond the technical performance of CE solutions and examine the organizational, behavioral, and territorial conditions that shape their feasibility. Empirical case studies and integrative modeling approaches may offer valuable insights into how small breweries adopt and scale circular strategies. Such knowledge is essential for supporting a transition that is both environmentally effective and grounded in the operational realities of the craft brewing sector.

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THE EFFECT OF DIFFERENT COFFEA ARABICA SEED EXTRACTS ON THE FUNCTIONAL PROPERTIES OF SHOWER GELS

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Abstract

Coffea Arabica Seed Extract is a valued source of polyphenols and caffeine, which makes it an attractive ingredient in the technology of body care products. Phytochemicals contained in shower gels can improve their care properties and influence i.a., the surface properties of surfactants contained in the products. Therefore, the aim of the study was to assess the effect of Coffea Arabica Seed Extract on the functional properties of shower gels.

Model shower gels containing two different types of Coffea Arabica Seed Extracts as well as the shower gel containing no extract were prepared for the study and compared with two commercial shower gels. The performed analysis included measurements of surface tension, foaming properties, and solubility in water.

Keywords: shower gels, Coffea Arabica Seed Extract, quality, sustainability.

INTRODUCTION

Coffee plant (*Coffea Spp.*) is a shrub of continuous growth which belongs to the order Gentianale, family Rubiaceae. Among 126 species described in Coffea tribe the most important are Coffea arabica Linnaeus and Coffea canephora Pierre, which is known as Coffea robusta [Anthony et al. 2011; Lachenmeier et al. 2022]. Coffea arabica originates from Ethiopia and Mozambique, but nowadays is mainly cultivated in Colombia, Brazil, India, Costa Rica, Mexico and in the Middle East. On the other hand, Coffea robusta grown in the Ivory Coast, Zaire, Indonesia, and Angola [Matysek-Nawrocka & Cyrankiewicz 2016]. Generally, both species require a tropical climate, typical of intertropical areas, with an average rainfall of 1500–2000 mm per year. Coffee plants grow in areas located at an altitude of up to 2900 m above sea level. It is assumed that the quality of the harvest increases with the altitude of the plantation [Kwiatkowska-Sienkiewicz 2005].

The coffee fruit is a fleshy cherry that turns red as it ripens due to the replacement of chlorophyll in the exocarp by red flavonoid pigments. Inside of the fruit there are two oval seeds [Osorio et al. 2023]. The beans are extracted from the harvested fruit, which are then shelled and selected. Because the coffee fruits on the same plants usually do not reach maturity simultaneously harvesting starts when most fruits are ripe. This process may be performed manually or mechanically [Farah & Ferreira dos Santos 2015]. Coffee beans may vary in chemical composition due to many factors, such as soil quality, seed maturity at harvest, or harvesting technique [Brzezicha-Cirocka et al. 2018].

Green coffee beans are a rich source of bioactive compounds, which may be susceptible to thermal decomposition [Bagchi et al. 2017]. The roasting process may contribute to significant reduction in the water content of the coffee beans and partial degradation of chlorogenic acid and trigonelline. The exception is caffeine, which is resistant to high temperature [Popek & Halagarda 2022]. For this reason, green coffee and its extracts have found wide applications in both the food and cosmetics industries. According to literature data, green coffee beans extract can be used as an ingredient in shampoos, creams, masks, and bath products. Due to the content of caffeine and chlorogenic acid it exhibits strong anti-aging and photoprotective properties [Böger et al. 2023]. Moreover, chlorogenic acid is commonly known for its antioxidant, anti-inflammatory and antibacterial properties while caffeine is used in cosmetic formulations for lipolytic action in cellulitis, and hair regrowth [Rodriques et al. 2023].

Currently, the cosmetics market offers a wide range of products containing plant extracts produced from both, native and exotic plants. This is consistent with the current trend of increasing popularity of products manufactured using sustainable production and consumption methods. Most of plant extracts are abundant source of active ingredients with diverse properties such as anti-aging, soothing, sebostatic, keratolytic etc. Phytochemicals contained in body wash cosmetics can improve their care properties, including cleansing properties, but also affect the functional properties of the products [Malinowska & Kiewlicz 2017]. Therefore, the authors attempt to determine the effect of Coffea Arabica Seed Extract on the functional properties of model shower gels. Two types of Coffea Arabica Seed Extract were included in the recipes for preparation model shower gels, i.e., the extract standardized for the content of chlorogenic acid at least 10% and the extract non-standardized for the content of chlorogenic acid. The surface tension, foaming properties and solubility in water have been evaluated. For comparison, the similar analysis was also performed for two commercial shower gels containing Coffea Arabica Seed Extract.

1. MATERIAL AND METHODS

1.1. Chemicals

Model shower gels were prepared using: Sodium Laureth Sulfate (Sulforokanol L225/1, PCC Group), Cocamidopropyl Betaine (Zrób Sobie Krem), Sodium Chloride (Chempur), Lactic Acid (Zrób Sobie Krem), Sodium Hydroxide (0.1 mol/dm^3, 0.1 N, Chempur), Coffea Arabica Seed Extract (Zrób Sobie Krem), Coffea Arabica Seed Extract standardized for chlorogenic acid content, min. 10% (Beauty Ever).

1.2. Material

The study involved five shower gels. The model shower gels included:

- shower gel containing no extracts (marked later in the article as Gel 0),
- shower gel containing Coffea Arabica Seed Extract non-standardized for the content of chlorogenic acid (Gel 1),
- shower gel containing Coffea Arabica Seed Extract standardized for chlorogenic acid content at least 10% (Gel 2).

Each of them was prepared according to the procedure given below. The other two products used in the research were commercial shower gels purchased on the Polish market. Both of them contained Coffea Arabica Seed Extract. The description of commercial shower gels was presented in Table 1.

Table 1. The description of commercial shower gels

Symbol	Brand	Ingredients
Gel 3	Green Pharmacy	Aqua, Sodium Coco-Sulfate, Sorbitol, Cocamidopropyl Betaine, PEG-7 Glyceryl Cocoate, Coffea Arabica Seed Extract, Zingiber Officinale Root Oil, Sodium Lauroyl Methyl Isethionate, Glyceryl Oleate, Coco-Glucoside, Sodium Chloride, Trisodium Ethylenediamine Disuccinate, Glycerin, Citric Acid, Parfum, Potassium Sorbate, Sodium Benzoate, Hydrogenated Palm Glycerides Citrate, Tocopherol, Citral, Eugenol, Linalool, Limonene, Geraniol, Eucalyptus Globulus Oil, Citrus Aurantium Peel Oil, CI 15985, CI 19140
Gel 4	Yves Rocher	Aqua/Water, Cocamidopropyl Betaine, Glycerin, Sodium Cocoyl Isethionate, Sodium Methyl Cocoyl Taurate, Glycol Distearate, Decyl Glucoside, Coffea Arabica (Coffee) Seed Extract, Parfum/Fragrance, Sodium Benzoate, Xanthan Gum, Citric Acid, Potassium Sorbate, Cellulose Gum, Cellulose, Benzoic Acid

Source: own study based on the manufacturer's declarations.

1.3. Methods

Preparation of shower gels

The model shower gels were prepared according to the recipe presented in Table 2. Coffea Arabica Seed Extract and two popular commercial surfactants, Sodium Laureth Sulfate (SLES) and Cocamidopropyl Betaine (CAPB), were dissolved in a measured amount of water. The obtained clear solution was thickened with Sodium Chloride. Then, the pH value of shower gel was checked and, if necessary, adjusted to 5.0–5.5 using Sodium Hydroxide at the concentration of 0.1 mol/dm^3. A shower gel containing no extract was also prepared as reference sample [Kiewlicz & Kwaśniewska 2023b; Sarna et. al. 2018].

Table 2. Formulation of the model shower gels

INCI	Concentrations [%]		
	Gel 0	Gel 1	Gel 2
Aqua	Ad 100		
Sodium Laureth Sulfate	7.5		
Cocamidopropyl Betaine	1.8		
Sodium Chloride	3.0		

cont. Table 2

Coffea Arabica Seed Extract	0.0	2.0	
Sodium Hydroxide	–	To pH approx. 5.0-5.5	–

Gel 0 – shower gel containing no extract, Gel 1 – shower gel containing Coffea Arabica Seed Extract (non-standardized for the content of chlorogenic acid), Gel 2 – shower gel containing Coffea Arabica Seed Extract (standardized for chlorogenic acid content, min. 10%).

Source: own study based on: Kiewlicz & Kwaśniewska 2023b.

Surface tension measurements

Surface tension measurements were performed using the PI-MT1M apparatus (Donserv, Poland). The analysis was made at temperature of 296 K by drawing up liquid films method with the use of the platinum ring. The aqueous solutions of shower gels at the concentration of 4% were tested.

Foaming properties

100 cm^3 of 4% aqueous solution of the shower gel was placed in the glass measuring cylinder equipped with a perforated disc, permanently mounted on the end of the rod. Foam was generated by performing 60 blows in 60 s. The volume of foam was read 10 s after its forming then at one-minute intervals up to 10 minutes. The volume of foam (cm^3) read directly after its formation is defined as foam-forming capability. The foam stability index (X%) was calculated based on the following formula [Kowalik & Szyrej 2016]:

$$X = \frac{V_2}{V_1} \cdot 100\% \qquad (1.1)$$

V_1 – foam volume measured after 10 s, cm^3,
V_2 – foam volume measured after 10 min, cm^3.

The measurements were performed at a temperature of 296 K.

Solubility in water

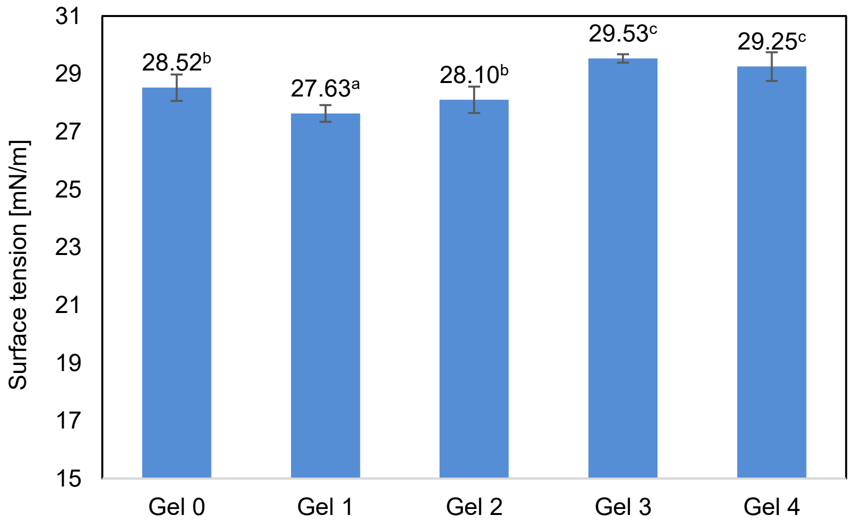
2 cm^3 of tested shower gel was added to 100 cm^3 of distilled water in a beaker placed on a magnetic stirrer at a rotational speed of 100 rpm. Subsequently the time necessary for the completely dissolving of shower gel in water was measured. The measurement was performed at a temperature of 296 K [Kowalik & Szyrej 2016; Zięba et al. 2017].

Statistical analysis

The results obtained were presented as mean values from three determinations with standard deviations. If necessary, the data were also subjected to one-way analysis of variance (one-way ANOVA). To identify significant differences between mean values, Tukey's post-hoc test was performed at $\alpha = 0.05$. The analysis was performed using Statistica 13.0 software (StatSoft Inc.).

2. RESULTS

Reducing surface tension is crucial for the performance of cleansing products, due to better distribution of the product on the skin and more effective removal of pollutants, which can then be easily rinsed with water. In this study, the values of surface tension of solutions of shower gels with a concentration of 4% was compared.



Mean values with the same letter were not significantly different at $\alpha = 0.05$ (sorted from the lowest to highest values).

Figure 1. The surface tension of shower gels at the concentration of 4%

Source: own study.

The analysis of the obtained results shown that each tested product effectively reduced the surface tension of water. The surface tension values obtained in this study were consistent with those obtained by Kowalik and Szyrej [2016] for the solutions of shower gels at analogous concentration. As can be seen in Figure 1, the solutions of model shower gels (Gels 0-2) showed lower surface tension values than those prepared for commercial shower gels (Gels 3 and 4). The solution of Gel 1 exhibited the lowest surface tension value among all tested gels which was 27.63 mN/m. Moreover, there was no significant differences observed in surface tension values between the solutions of Gel 0 and Gel 2.

The foam-forming capability was evaluated as the volume of foam produced by 100 cm^3 of a 4% aqueous solution of tested shower gels. The volume of foam was read 10 s after its production The data presented in Figure 2 show that the highest foam-forming capability was observed for Gels 0 and 1. The lowest foam-forming capability exhibited both commercial shower gels.

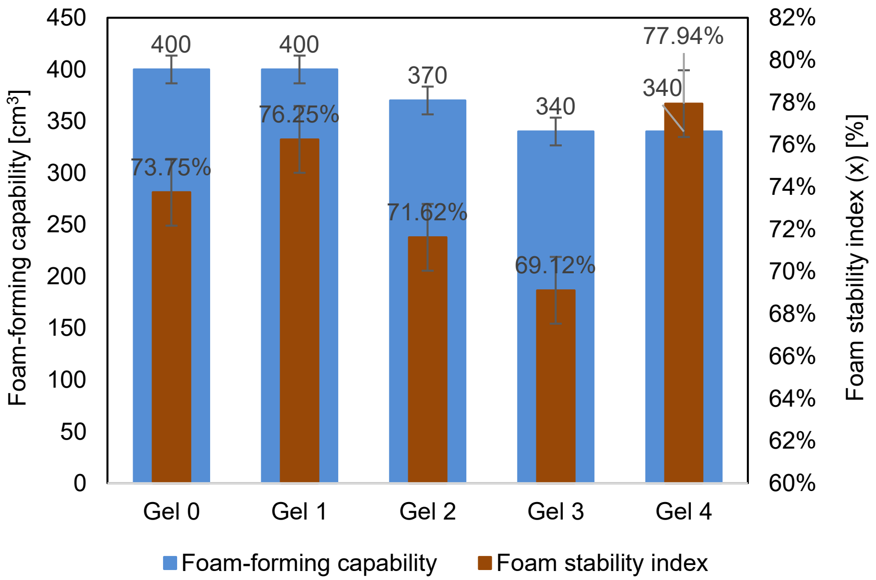


Figure 2. Foam-forming capability and foam stability index (X) of tested shower gels

Source: own study.

On the other hand, Gel 4 shown the highest foam stability index (77.9%), however, it was a slightly higher value than that observed for Gel 1 (76.3%). The lowest value of foam stability index exhibited Gel 3 (69.1%).

The solubility of shower gels in water was expressed as the time necessary for the completely dissolving of preparation in water. The results were presented on Figure 3.

A large variability in the solubility of the tested shower gels was observed. The results obtained ranged from 9 s for Gel 1 to 505 s for Gel 4.

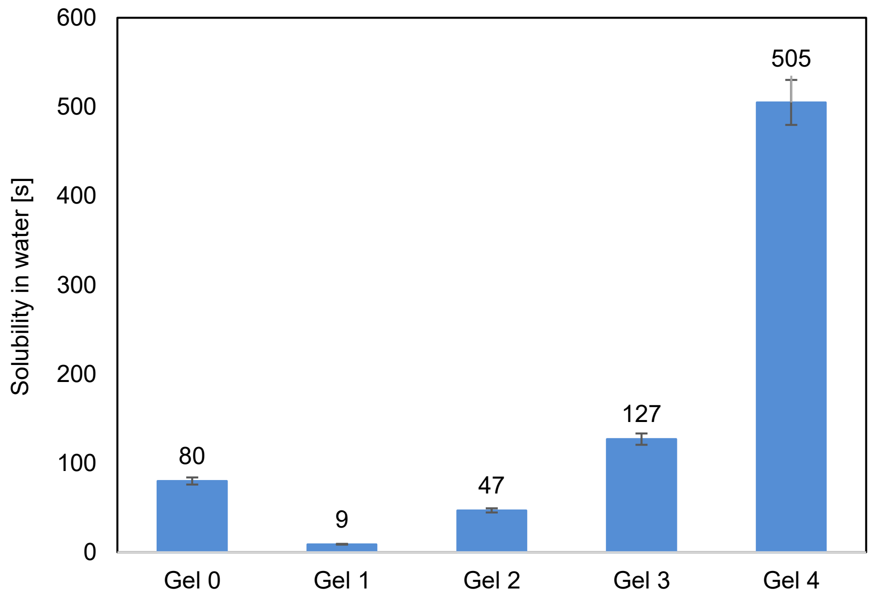


Figure 3. The solubility of shower gels in water

Source: own study.

3. DISCUSSION

Analysis of the results obtained for the model shower gels showed that the addition of Coffea Arabica Seed Extract non-standardized for the content of chlorogenic acid caused an improvement in the functional properties of the product compared to the gel containing no extracts. This beneficial effect was observed in terms of all the parameters assessed. On the other hand, the influence of Coffea Arabica Seed Extract standardized for chlorogenic acid content (at least 10%) on these properties was minor. It is worth emphasizing that during the preparation of model shower gels, certain differences were observed in selected properties of both extracts. Coffea Arabica Seed Extract standardized for chlorogenic acid content showed very high water solubility, whereas the non-standardized extract dissolved in water only after the addition of the surfactants. Moreover, a 2% aqueous solution of the extract not standardized for chlorogenic acid content had a significantly lower pH value (measured value was at the level of 2.3) compared to the analogous solution of the extract standardized for chlorogenic acid content (measured value was at the level of 5.4). It may therefore be presumed that both extracts differed significantly in chemical composition, which was probably due to the use of different extraction conditions by their producers. More importantly, it may indicates a higher content of organic acids in the non-standardized extract which influenced the obtained results.

According to literature data, the main factors influencing the surface tension of aqueous surfactant solutions include: temperature, surfactant concentration, and the structure of its molecule as well as the composition of the solution. The available studies show that for aqueous solutions of ionic surfactants in the presence of salt, e.g., Sodium Chloride, a lower surface tension values are observed than in the case of solutions not containing such an electrolyte [Zieliński 2021]. It is also suggested that addition of selected acids with bioactive properties may affect the surface activity of ionic surfactants. This activity was proven for ascorbic and chlorogenic acids [Kiewlicz & Kwaśniewska 2023a; Kwaśniewska & Kiewlicz 2022; Kwaśniewska & Kiewlicz 2024]. It can be assumed that the addition of Sodium Chloride to the model shower gels influenced their surface properties as well as considering the results obtained for Gel 1, this effect could be also enhanced by organic acids originating from the non-standardized extract.

Foam is a characteristic system in which a gas phase is dispersed in a continuous liquid or solid phase, creating a structure with a large interfacial surface area [Myers 2006]. The foam-forming capability is influenced by factors such as: the structure and concentration of surfactants, the pH value, the water hardness, or the content of other ingredients [Zieliński 2021]. Moreover, the literature data show, that the foaming properties are correlated with surface tension value. According to literature data [Obisesan et al. 2021] surfactants are added to the base liquid to generate more stable foam by reducing interfacial tension. Referring to the results of surface tension measurements, it can be assumed that this phenomenon may partially explain the slightly better foaming properties of model shower gels compared to commercial preparations. On the other hand, the commercial shower gel, marked as Gel 4, had the highest foam stability index. According to the manufacturer's declaration, Gel 4 contained foam stabilizers such as Cocamidopropyl Betaine, Ethylene Glycol Distearate, and Decyl Glucoside as well as hydrocolloid-forming substances: Cellulose Gum and Xanthan Gum. The lasts of the mentioned ingredients, which are commonly used in cosmetic products to increase their viscosity, were not contained in the other tested shower gels. According to literature data, an increase in the viscosity of an aqueous surfactant solution is correlated with an increase in the stability of the foam produced [Zieliński 2021]. Moreover, the positive effect of hydrocolloids on the stability of food foams was described earlier by Kabziński et al. [2018].

Apart from this effect, the content of mentioned thickeners could also be the reason for the long time of dissolution of Gel 4 in water. According to literature data [Zięba et al. 2017] the higher viscosity of cosmetics the worse is solubility in water. It is undesirable effect because the appropriate solubility of body wash cosmetics in water is closely related to the effectiveness of the washing process, as it contributes to faster rinsing of the preparation from the skin surface.

CONCLUSIONS

According to the literature data, the sustainable production and consumption methods should meet environmental and justice criteria and lead to efficient use of resources and reduction of possible waste. Therefore, the particular importance is attached to global reducing the consumption of resources and the scale of degradation and pollution. This effect can be achieved by searching for new, effective, and safe raw materials that can replace synthetic substances. Plant extracts are certainly ones of them.

The analysis of the obtained results confirmed that the addition of Coffea Arabica Seed Extract non-standardized for the content of chlorogenic acid contributed to an improvement in the functional properties of prepared shower gel such as surface tension, foaming properties and water solubility compared to the other model shower gels. Potential perspective of modifying the functional properties of cosmetic products such as shower gels by adding plant extracts may be an another tool to attempt of limiting the use of synthetic surfactants in the cosmetic formulations.

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PACKAGING TECHNOLOGIES AND TRACKING SYSTEMS IN COLD CHAIN LOGISTICS

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Abstract

Cold chain logistics management is crucial for ensuring the quality and safety of temperature-sensitive products, such as pharmaceuticals, food, and chemicals. The article discusses the importance of this logistics in product quality and analyzes regulations governing the storage and transportation of goods under controlled temperature conditions. It presents technologies used in intelligent and active packaging, tracking systems (GPS, IoT, blockchain), and their role in maintaining product quality. The integration of these technologies with large-scale transportation solutions, such as refrigerated containers, is also considered, analyzing their advantages and disadvantages across various industrial sectors.

Keywords: cold chain logistics, intelligent packaging, active packaging, tracking systems, refrigerated containers.

INTRODUCTION

In the era of globalization and increasing consumer expectations regarding product quality, cold supply chains are gaining prominence as a critical component in the logistics of perishable goods. Products such as fresh fruits and vegetables, frozen items, and pharmaceuticals require strict temperature control at every stage of their journey – from the point of production, through storage and transportation, to the final recipient. The proper functioning of cold supply chains is essential to ensure product quality and shelf life. The aim of this study is to discuss the significance of cold supply chains, provide their definition, examine the challenges involved, and explore the technologies that support the maintenance of uninterrupted refrigeration throughout the supply chain.

1. THE ROLE OF COLD SUPPLY CHAINS IN THE CONTEXT OF PRODUCT QUALITY

Cold supply chains represent a key area of modern logistics, particularly in the context of increasing globalization, the intensification of international trade, and growing consumer demands regarding the quality and safety of perishable goods. This category includes, among others, fruits and vegetables, agricultural products, seafood, frozen items, as well as pharmaceuticals and vaccines. Due to their sensitivity, such products require strict temperature control at every stage of the supply chain, from production, through transportation and storage, to the point of consumption. In the academic literature, cold supply chains are defined in various ways. Several definitions of the cold supply chain are presented in Table 1.

Table 1. Selected definitions of the cold supply chain

Definition of the Cold Chain	Author(s)
The cold chain is a temperature-controlled supply chain with an uninterrupted series of production, storage, distribution, and logistics activities designed to preserve, extend, and ensure that food and pharmaceutical products reach consumers safe and sound	[FSI 2025]
Temperature management of perishable products from the farm all the way to the end consumer	[Kitinoja 2014]
Food Cold Chain Logistics and Management (FCCLM) are comprehensive approaches that ensure the preservation, quality, and safety of perishable goods to be delivered effectively from the point of origin to the consumer. This multifaceted system encompasses the strategic implementation of infrastructure, stakeholder integration, and the enhancement of both value and performance across the cold chain	[Shashi et al. 2018]
Cold chain refers to a temperature-controlled supply chain	[Aung & Chang 2014]
Cold Chain is a system for maintaining freshness by managing products that are sensitive to temperature such as food, at an appropriate temperature throughout the entire process from production to consumption. This is	[Cello Square 2014]

cont. Table 1

a logistics system that can ensure product stability. The cold chain system is maintained from the packaging of products to transport, handling, cold storage, distribution, delivery, and placement	
A cold chain is a supply chain of perishable items, which protects a wide variety of food, pharmaceutical, and chemical products from degradation, improper exposure to temperature, humidity, light or particular contaminants to keep them frozen, chilled and fresh state	[Bishara 2006]
In general, the supply chain requires systematic and strategic coordination of all activities related to the flow and transformation of inputs, finished goods, information, and financial re-sources. The PCC refers to a system in which perishable drugs that require low-temperature conditions are always collected in an environment with specific temperature ranges before they are delivered to consumers	[Montoya et al. 2021]
A cold chain is a 'temperature-controlled' supply chain. An unbroken cold chain is an uninterrupted series of refrigerated production, storage, and distribution activities, along with associated equipment and logistics, which maintain quality via a desired low-temperature range	[Ahmed et al. 2022]

Source: own study.

The contemporary logistics services market is evolving towards globalization, a trend clearly reflected in statistical data. In 2020, the global capacity of cold storage warehouses reached 719 million cubic meters, while in 2023, the demand for temperature-sensitive products in China alone amounted to 350 million metric tons [Statista 2024]. This indicates an intensification of long-distance intercontinental transport and underscores the necessity of implementing complex and reliable temperature control systems.

Failure to maintain an unbroken cold chain can result in quality degradation, loss of nutritional value, and even pose risks to the health of end consumers. For this reason, cold supply chains play a vital role not only in the food sector but also in safeguarding public health particularly in the context of pharmaceutical logistics, where products such as vaccines and insulin require storage temperatures between 2–8°C [Rodrigue & Notteboom 2017].

There is also a marked disparity in the level of technological advancement depending on a country's stage of economic development. In highly developed nations, there is growing interest in sustainable solutions, including the use of eco-friendly packaging materials in e-commerce [Pan et al. 2020; Tsang et al. 2016]. However, in developing countries, challenges persist, including inadequate infrastructure, lack of quality standards, and discontinuities in cold chain processes.

Key global market players include Lineage Logistics, Americold Logistics, and United States Cold Storage, companies generating billions in revenue and playing a strategic role in ensuring supply chain continuity [Statista 2024]. Alongside market expansion, increasing segmentation is observed, with individual operators developing specialized competencies in handling specific product categories.

Cold supply chains require a synergy of refrigeration technologies, information systems, and standardized operational processes. Designing an efficient supply chain involves balancing cost, quality, and environmental objectives. To this end, mathematical and simulation models are employed to assess system performance in terms of cost-efficiency, quality assurance, and emissions. Consequently, ensuring temperature continuity at every stage of the process remains one of the primary challenges. Responsibility for this continuity lies with all stakeholders in the supply chain, from producers to end users. According to market data, 62% of logistics companies consider cold chain services to be of strategic importance and a cornerstone of future development [Statista 2024]. The use of advanced monitoring technologies and smart packaging solutions minimizes the risk of spoilage and value loss, while also safeguarding consumer health.

2. REGULATIONS, STANDARDS, AND NORMS GOVERNING THE OPERATION OF COLD SUPPLY CHAINS

The international scope and complexity of operations within the global supply chain mean that no single, universal set of regulations governs the technologies used in the cold chain. Instead, different regulatory frameworks are applied depending on the specific application and region. In the European Union, regulations concerning cold supply chains are complex and continue to evolve. The introduction of new regulations-such as those related to temperature logging-places increasing emphasis on data reliability, traceability, and protection against tampering, which is particularly critical for maintaining the quality of temperature-sensitive products.

One of the key differentiating factors in cold supply chains is the industry sector-particularly pharmaceuticals and food. Another determinant is the mode of transportation, which dictates the applicable regulations. In the case of pharmaceuticals, the United States Food and Drug Administration (FDA) has established regulations under CFR 21 Part 211 concerning the storage and transport of medicines, which include requirements related to temperature control. Similar regulations are enforced in other countries by national health agencies. For food products, most countries maintain regulations on food storage and transportation, developed by national or regional food safety authorities. These regulations focus on maintaining appropriate temperatures for various types of food in order to prevent spoilage and the growth of pathogens [Stern 2006].

Another important differentiator in cold chain regulation is the regulatory scope itself. These frameworks define thresholds in areas such as temperature, data monitoring, equipment, and packaging. With regard to temperature control, regulations may specify required temperature ranges for different products during storage and transport. In certain countries, data monitoring is mandatory and involves recording and preserving temperature data throughout the cold chain to ensure regulatory compliance [Sensitech 2024; Tzone 2024]. Furthermore, regulations may mandate the qualification and validation of equipment used in cold chains (e.g., refrigerated vehicles, freezers) as well as packaging materials (e.g., insulated containers) to meet specific performance standards [WHO Technical Supplement – Qualification of temperature-controlled storage areas].

Despite regional differences in logistical operations, several regulatory bodies set industry-wide standards. These include national health agencies such as the FDA in the United States, industry-specific organizations in the fields of pharmaceuticals, food, or cold chain logistics, and international bodies such as the International Organization for Standardization (ISO).

Technologies employed in the cold chain must comply with internationally recognized standards and regulations designed to ensure the safe transport and storage of goods. Among the most significant are: the Agreement on the International Carriage of Perishable Foodstuffs (ATP), which sets requirements for vehicles transporting perishable food; ISO 22000, a global food safety management standard that includes provisions for temperature control; the Hazard Analysis and Critical Control Point (HACCP) system, which identifies food safety risks and control points; ISO 23412, which regulates last-mile delivery of chilled goods, including temperature and insulation specifications; and Good Distribution Practice (GDP) guidelines for pharmaceuticals, which govern temperature control during the transport of medicines and vaccines.

The ATP Convention plays a crucial role in ensuring proper temperature control within the supply chain of perishable food products. It is a comprehensive legal framework regulating various aspects of transporting perishable food items. First adopted in Geneva in September 1970, it outlines transport conditions (e.g., for raw meat, fish, milk), technical requirements for transport vehicles, and certification and marking standards for vehicles carrying these products [Ministerstwo Infrastruktury 2024; UK Government 2013; UNECE 1970; UNECE 2023]. Perishable goods covered by the convention include plant-based foods, products of animal origin, goods refined from plant or animal materials, and live plants. These regulations aim to optimize vehicle suitability for transporting such goods, which is essential to public health protection [UNECE 2023].

ATP sets clear standards for isothermal vehicles, refrigerated and frozen transport units, as well as heated vehicles, thereby minimizing the risk of cold chain disruption [Ministerstwo Infrastruktury 2024; UNECE 2023]. The agreement ensures the application of appropriate technologies such as refrigeration units and thermal insulation, enabling the preservation of product quality and consumer safety throughout the transport process [Sensitech 2024]. In the context of cold chains, ATP not only establishes explicit requirements for vehicles and containers used in the transport of temperature-sensitive foods but also mandates the use of technologies that mitigate risks of disruption, thereby reinforcing chain integrity [Tzone 2024; WHO TRS 961 2011].

However, the ATP Convention does not hold universal legal authority at the international level. It applies only in countries that have ratified it primarily in Europe, as well as in countries such as the United States, Kazakhstan, Morocco, the United Kingdom, and the Russian Federation. It is applicable to international road and rail transport, although many countries have also adopted its provisions for domestic transportation.

Although the ISO 22000 standard does not provide specific guidelines for cold chain management, it establishes a Food Safety Management System (FSMS) (Clause 4.4), which encompasses all aspects of food safety, including temperature control as part of hazard analysis (Clause 8.5) and prerequisite programmes (Clause 8.2). Organizations are required to determine risks (Clause 6) and provide infrastructure and resources (Clause 7.1) necessary to maintain appropriate storage and transport conditions. Therefore, ISO 22000 can be used to develop a cold chain management plan tailored to specific organizational needs and aligned with regulatory requirements, supporting the minimization of food spoilage and contamination risks caused by temperature fluctuations [International Organization for Standardization 2024].

The FSMS also incorporates the Hazard Analysis and Critical Control Points (HACCP) system to identify potential hazards throughout the food supply chain, including temperature control failures. In the context of the cold chain, this may involve identifying Critical Control Points (CCPs) such as receiving temperatures, storage conditions, and transportation parameters. FSMS also includes Prerequisite Programs (PRPs), which establish the fundamental food safety conditions and can be adapted to cold chain management. Examples of PRPs related to the cold chain include calibration and maintenance procedures for temperature monitoring devices, training of cold chain personnel in appropriate temperature control procedures, documentation of temperature control protocols and monitoring logs, as well as validation of cleaning and disinfection procedures for cold chain equipment [Gustavsson et al. 2011].

ISO 22000 does not define exact temperature values but requires the establishment of appropriate temperature ranges depending on the type of food and applicable regulations. The FSMS should also include procedures for temperature monitoring at critical control points and for maintaining compliance records. In the event of temperature deviations, corrective actions should be implemented to minimize risks to food safety. Overall, ISO 22000 provides a framework for food safety management, including cold chain-related processes. By implementing an FSMS that incorporates these principles, organizations can ensure that cold chain operations align with best practices and contribute to overall food safety.

ISO 23412, on the other hand, sets international standards for logistics companies involved in refrigerated transportation, requiring the use of modern temperature monitoring and control technologies. Through the application of refrigeration units, intelligent transport management systems, and advanced insulation, stable temperature conditions can be maintained – even during complex deliveries with multiple transhipment points. The implementation of this standard is crucial for improving the safety and quality of deliveries involving temperature-sensitive products, reducing spoilage risks and economic losses [ClassNK 2021; ISO 23412 Guidelines].

ISO 23412 specifies requirements for providing temperature-controlled transport services for shipments containing temperature-sensitive goods (including food) by road. It encompasses all stages of refrigerated delivery – from the acceptance of goods from the service user, through transfer between refrigerated vehicles or containers, to the final delivery to the destination. Although the standard itself does not mandate the use of advanced cooling technologies, it defines requirements for cooling systems in vehicles and containers (as in the ATP Agreement) as well as requirements for maintaining stable temperature conditions. In practice, these requirements are most effectively fulfilled through the use of advanced solutions such as temperature sensors, GPS systems with temperature logging functions, and Internet of Things (IoT) technologies. IoT-, RFID-, and EPCIS-based platforms are commonly applied for remote temperature logging, integration with traceability systems (e.g., GS1 EPCIS), and automated notifications and auditing of cold chain events [GS1 2017; Urbano et al. 2020]. Automated route planning and optimization systems are also widely used in cold chain logistics to reduce transport time and minimize the risk of temperature fluctuations caused by long stops or inefficient scheduling [Lu et al. 2025].

The standard also specifies procedures for the safe transfer of goods between refrigeration units to ensure the continuity of the cold chain. It further highlights the need for electronic shipment tracking systems, allowing clients and logistics providers to monitor transport. However, ISO 23412 has limited applicability. It does not cover all modes of transport and excludes air, sea, and rail transport. It also does not apply to shipments with self-contained refrigeration systems or direct refrigerated deliveries. Moreover, ISO 23412 does not provide guidelines for measuring the temperature of the product itself; it refers only to the transport system and not the quality of goods prior to collection. The transport of pharmaceuticals and medical products is governed by separate regulations [ClassNK 2021].

In the context of the cold supply chain, Good Distribution Practices (GDP) play a crucial role in ensuring appropriate storage and transportation conditions for temperature-controlled products. GDP constitutes a quality system defining responsibilities and procedures for managing risks associated with the wholesale distribution of pharmaceutical products. It includes the organizational structure of companies, procedures, resources, and processes. Quality control systems in the pharmaceutical industry are essential for ensuring the safety and high quality of medicinal products.

Companies are required to continuously monitor processes such as transportation, distribution, storage, and sale of medicines in accordance with national and international regulations. Pharmaceutical wholesalers must guarantee the high quality of medicinal products. Warehouse operators are responsible for maintaining proper storage conditions, including cleanliness, humidity control, temperature monitoring, air circulation, and appropriate labeling. Distributors must also prove the legitimacy of medicine sources and monitor the entire supply chain. GDP regulations apply to companies involved in the procurement, sale, storage, and transportation of human and veterinary medicines. These requirements also extend to the personnel of distribution companies [European Commission 2013; Qualityze 2025].

GDP mandates the use of suitable refrigeration technologies, such as coolers and refrigeration units, for products requiring cooling, as well as continuous temperature monitoring throughout the supply chain. The warehouse owner must hold a permit certifying compliance with health standards and GDP norms. Key components include room temperature monitoring, temperature mapping, and the installation of temperature sensors and data loggers. Automated temperature measurement systems help reduce loss risks and avoid financial penalties [Stajniak & Konecka 2014].

A practical example of regulatory implementation in the cold chain is the IATA Temperature Control Regulations (TCR), which address temperature management in air transport. Through cooperation with leading agencies and organizations, IATA significantly improved preparations for transporting COVID-19 vaccines, which posed a major challenge in the pharmaceutical cold chain context [IATA, 2023].

3. ACTIVE AND INTELLIGENT PACKAGING TECHNOLOGIES

An essential element in logistics, and especially in cold supply chains, is appropriate packaging. It must be adapted to the properties of the products being transported and stored and the specific conditions prevailing in the means of transport and warehouses. In the case of cold supply chains, this issue concerns products sensitive to temperature changes, mentioned in the introduction.

The world is observing continuous development and a wide range of innovative solutions in the field of traditional packaging materials designed for cold chains. Despite this, alternative and at the same time even more effective ways of ensuring and controlling the quality of products in cold supply chains are sought. An example of technologies that fit into this trend is active and intelligent packaging, extending the functionality of existing solutions.

Active packaging refers to packaging systems designed not only for the storage and passive protection of food, but also for the active and intentional interaction with the product or its environment, in order to extend the shelf life, improve safety and maintain the quality of products [Ahmed et al. 2022]. In cold supply chains, active packaging plays a key role by changing the conditions inside the package (including humidity, gas concentration, and temperature), which directly affect the development of microorganisms and the physicochemical processes occurring in the products. Active packaging can take different forms, including non-migratory systems (such as moisture or oxygen scavengers) and active release systems (such as emitters of CO_2, antimicrobial, or antioxidant components), which contribute to product stability during transport and storage, and consequently prevent product spoilage and losses [Dainelli et al. 2008; Robertson 2012; Soltani Firouz et al. 2021].

Active packaging is a wide range of solutions, can fulfil different roles and take different forms. In cold supply chains, active packaging most often plays the role of various types of absorbers or emitters, regulators and indirectly controllers of conditions in the package [Lou et al. 2025]. Absorbers primarily absorb moisture, preventing condensation and the associated growth of mould and bacteria [Bovi et al. 2019]. Also used are absorbers of specific gases (i.e., oxygen, carbon dioxide, ethylene), the source of which may be the product environment or the product itself [Wu et al. 2024]. These gases contribute to the occurrence or acceleration of unfavourable processes that directly affect the durability of products. Absorbers can also remove undesirable odours from the packaging atmosphere, which arise during storage.

Another interesting solution used in cold chains are various types of cooling inserts that support classic cooling systems at critical points in cold chains, e.g., during reloading. These can be single-use or reusable solutions. Cooling agents in this case can be dry ice, water, gels, salt solutions or phase change materials (PCM). The latter are classified as temperature regulating materials (TRM) by changing the phase of matter, are able to absorb, accumulate or release a significant amount of energy in the phase change range. Thanks to these unique properties, they can, in addition to the role of a cooling agent, act as specific temperature regulators [Bahrami & Sablani 2025; Bing et al. 2019; Meng at al. 2022; Soo at al. 2025]. In the case of some products, emitters of various substances (e.g., CO2) are used, which have specific protective effects (e.g., bacteriostatic) [Almasi et al. 2021; Gurusamy et al. 2024].

Active packaging used in cold supply chains also includes so-called thermoelectric modules (also known as Peltier cells) using the Peltier effect. Depending on the needs, these elements can lower or raise the temperature of the product's environment independently of the main cooling installation. However, unlike the previously described cooling elements, they require power supply [Kan et al. 2023; Wang et al. 2024].

The second group of solutions increasingly used in cold supply chains are the previously mentioned intelligent packaging also called smart packaging. These are solutions that are diverse in terms of functionality and design. Intelligent packaging refers to advanced packaging systems integrated with sensing, monitoring, and communication technologies to ensure product quality, safety, and integrity throughout the supply chain. In cold chain logistics they are used for temperature-sensitive and thus perishable goods such as food, pharmaceuticals, playing a crucial role in maintaining optimal conditions.

The solution that can effectively support cold chain logistics are so-called time--temperature integrators (TTIs) and smart labels that visually indicate if the product has been exposed to unacceptable conditions [Kashem et al. 2024; Lanza et al. 2025]. This is a group of solutions that are placed on the outside of the package. Reversible and irreversible indicators are available, depending on the specific application in the cold supply chain. They can signal breaches in cold chain integrity through color changes or digital alerts. They can show the time remaining until the product is used up under given temperature conditions or indicate a change in storage conditions outside the permissible ranges (e.g., by informing about product defrosting).

Moreover, these technologies enable a shift from static expiration dates to a dynamic determination of product shelf life. Traditional use-by or best-before dates are based on recommended storage and transport conditions, and any deviation may lead to premature spoilage. Intelligent packaging, through real-time monitoring and predictive analytics, allows updating the remaining shelf life according to actual conditions, providing a more precise assessment of product safety and quality [Wu et al. 2025].

The next type of smart solutions consists of real-time monitoring systems. They incorporate sensors that continuously track temperature, humidity, and other environmental parameters (e.g., concentration of specific gas) [Cao et al. 2024;

Chu et al. 2025; Jin et al. 2025]. Thus, provide real-time data to stakeholders, enabling immediate corrective actions if deviations occur.

Data logging and communication systems are directly related to them. They enable the collection and/or transmission of information about the product or its storage conditions in real time [Gautam & Kumar 2024]. Nowadays embedded RFID (Radio Frequency Identification) tags or IoT (Internet of things) devices that record environmental data throughout transit are used for this purpose enabling remote monitoring and retrieval of data for quality assurance and compliance [Baghel et al. 2024; Bouazzi et al. 2025]. The data collected this way are used in so-called predictive analytics, which allows to predict potential spoilage or quality degradation of products. It also helps in optimizing logistics schedules and ensuring product freshness upon delivery [Ding et al. 2025; Fatorachian & Pawar 2025; Gautam & Kumar 2024].

Additionally smart packaging can be used for traceability and authentication. It provides transparency and traceability of products' journey on particular stages of supply chain, contributing directly to the safety of products and better control of their flows. It also combats counterfeiting, especially important for pharmaceuticals.

Active and intelligent packaging significantly enhance the reliability and safety of cold chain logistics. They ensure product quality and safety by preventing temperature excursions, thus reduces spoilage and product wastage. They also enhance compliance with regulatory standards and improves supply chain efficiency through data-driven decision-making. And in the end build consumer trust through transparent monitoring. As technology advances, their adoption is expected to grow, ensuring better quality management and consumer confidence in temperature-sensitive products. Future trends in this area will include integration of AI (artificial intelligence) for predictive insights, development of biodegradable and sustainable active/intelligent packaging materials and increased adoption of IoT and blockchain for enhanced traceability [Biswas et al. 2023]. Due to their particular importance in cold supply chains, selected solutions will be presented in more detail in the following chapters.

4. TEMPERATURE CONTROL AND TRACKING TECHNOLOGIES IN THE COLD SUPPLY CHAIN

Quality management within cold supply chains is associated with numerous challenges, chief among them being the necessity to ensure appropriate storage and transport conditions for perishable products. In this context, not only compliance with applicable regulations is critical, but also the maintenance of required temperatures and continuous monitoring of environmental conditions at every stage of the product flow. Inadequate supervision of temperature parameters results not only in the deterioration of product quality but also in tangible economic losses that directly impact a company's profits [Aghaei Afshar et al. 2022]. The expansion of global supply networks naturally increases the risk of product quality degradation, while effective coordination of efforts to reduce waste requires the implementation of advanced technological solutions [Asadi & Hosseini 2014].

4.1. Tracking systems and intelligent containers

With the ongoing digitalization of logistics processes, the use of tracking systems and smart containers is increasingly recognized as a key tool supporting supply chain management [Alshdadi et al., 2024; Luo et al. 2016]. The literature emphasizes the significance of these solutions in ensuring transparency, continuity, and quality of transport – particularly for products sensitive to environmental conditions.

Smart containers, equipped with IoT sensors, enable real-time monitoring of key parameters such as temperature, humidity, and the location of transported goods. The use of wireless sensor networks (WSNs) facilitates the collection and transmission of data in real time, both from warehouses and transport vehicles, including refrigerated trucks [Fu et al. 2008]. Simultaneously, the integration of GPS positioning systems with Android technology and web services allows for the visual representation and control of logistics operations. Blockchain technology, increasingly cited as important for supply chain management, functions as an immutable data ledger, thereby enhancing accountability and trust among supply chain participants. The data generated by smart tracking systems also enable route optimization, reducing both operational costs and delivery times [Luo et al. 2016].

The literature highlights the evolution of temperature monitoring technologies. Initially, analog solutions were used, such as paper thermographs, whose limitation was the lack of real-time data access [González-García & Muñoz-Antón 2022]. Modern electronic systems, including data-logging temperature recorders, are technologically more advanced and enable data transmission to cloud platforms. This ensures the continuity of the so-called cold chain, even in cases of geographic dispersion or multimodal transport-including road, maritime, and air transport. These systems comply with current standards such as EN 12830 or ISO 17001.

Wireless sensor networks (WSNs), which combine detection, computation, communication, and data transmission capabilities, offer a favorable cost-to--functionality ratio, ease of implementation, and high mobility. Their application in cold chain management involves the control of environmental conditions – particularly temperature, humidity, and the presence of selected gases [Wang et al., 2017]. One example is the WGS2 system, operating at 433 MHz, designed for monitoring the quality of table grape transportation. Test results indicate improved traceability and transparency, and its modular architecture allows adaptation for various applications.

RFID technology is also widely used, particularly in tracking goods flow and managing inventory. The integration of RFID tags with environmental sensors, including temperature sensors, allows for real-time tracking of both product condition and location (WSN – The 6th International Conference on Manufacturing Research (ICMR08), Brunel University, UK, 9-11 September 2008). Time--temperature indicators (TTIs) are also used, functioning as tools for detecting deviations from programmed storage conditions-typically via irreversible color change. The use of TTIs contributes to improved quality control of food products [Jedermann & Lang 2014].

The Internet of Things (IoT) is increasingly used as a platform that integrates sensors and data transmission technologies in projects aimed at automating the monitoring of transport conditions. An example is the use of the NodeMCU-ESP32 platform, which supports WiFi connections, enabling data transmission to cloud environments such as AWS [Popek & Świda 2016]. These sensors, installed in smart containers, also enable the detection of shocks and damage.

Considering the broader application of tracking systems in cold supply chains, solutions based on ubiquitous computing, RFID, and WSN technologies hold significant potential. Their joint integration enables real-time environmental control and supports operational decision-making [Luo et al. 2016]. An interesting solution also involves the use of mobile devices with Android, GPS, and internet services for data visualization and integration.

Particular attention should be paid to the concept of smart containers, which are systems capable of automatically alerting stakeholders to deviations from programmed conditions and analyzing environmental data in real time. In addition to monitoring parameters such as temperature and humidity, they may also be equipped with gas sensors (e.g., CO_2, O_2), quality indicators, and diagnostic tools for detecting mechanical damage. This information can be transmitted to central management systems or shared with supply chain partners, facilitating coordination, and promoting operational optimization. Projects such as 'Smart Container' have also incorporated communication components and automatic data analysis mechanisms [Limani Supply Group 2025; Wattanakul et al., 2018].

In the context of technologies supporting the operation of smart containers, GPS, IoT, and blockchain should be highlighted. GPS allows for real-time container localization, which enables ongoing route monitoring and quicker response to disruptions. The integration of these data with ERP systems supports coordination of logistics processes [Cichoń & Lesiów 2013; Freitag et al. 2021; Popek & Świda 2016; Renko 2018]. The Internet of Things allows for automatic data collection from sensors and transmission to supervisory systems. IoT not only promotes transparency but also enables the implementation of rapid response mechanisms. Meanwhile, blockchain technology, functioning as a decentralized ledger, enables the recording of transport condition data that cannot be altered. This ensures high levels of trust and full product traceability, which is particularly valuable in the pharmaceutical and food sectors [Aeler 2025; Balfaqih et al. 2023; Gondal et al. 2023; Vitaskos et al. 2024].

4.2. Integration and alternatives between packaging systems and large-scale transportation

With the advancement of packaging technologies, the nature of the relationship between packaging systems and large-scale transportation is undergoing significant transformation. There is a clear trend toward integrating active and intelligent packaging solutions with conventional refrigerated transport methods. In the case of short-distance deliveries or shipments involving smaller product quantities, modern packaging can not only support but, in certain situations, also replace traditional temperature control measures. The selection of packaging materials with appropriate insulating properties can significantly reduce the demand for mechanical refrigeration during transit [Majid et al. 2018; Unisco 2025].

Nevertheless, for large-scale, long-distance transportation, refrigerated containers and specialized trailers remain indispensable. In such cases, packaging technology plays a primarily supportive role, enhancing quality control mechanisms within the established environmental parameters. The integration of packaging solutions with cold chain transport systems aims to provide optimal conditions for particularly sensitive products. Active packaging can release preservative substances, absorb undesirable gases, or regulate humidity in the immediate environment of the product – features particularly important when micro-environmental conditions must be strictly controlled.

A functional distinction emerges: refrigerated containers provide macro-level environmental management (temperature, humidity, controlled atmosphere), while intelligent packaging offers micro-level insights, enabling monitoring of the condition of individual products or product batches. Time-temperature indicators (TTIs) allow the recording of temperature variations over time, facilitating the identification of any breaches in cold chain parameters. Gas sensors, including those for CO_2 and O_2, provide information about air tightness and atmospheric conditions within the product's microenvironment. Biosensors can detect both microbiological and chemical contaminants, although their interpretation may require specialized knowledge and results can occasionally be false positives. Freshness and interactive quality indicators provide immediate feedback on product quality, while RFID technology enables identification, localization, and integration of product batches with transport management systems.

Despite the clear advantages of active and intelligent packaging, their adoption across cold supply chains is influenced by both organizational and economic factors. Studies indicate that acceptance among stakeholders – including manufacturers, distributors, and retailers – depends on perceived benefits such as reduced spoilage, improved quality control, and enhanced traceability, as well as the ease of integrating these solutions into existing logistics processes [Aung & Chang 2014; Wu et al. 2025]. High initial costs, including investment in smart labels, sensors, and monitoring infrastructure, can limit implementation, particularly for small- and medium-sized enterprises [Aliakbarian 2019]. Additionally, technological challenges remain, such as ensuring the reliable activation of active components, sensor calibration, and compatibility with different transport modes and packaging formats [Sobhan et al. 2025]. Energy requirements, data management, and potential environmental impacts of disposing advanced materials further complicate large-scale deployment [Smart Packaging Hub 2025]. Addressing these issues is essential for achieving broader acceptance and realizing the full potential of active and intelligent packaging in cold chain logistics.

Integration of sensor data-temperature, humidity, shock – with local or cloud-based monitoring systems allows detailed tracking of conditions independent of the overall vehicle environment. Coupling these data streams with GPS systems can provide spatially correlated information on environmental conditions, although both GPS and automatic alarm systems can be susceptible to external interferences.

An emerging area in cold chain logistics is the development of predictive models that estimate product shelf-life under varying conditions of temperature and handling deviations. These models integrate data from sensors, time-temperature indicators (TTIs), and IoT devices to forecast quality degradation and potential spoilage. They range from empirical statistical approaches, such as regression and Arrhenius-based models, to mechanistic and hybrid models that incorporate microbiological and physicochemical processes alongside historical transport data [Aung & Chang 2014; Wu et al. 2025].

Predictive models allow dynamic assessment of shelf-life according to severity and duration of cold chain breaches. Short-term minor deviations may have minimal impact, while prolonged or severe breaches can rapidly reduce product quality. Integrating predictive models with intelligent packaging systems provides actionable insights for stakeholders, enabling optimized routing, proactive intervention, and improved inventory management [Sobhan et al. 2025].

The application of these technologies introduces numerous benefits, including enhanced monitoring, operational transparency, and improved quality control, but also presents challenges. High implementation and operational costs, the need for integration across various technological platforms, energy efficiency considerations, and environmental impacts related to packaging material disposal must all be addressed.

4.3. The application of packaging technologies and tracking systems in cold supply chains across various industries

The application of packaging technologies and tracking systems within the cold supply chain is gaining increasing relevance in sectors where maintaining specific environmental parameters-particularly temperature is of critical importance. This applies especially to the food and pharmaceutical industries, as well as segments involving the transport of products highly sensitive to external conditions.

In the food industry, the use of the cold chain is driven by the necessity to preserve the quality of perishable goods, including fresh fruits and vegetables, meat, fish, and dairy products. It is essential to maintain uninterrupted temperature control throughout the entire chain from production, through distribution, to the end consumer. The use of solutions such as time-temperature indicators (TTIs) enables real-time monitoring of conditions and provides a basis for operational decisions regarding further distribution or product withdrawal from the market.

Similar requirements exist in the pharmaceutical industry, where the stability of thermolabile drugs is of particular concern. In this context, cold chain operations are strictly regulated by standards such as Good Distribution Practice (GDP), and the transport and storage process must meet high-precision temperature criteria (typically in the 2-8°C range). This requirement applies, for example, to vaccines, biological preparations, and certain antibiotics, whose effectiveness directly depends on maintaining proper thermal conditions [Stajniak & Konecka 2014].

The applications of cold chain technologies and tracking systems also extend to other industries, including the transportation of plants, cut flowers, chemicals, and electronic components that are highly sensitive to temperature [Kumar et al. 2020]. In these cases, it is not only important to maintain the appropriate environmental conditions but also to precisely locate the product within the supply chain and analyze the conditions it experienced at various stages of transportation [PAHO 2006].

The implementation of monitoring solutions, regardless of the industry, brings several benefits, including enhanced product safety, improved traceability, and the ability to respond rapidly to observed deviations. Furthermore, monitoring systems support planning and logistics processes, allowing for supply chain optimization and reduction of losses resulting from poor quality management.

However, it is important to recognize that the implementation of advanced solutions involves certain challenges. Commonly cited barriers include high investment costs, the need to integrate data from multiple sources, and difficulties in interpreting spatiotemporal correlations. Nevertheless, technological advancements in this field are progressing rapidly with real-time systems, the integration of RFID and wireless sensor networks (WSN), and the use of artificial intelligence and cloud-based data processing tools becoming increasingly significant.

CONCLUSIONS

Cold supply chains are a fundamental element of modern logistics for temperature-sensitive products. Their effective management directly affects the quality, shelf life, and safety of food and pharmaceuticals. As demonstrated in this study, the implementation of modern technologies, strict process control, and cooperation among all links of the logistics chain are essential for maintaining product integrity from production to consumption. In the face of growing market demands and risks associated with cold chain disruptions, investment in the development and optimization of cold supply chains is becoming not only a necessity but also a strategic advantage for logistics providers and producers.

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ASSESSMENT OF WOMEN'S ATTITUDES TOWARDS PRODUCTS CONTAINING FIBER AND FATS

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Abstract

The aim of the study was to assess women's knowledge and attitudes regarding the consumption of dietary fiber and fats. Both nutrients play a key role in maintaining metabolic health and preventing diet-related diseases. A CAWI survey was conducted among 150 women under and over 35 years of age. Positive, neutral, and negative attitudes as well as actual eating behaviors were analyzed. The results revealed discrepancies between declared and actual practices and only partial awareness of healthy eating principles. The study highlights the need for enhanced nutrition education promoting fiber and unsaturated fat intake, considering generational differences.

Keywords: fats, dietary fiber, consumer attitudes, consumer behavior.

1. THE IMPORTANCE OF FATS AND DIETARY FIBER IN THE DIET

Proper nutrition plays a key role in maintaining the body's homeostasis, and its quality and quantity have a significant impact on metabolic, nutritional, and circulatory health [Bienkiewicz et al. 2015]. Dietary fiber and fats are among the components of the diet that specifically support the functioning of the body. Dietary fiber, defined as carbohydrates with a degree of polymerization above three that are not digested in the small intestine, performs numerous physiological functions, including regulating intestinal transit, supporting digestion and absorption of nutrients, and acting as a prebiotic by supporting the development of intestinal microflora [Galanakis & Charis 2019; Godula et al. 2019; Karwowska & Majchrzak 2015]. An adequate supply of dietary fiber contributes to reducing the risk of metabolic diseases, overweight, and obesity, and also helps regulate cholesterol and blood glucose levels [Bienkiewicz et al., 2015; Musioł et al., 2015]. Due to the growing interest in a healthy lifestyle, the importance of high-fiber functional foods is also growing, allowing for the enrichment of the diet with soluble and insoluble fiber and supporting the prevention of diet-related diseases [Grajeta 2004; Kozłowska-Strawska et al. 2017].

Fats, alongside fiber, play an equally important role in the diet. They are a source of energy, essential fatty acids (EFAs), and fat-soluble vitamins (A, D, E, K), affect the functioning of the nervous, endocrine, and circulatory systems, and participate in thermoregulation and the protection of internal organs [Gawęcki 2011; Wilczyńska 2012].

Many studies show women tend to have higher fiber intake and avoid high-fat foods more than men, driven partly by higher rates of dieting and prioritizing healthy eating. Research indicates that a higher fiber intake is linked to reduced weight and fat gain in women, while lower fiber consumption is associated with higher body fat mass [Al-Shammari et al. 2015; Anderson et al. 2009; Feraco et al. 2024; Nketia et al. 2022; Ruhee & Suzuki 2018; Platta 2020; Wardle et al. 2004].

Women are more likely to avoid high-fat foods, eat more fruits and fiber, and diet more frequently than men, according to a study of young adults in many countries. These choices are linked to women's greater involvement in weight control and stronger beliefs in the importance of healthy eating. Women often show a greater appeal for low-calorie foods [Feraco et al. 2024; Wardle et al. 2004].

Health outcomes is associated with fiber intake. A high-fiber diet has been linked to a lower risk of weight and fat gain in women. Studies have found that women with higher body fat percentages consumed less fiber, particularly from fruits, cereals, potatoes, and other vegetables. A high-fiber diet can promote metabolic, hormonal, and satiety effects in women, particularly in those who are obese and on a short-term calorie-restricted diet [Platta 2020; Triffoni-Melo et al. 2023; Tucker & Thomas 2009].

Understanding consumer behavior regarding fiber and fat consumption is important in the context of preventing diet-related diseases, promoting a healthy lifestyle, and effectively designing functional foods. Analyzing consumer preferences and practices allows not only for assessing the degree of adherence to dietary recommendations but also for identifying barriers to implementing healthy eating habits in women's daily diets. Therefore, the aim of this study was to assess women's attitudes toward products containing dietary fiber and fat, taking into account their age as the main differentiating factor.

2. MATERIAL AND METHODS

The survey was conducted from November 2024 to February 2025. A proprietary electronic questionnaire was used to collect data via the Microsoft Forms platform (CAWI – Computer-Assisted Web Interview). Pilot studies were conducted, and the questionnaire was validated. Subsequently, a full-scale survey was conducted.

A total of 150 women participated in the survey (detailed data are presented in Table 1). Three basic demographic variables were analyzed, allowing for a detailed characterization of the respondents: age, education level, and place of residence, taking into account the population size.

With respect to age, the study group was divided into two groups: women under 35 years of age constituted 51% of all respondents (n = 76), while women over 35 years of age constituted 49% (n = 74). This means that the sample was almost evenly distributed in terms of age, allowing for cross-group comparisons. In terms of education, the largest group consisted of those with higher education (46%, n = 69), followed by those with secondary education (34%, n = 51). Female students constituted 12% (n = 18), and those with vocational education (8%, n = 12). Individuals with only primary education did not participate in the study.

In terms of place of residence, respondents came from a variety of demographics. The majority of participants lived in cities with up to 50,000 inhabitants (31%, n = 46). Next, the largest groups were those living in cities with 150,000 to 500,000 inhabitants (23%, n = 35), followed by rural areas (15%, n = 22), and cities with 50,000 to 150,000 inhabitants (15%, n = 23). Women from the largest cities, with populations exceeding 500,000, constituted 16% of the sample (n = 24).

Table 1. Characteristics of the surveyed group of respondents

Variable		Number of indications (n)	% of indications
Age	Under 35 years old	76	51
	Over 35 years old	74	49
Education	Primary	0	0
	Secondary	51	34
	Vocational	12	8
	Female students	18	12
	Higher	69	46
Place of residence – number of inhabitants	Countryside	22	15
	up to 50 thousand	46	31
	50–150 thousand	23	15
	150–500 thousand	35	23
	> 500 thousand	24	16

Source: own study.

The assessment of consumer attitudes was conducted in two stages.

1. Assessment of consumer attitudes categorized as positive, negative, and neutral.

Respondents were asked to rate their level of agreement with the statements using a five-point Likert scale, with responses ranging from: strongly disagree (1), disagree (2), no opinion (3), agree (4) and strongly agree (5).

The questions addressed three categories of attitudes:

- Positive attitudes (P), indicating awareness and concern for the quality of their diet.
- Neutral attitudes (Ne), suggesting a lack of a firm stance.
- Negative attitudes (N), which may indicate an incorrect approach to the role of fats in nutrition.

2. Assessment of respondents' actual eating behaviors

Respondents had the opportunity to rate each statement on a five-point Likert scale, with the following responses: 'strongly disagree', 'disagree', 'no opinion, 'agree, and 'strongly agree'.

3. RESULTS AND DISCUSSION

In the case of positive nutritional attitudes, the results suggest a high level of awareness in both age groups. For example, as many as 59% of women under 35 and 65% of older women declared that they 'ensure their diet is rich in dietary fiber'. In turn, 63% of younger women and 77% of older women stated that they 'ensure their diet is rich in healthy fats'. Data are presented in Table 2. These results indicate women's high willingness to implement healthy eating principles, which is consistent with the literature emphasizing women's growing interest in a healthy lifestyle [Kołłajtis-Dołowy et al. 2007; Wądołowska et al. 2013].

Table 2. Assessment of women's attitudes

Statements	Age group of respondents	Answers*				
		1	2	3	4	5
It's important to me that my diet is low in fat (P)	Under 35	8	36	36	20	0
	Over 35	11	23	35	23	8
I make sure my diet is rich in dietary fiber (P)	Under 35	1	16	24	43	16
	Over 35	4	0	31	53	12
I make sure my diet is rich in healthy fats (P)	Under 35	1	10	26	50	13
	Over 35	6	0	17	62	15
I'd rather eat products enriched with dietary fiber (P)	Under 35	1	7	34	54	4
	Over 35	6	1	25	54	14
I believe I eat enough dietary fiber daily (P)	Under 35	0	37	26	34	3
	Over 35	3	19	44	26	8
I don't worry about the quality of the fats I consume (N)	Under 35	17	41	12	28	2
	Over 35	24	34	14	23	5
The health benefits of fats don't influence my choices (N)	Under 35	16	35	32	17	0
	Over 35	16	28	26	22	8
I believe that fats have a negative impact on body weight (N)	Under 35	20	39	12	25	4
	Over 35	12	28	17	28	15
I believe fats should be avoided (N)	Under 35	32	43	12	13	0
	Over 35	11	49	14	19	7
I don't pay attention to the type of fat I fry with. I believe any type of fat can be used for frying (N)	Under 35	46	36	8	8	2
	Over 35	27	51	10	4	8

1 – strongly disagree, 2 – disagree, 3 – no opinion, 4 – agree, 5 – strongly agree.
* values n given in %

Source: own study.

In the case of neutral attitudes, which may suggest a lack of specific nutritional beliefs, such as statements like 'I don't care about the quality of fats' or 'the health benefits of fats don't influence my choices', the results were mixed. Although the majority of respondents in both groups disagreed with these statements, the percentage of those declaring no opinion reached as high as 32% among younger women and 26% among older women, which may indicate the need for further education in this area.

Negative attitudes, reflecting persistent nutritional myths, were also identified. As many as 19% of women over 35 years of age completely agreed with the statement 'fats have a negative impact on body weight', and 8% with the statement 'fats should be avoided'. Although the majority of respondents generally rejected these claims, the results confirm the existence of certain incorrect beliefs about fats that can lead to dietary errors – a fact also emphasized by the study authors, who point to an insufficient understanding of the role of fats among consumers [Pilska 2020].

A particularly disturbing fact is that as many as 10% of women over 35 agree with the statement that 'you can fry in any type of fat', which may have direct health consequences, including an increased risk of developing cardiovascular disease [Szostak-Węgierek 2013].

Based on the results, it was found that the women participating in the study demonstrated moderate to high awareness of the importance of fats and dietary fiber, particularly with regard to positive attitudes. However, the noticeable level of uncertainty and the presence of negative beliefs among some respondents, especially in the group over 35, indicate the need for consistent educational activities based on sound dietary knowledge. It is recommended to promote knowledge about the quality of fats, the role of fiber in the diet, and counteract widespread nutritional myths.

Another aspect analyzed within the study was the assessment of respondents' actual behaviors related to fat and fiber consumption. The aim of this stage was to determine which dietary practices dominate women's daily choices and to what extent they align with current dietary recommendations.

Similarly, to the attitude assessment, the surveyed women were asked to express their opinions on ten statements regarding daily purchasing and culinary decisions related to sources of fat and fiber. Data are presented in Table 3.

Table 3. Assessment of women's behavior in relation to actual activities in terms of fat and dietary fiber consumption

Statements	Age group of respondents	Answers*				
		1	2	3	4	5
I'm more likely to use olive oil for frying than sunflower oil	Under 35	14	17	15	25	29
	Over 35	9	32	7	36	16
I'm more likely to use heavy cream butter than extra-virgin butter for spreading on bread	Under 35	15	22	33	25	5
	Over 35	8	24	22	31	15
I use vegetable fats more often for frying than, for example, as a salad dressing	Under 35	7	16	20	50	7
	Over 35	18	23	16	32	11
I'm reluctant to eat fatty cottage cheese and other full-fat products	Under 35	18	33	16	33	0
	Over 35	12	38	16	27	7
I only use animal fats for frying. I consider them the best choice	Under 35	42	37	16	3	2
	Over 35	23	50	14	9	4
I'm reluctant to eat multigrain products	Under 35	22	34	17	20	7
	Over 35	17	31	7	38	7
My main source of dietary fiber is fruits and vegetables	Under 35	0	24	18	45	13
	Over 35	5	12	18	57	8
I usually choose products made with wheat flour rather than whole grains	Under 35	11	29	13	45	2
	Over 35	16	32	15	30	7
When I eat more fiber-rich foods throughout the day, I feel fuller longer	Under 35	0	2	37	45	16
	Over 35	3	7	39	43	8

1 – strongly disagree, 2 – disagree, 3 – no opinion, 4 – agree, 5 – strongly agree.
* values n given in %

Source: own study.

The study also assessed the respondents' actual dietary behaviors, including their choices of products that were sources of fat and dietary fiber. The data collected in Table 3 reflected the degree to which women of different ages identified with individual statements, allowing for an in-depth analysis of their dietary practices in relation to current dietary recommendations.

Women under 35 years of age, as many as 54% of respondents declared that they would prefer to use olive oil for frying over sunflower oil. Among older women, this percentage was 52%. This choice may have resulted from the growing awareness of the health-promoting properties of olive oil, which is considered a source of monounsaturated fatty acids and antioxidants. Similar conclusions were presented by [Covas el al. 2006], who demonstrated that olive oil consumption has a beneficial effect on lipid profiles and reduces the risk of cardiovascular disease. Regarding the use of butter for spreading, respondents' attitudes were more diverse – 30% of younger women and 46% of older women expressed approval for the more frequent use of cream butter than extra-cream butter. These results could reflect a preference for traditional products or a belief that they are more natural. Similar phenomena were described by [Świątkowska et al. 2022], indicating the influence of cultural habits on consumer choices.

Among the respondents, 57% of younger and 43% of older women were more likely to use vegetable fats for frying than, for example, as salad dressings. This result could indicate a greater prevalence of modern food preparation methods among younger respondents, such as stir-frying, which could be inspired by the Mediterranean diet. Similar observations were noted by [Rybicka et al. 2024], who analyzed consumer preferences regarding fat selection. Women declared that they did not consume fatty cottage cheese and other full-fat products – 51% of younger and 50% of older women expressed their reluctance in this regard. These responses may have stemmed from persistent beliefs that full-fat products have a negative impact on body weight and health. However, more recent data indicate that consuming full-fat dairy products in moderate amounts can have a positive impact on health, as emphasized by [Thorning et al. 2016].

Women participating in the study (as many as 79% of younger women and 73% of older women) declared that they rarely choose animal fats for frying. Most respondents expressed disapproval. These responses confirmed a high awareness of the harmful effects of excess saturated fat on cardiovascular health, consistent with research by Micha and Mozaffariana [2009]. Women are reluctant to consume multigrain products, as confirmed by their declarations – 27% of younger women and 45% of older women. In turn, as many as 47% of younger women and 37% of older women confirmed that they more often choose products made with wheat flour than whole grains. These results could suggest sensory barriers or a lack of knowledge about the higher nutritional value of whole grain products. Meanwhile, according to research [Slavin 2013], regular consumption of whole grain products is associated with a reduced risk of many lifestyle diseases, including type 2 diabetes and obesity.

Women were observed to be aware of the sources of fiber in their diet. As many as 58% of younger women and 65% of older women declared that, in their case, it comes mainly from fruits and vegetables. Fruits and vegetables are, alongside cereal products, among the most valuable sources of dietary fiber [Anderson et al. 2009].

Respondents participating in the study declared that consuming fiber-rich foods makes them feel fuller longer. This was confirmed by 61% of younger women and 51% of older women. This result was consistent with the literature – studies have confirmed that fiber consumption increases the feeling of fullness, which may positively impact weight control [Wanders et al. 2011].

The study revealed relatively good dietary behaviors among respondents, particularly in terms of avoiding animal fats and preferring plant fats and fruits and vegetables as sources of fiber. At the same time, areas requiring education were identified, including greater awareness of the benefits of whole grain products, and expanding knowledge about various sources of fiber. Due to intergenerational differences, it is recommended to conduct informational activities that take into account the communication preferences of both age groups.

CONCLUSIONS

The study aimed to assess women's attitudes and behaviors toward dietary fats and fiber and to identify differences between women under and over 35 years of age.

The observed discrepancy between declared attitudes and actual eating behaviors indicates that nutritional knowledge alone does not translate into practice. This suggests that educational initiatives should not only provide information but also include practical tools that facilitate behavioral change.

Women most frequently identified nuts, olive oil, and vegetables and seeds as main sources of healthy fats and fiber, demonstrating partial alignment with dietary recommendations. However, the limited variety of indicated sources suggests that awareness does not always ensure dietary diversity.

The findings highlight the necessity of ongoing nutrition education campaigns emphasizing the health benefits of unsaturated fats and dietary fiber. These programs should be tailored to communication preferences: younger women respond better to social media outreach, whereas older women benefit more from traditional or institutional channels.

Effective nutrition interventions should integrate educational content with actionable guidance-such as meal planning, food selection, and preparation techniques-to translate awareness into sustained healthy eating practices.

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SILICONES USED IN COSMETICS AND THEIR SUSTAINABLE SUBSTITUTES

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Abstract

This review explores the widespread use of silicones in cosmetic formulations, highlighting their functional benefits, and emerging environmental, and health concerns. It examines the chemical nature, applications, and regulatory status of key compounds such as D4 and D5, which are suspected as persistent, bioaccumulative, and toxic. In response, the industry is increasingly shifting towards sustainable alternatives, including plant-derived esters and biopolymers, which offer comparable performance with improved ecological profiles. The study underscores the need for ongoing research, regulatory oversight, and innovation to ensure the safe and sustainable use of cosmetic ingredients.

Keywords: silicones, cosmetics, sustainability, quality of cosmetics.

INTRODUCTION

Silicon (Si), the fundamental element for producing all silicone-based substances, is the second most plentiful element in the Earth's crust, following oxygen. It naturally occurs in forms such as quartz, sand, and even in plant husks. Silicones, which are synthesized from quartz a mineral consisting of silicon and oxygen-belong to a diverse group of polymers known for offering a variety of material properties. The term 'silicone' refers to commercially used polymers made up of siloxane chains, where silicon atoms are interconnected by oxygen atoms, resulting in distinctive silicon–oxygen (Si–O) bonds [Ivanova et al. 2023; Kostic 2021].

Since their incorporation into the cosmetics industry, silicones have established themselves as vital constituents in a wide range of daily formulations, particularly in hair and skincare products. Their emollient and semi-occlusive properties contribute to enhanced skin hydration and soothing effects, while minimizing the perception of oiliness or residue on the skin [de Castro et al. 2025].

The growing consumer demand for advanced and multifunctional personal care products has prompted manufacturers to develop innovative formulations tailored to evolving preferences. The design of novel cosmetic products requires careful consideration of various parameters, including aesthetic appeal, rheological behavior, texture, ease of removal, and functional properties such as UV protection, antioxidant activity, and moisturization. In recent decades, silicones have gained increasing prominence in contemporary cosmetic formulations. Notably, their initial application in personal care products dates back to the 1940s. Since then, the production and utilization of silicone-based ingredients in cosmetics have expanded significantly. It is important to note that the term 'silicone', commonly used in the cosmetics industry, encompasses a wide array of compounds characterized by diverse solubility profiles and unique physicochemical properties [Olejnik et al. 2022].

Silicones possess a unique combination of physicochemical properties that render them particularly well-suited for personal care applications. Their biocompatibility, chemical inertness, lubricity, and low surface energy, along with favorable sustainability characteristics, contribute to their growing preference in the formulation of cosmetic products. One of the distinct advantages of silicones lies in their structural versatility, which allows for the molecular tailoring of compounds to meet specific functional requirements through a wide array of synthetic pathways. Although the personal care industry has long recognized the functional benefits of silicones, their integration into high-value, multifunctional cosmetic formulations remain relatively limited. This slower rate of adoption is primarily attributed to compatibility challenges with organic formulation matrices. However, these limitations can be effectively addressed by designing silicone-based compounds with integrated organic moieties at the molecular level, thereby enhancing formulation compatibility.

Key functional advantages of silicones in cosmetic science include:

1. Exceptional spreading and skin penetrability due to their inherently low surface and interfacial tensions.

2. High biocompatibility and chemical stability across a broad pH and temperature range, owing to their hybrid organo-inorganic structure.
3. Ease of formulation and processing, facilitated by their broad liquid-phase temperature range (from –55 °C to +320 °C) and variable molecular weights (300 to 300,000 Da).
4. Superior oxygen permeability of silicone films, resulting from approximately fivefold greater oxygen solubility compared to conventional polymers.
5. Enhanced tactile performance, including smooth glide, soft texture, and non-tacky feel, attributable to low cohesive forces and minimal surface energy.
6. Synthetic flexibility, allowing for the incorporation of diverse functionalities at the molecular level to improve compatibility and performance.
7. Effective moisture control, both on the surface and within the bulk, due to the hydrophobic and low-energy nature of silicone materials.
8. Improved optical properties, such as gloss and shine, resulting from high refractive indices and optical clarity.

While numerous additional benefits of silicones continue to emerge, the aforementioned attributes represent the core functionalities that are currently leveraged across diverse applications. These features underpin the strategic value of silicones in four key application domains within the personal care industry, where their roles are both well-established and continuously evolving [Sayyed & Kulkarni 2022].

It is well established that silicones are extensively incorporated into a wide variety of personal care formulations, owing to their multifunctional roles. In sunscreen products-including lotions, skin creams, and foundations-silicones enhance water resistance, increase the sun protection factor (SPF), and reduce the tackiness typically associated with organic UV filters. Within hair care applications, such as conditioners, shine sprays, anti-frizz serums, and shampoos, silicones contribute to improved hydration, enhanced shine, frizz control, ease of detangling, and protection against further hair damage. In skin care products-including anti-aging serums, acne treatments, and moisturizing creams-silicones impart a smooth, silky texture to the skin, help mask fine lines, and contribute to a more youthful and healthy appearance. In deodorants and antiperspirants, including gels, roll-ons, sticks, and aerosols, silicones improve skin feel, enhance spreadability, and reduce both the whiteness and tackiness of antiperspirant salts. In color cosmetics such as lipsticks, eye shadows, foundations, primers, and powders, they support long-wearing performance, color intensity, homogeneity, transfer resistance, luminosity, and user comfort.

The performance advantages of silicones arise from a combination of surface and bulk properties, which collectively contribute to their distinctive functional profile. These include low surface tension, favorable spreading and migration (or 'creep') behavior, moderate interfacial tension with water, versatile structural configurations, low surface viscosity, high free volume, low activation energy for viscous flow, low glass transition temperatures, minimal thermal variation of physical properties, liquid state at high molecular weights (in linear polymers), low pour and freezing points, low boiling points in oligomeric forms, high compressibility, and elevated permeability to gases and low-molecular-weight compounds. Furthermore, silicones exhibit outstanding resistance to environmental weathering.

This chapter explores the molecular engineering of silicones, their functional roles in cosmetic formulations, and their implications for environmental sustainability. Additionally, it provides several alternatives of replacing silicones with more environmentally friendly substitutes, underscoring their value in sustainable product development [Sayyed & Kulkarni 2022].

1. SILICONES IN COSMETICS

The global cosmetics market generated a revenue of USD 295,950.2 million in 2023 and is expected to reach USD 445,977.7 million by 2030 [https://www.grandviewresearch.com]. In 2023, the global market for silicones used in personal care products was valued at approximately USD 3.17 billion, with forecasts indicating a compound annual growth rate of 6.0% between 2024 and 2030 (Figure 1). The increasing emphasis on personal hygiene, growing disposable income across various regions, and the expanding impact of social media are expected to drive the demand for silicones in the production of a wide range of personal care items, including shampoos, conditioners, serums, sunscreens, body lotions, and cosmetic products such as lipsticks and eyeliners [https://www.grandviewresearch.com].

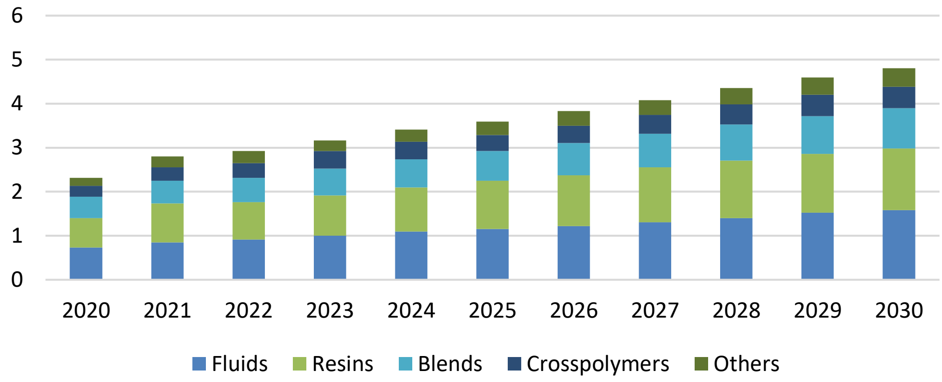


Figure 1. Global silicone in personal care market, USD Billion

Source: https://www.grandviewresearch.com.

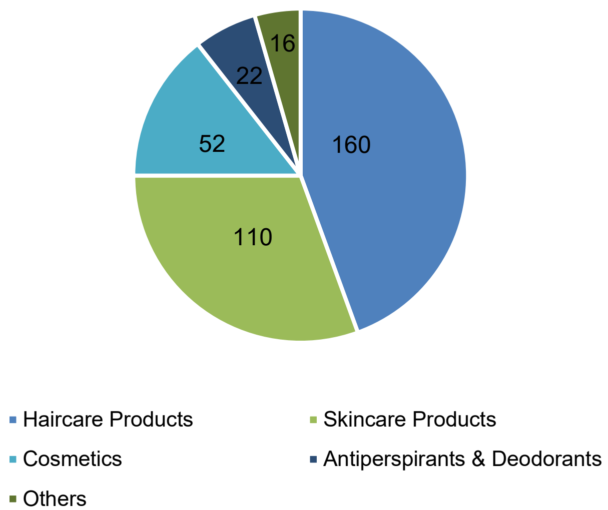


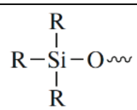
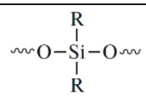
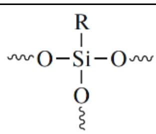
Figure 2. Global silicone in personal care market share, by application 2023 [%]

Source: https://www.grandviewresearch.com.

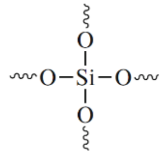
In terms of application segments, the haircare category dominated the market in 2023, accounting for over 45.0% of total revenue. Silicones function as protective agents, forming a smooth, uniform coating over individual hair fibres. This not only enhances surface alignment, resulting in a sleek and polished appearance, but also contributes to optical brilliance through light-reflective properties, imparting a glossy and healthy-looking finish. The skincare segment represented more than 29.0% of market revenue in the same year. In these formulations, silicones play a key role in moisture retention by forming a semi-permeable, breathable film on the skin, which reduces transepidermal water loss and promotes sustained hydration. Additionally, their ability to fill fine lines and surface irregularities creates a uniform texture that serves as an ideal substrate for the application of foundation and other cosmetic products, thereby improving overall makeup performance. [https://www.grandviewresearch.com].

The rising prominence of silicones in cosmetic formulations over recent years can be largely attributed to advancing scientific research into their distinctive functional attributes. An enhanced understanding of their physicochemical properties, coupled with increasing expertise in the structural modification and synthesis of silicones with diverse molecular architectures, has significantly expanded their applicability across a broad spectrum of personal care products. Notably, silicones and their derivatives serve multiple roles in cosmetic systems, functioning as emollients, moisturizers, surfactants (including emulsifiers), antistatic and binding agents, film-forming agents, defoamers, and rheology modifiers [Ivanova et al. 2023].

Table 1. Type of silicones and shorthand notation

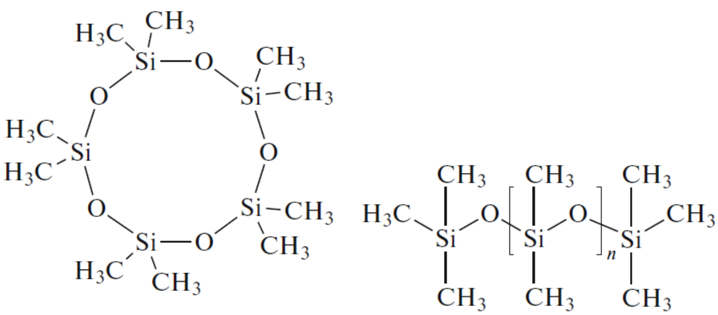
Notation	Structural features	Structural formula
M	Monosubstituted (one oxygen atom per silicon atom)	
D	Disubstituted (two oxygen atoms per silicon atom)	
T	Trisubstituted (three oxygen atoms per silicon atom)	

cont. Table 1

Q	Tetrasubstituted (four oxygen atoms per silicon atom)	

Source: Ivanova et al. 2023; Kunik et al. 2019.

The nomenclature employed for classifying siloxane compounds is based on the use of the letters M, D, T, and Q, which denote the number and type of siloxane structural units forming the molecular backbone. These designations are elucidated in Table 1. Among the most prevalent constituents in cosmetic formulations are methyl-substituted siloxanes, particularly polydimethylsiloxanes (PDMS). These compounds are generally found in two primary configurations: linear and cyclic, as illustrated in Figure 3. Cyclomethicone and dimethicone serve as representative examples of these structures, corresponding to the cyclic and linear forms, respectively [Ivanova et al. 2023].



A B

Figure 3. The structure of A – cyclomethicone and B – dimethicone

Source: Ivanova et al. 2023; Kunik et al. 2019.

In cosmetic applications, silicones, and their derivatives fulfill a variety of functional roles, acting as emollients, humectants, surfactants (particularly as emulsifiers), film-forming agents, antifoaming agents, viscosity modifiers, antistatic agents, and binding agents. A key advantage of silicones lies in their physiological inertness, which enhances both their biocompatibility and chemical stability upon topical application. Their widespread incorporation spans multiple product categories, including hair care, body washes, deodorants, and antiperspirants, shaving formulations, decorative cosmetics, and skin care products [Kostic 2021].

2. ALTERNATIVES FOR SILICONES

Sustainability has become a pivotal focus within the cosmetics and personal care sector, aligning industry practices with principles of environmental integrity and social responsibility. Sustainability in this context can be examined across three interrelated dimensions: individual-level sustainability, community-based sustainability, and global environmental sustainability. Each dimension presents distinct challenges and opportunities for fostering systemic and enduring transformations in product design and consumption [Lochhead 2024].

Despite their long-standing characterization as environmentally benign, the pervasive use of silicones has led to increased scrutiny. Recent toxicological and ecological evaluations have highlighted potential adverse effects on biotic systems, warranting ongoing environmental monitoring. Nevertheless, assessments by regulatory bodies such as the Cosmetic Ingredient Review (CIR) Expert Panel have affirmed the safety of widely used silicones, including amodimethicone and dimethicone, within current usage concentrations. Similarly, the Scientific Committee on Consumer Safety (SCCS) initially endorsed the use of octamethylcyclotetrasiloxane (D4) and decamethylcyclopentasiloxane (D5), the principal cyclic volatile methylsiloxanes, although this recommendation has since been restricted to specific applications such as hair styling aerosols and sunscreen sprays [Kostic 2021; Sayyed & Kulkarni 2022].

Silicones have been integral to cosmetic formulations for decades; however, escalating concerns about their toxicological profiles have emerged, especially in light of novel health and environmental challenges. Cyclopentasiloxane (D5), derived from D4, has undergone extensive toxicological assessments due to reported associations with reproductive toxicity in animal models, such as guinea pigs, following inhalation. Research has predominantly focused on inhalation and dermal exposure routes-primary pathways for human contact. Documented toxicological outcomes include uterine endometrial adenocarcinomas in rodents, transient pulmonary inflammation, perturbations in dopaminergic signalling, and hepatic hypertrophy [de Castro et al. 2025].

D4 and D5 are the most frequently utilized silicones in personal care products and exhibit a high affinity for adsorption onto organic material present in sludge, sediments, and soils. Under aerobic conditions, the degradation half-life in sediments is approximately 242 days for D4 and exceeds 1,200 days for D5 at 24 °C. Once volatilized into the atmosphere, both compounds exhibit atmospheric half-lives of around 13 days. Empirical studies have detected silicone residues within aquatic food webs, with peak concentrations near emission sources. Bioaccumulation has been confirmed in fish, avian species, and mammals, although oral exposure pathways remain poorly understood. The lipophilic nature of these substances facilitates their storage within adipose tissue. According to the European Chemicals Agency (ECHA) Annex XV restriction dossier, D4 fulfills the classification criteria for persistent, bioaccumulative, and toxic (PBT), as well as very persistent and very bioaccumulative (vPvB) substances. D5 is similarly categorized as a vPvB compound. D4 is also classified under reproductive toxicity category 2, based on data from both aquatic and mammalian studies. It is estimated that annually, approximately 4.7 tonnes of D4 and 205 tonnes of D5 are released into surface waters within the European Union, with the majority of emissions originating from wash-off personal care products. These applications account for 95% of D5 and 63% of D4 discharges, thus posing the highest environmental threat [Kostic 2021; Martins & Marto 2023; Sayyed & Kulkarni 2022].

As awareness of silicone-related environmental issues grows, alternatives derived from plant-based oils and esters are being actively developed. These substitutes are favored due to their low viscosity, superior skin compatibility, biodegradability, and limited aquatic toxicity. They can be classified based on their source as organic, natural, naturally derived, or nature-identical compounds. Their functional attributes include a lightweight sensory profile, rapid spreading, effective pigment dispersion (notably in sunscreen formulations), enhanced hydration, and a velvety skin finish. Many such alternatives are synthesized from enzyme-catalyzed branched esters, which are economical and environmentally sustainable, owing to mild synthesis conditions (ambient temperature, solvent-free, and free from toxic catalysts), resulting in high-purity products that require minimal post-synthesis processing [de Castro et al. 2025].

Ongoing research aims to identify effective replacements for conventional silicones. Structural modifications such as the ethoxylation and propoxylation of silicones have yielded derivatives with favorable safety profiles and desirable surface activity. These compounds not only exhibit reduced toxicity but may also counteract irritative effects from other formulation components [Sułek & Zięba 2010].

One promising alternative involves the use of polycitronellol homopolymers. Emulsions incorporating these biopolymeric substances have demonstrated acceptable moisturizing efficacy, favorable sensorial attributes, and high consumer approval. These findings support the feasibility of substituting traditional emollients with sustainable counterparts without compromising user satisfaction [Denois 2022; Meneguello et al. 2025].

Investigations into mixtures of natural oils and esters as silicone alternatives reveal that such combinations offer potent hair-conditioning effects. Esters particularly those with branched-chain structures are favored due to their fluidity across a broad temperature range, which enhances their tactile performance. Unlike linear analogues, branched esters exhibit disrupted molecular stacking, reducing London dispersion interactions and thereby providing superior skin feel and spreadability. These compounds are typically synthesized using classical high--temperature methods and inorganic catalysts, resulting in formulations that are lighter, less greasy, and better absorbed. Several of these esters are already commercially available as alternatives to D4 and D5 [Bom et al. 2020; Ferreira et al. 2024; Golemanov et al. 2024].

CONCLUSIONS

Heightened scrutiny of volatile methylsiloxanes stems from evidence indicating potential toxicity to multiple organ systems. As certain cyclosiloxanes have been classified as PBT or vPvB substances, their use is regulated under the European Union's REACH framework (Registration, Evaluation, Authorisation and Restriction of Chemicals). Regulatory restrictions currently limit the concentration of D6 in rinse-off cosmetics and D4, D5, and D6 in leave-on products to no more than 0.1% by weight. In May 2019, D4 was added to Annex II of the EU Cosmetic Regulation 1223/2009, thereby prohibiting its intentional inclusion in cosmetics sold within the EU. Although linear silicones may exhibit similar persistence and bioaccumulation characteristics, further studies are necessary to determine their risk classification and regulatory status. Nonetheless, the implementation of precautionary measures appears warranted given their ubiquity.

Given the widespread integration of silicones across industries – including pharmaceutical, medical, food, and particularly cosmetic sectors – it is imperative to intensify monitoring of their environmental emissions, promote independent scientific evaluation, and increase awareness of their potential ecological and human health impacts. Notably, over 50% of newly launched cosmetic products in the past decade contain at least one silicone-based compound, emphasizing the critical need for responsible management and sustainable innovation in formulation science.

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SAFETY AND QUALITY OF CHILDREN'S FOOTWEAR IN THE LIGHT OF THE REQUIREMENTS FOR THE 'HEALTHY FOOT' AND 'ŽIRAFA' LABELS

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Abstract

Footwear is an environment that shapes a child's feet and protects them from harmful external factors. However, poor quality footwear can be a source of danger to the developing organism. EU legislation does not contain mandatory directives which are dedicated exclusively to children's footwear. Therefore, it is not possible to use the CE mark, informing about compliance with regulations (as is the case with toys).

In such a situation manufacturers of children's footwear can only voluntarily assess their products in the procedures for awarding quality marks or labels.

The chapter discusses and compares the procedures for voluntary assessment of footwear for the Polish 'Healthy Foot' label and the Czech 'Žirafa' labels.

Keywords: quality, product safety, children footwear, Healthy Foot label, 'Žirafa' label.

INTRODUCTION

Footwear is an environment that shapes a child's feet. Shoes also play a critical role in shaping the structure of a child's feet and serve as a protective barrier against harmful external factors. In the context of children's footwear, its primary function is to support the proper development of the feet. To fulfill this role effectively, children's shoes must be designed with careful consideration of foot shape, dimensions, and biomechanics, while also ensuring an adequate internal microclimate. Footwear of inadequate quality may pose significant risks to the developing body.

According to a report by the Office of Competition and Consumer Protection (UOKiK), among 208 inspected batches of footwear, 63 were found to have non-compliances, particularly in product labeling and the presence of substances hazardous to health most notably the biocide dimethyl fumarate (DMF).

It is important to note, however, that the scope of the inspection did not include other critical criteria essential for ensuring product safety, such as the evaluation of shoe dimensions and shape, the integrity of decorative elements, or the finish of shoelaces.

What is important, an analysis of data from the European Union's Rapid Alert System for Dangerous Non-Food Products RAPEX (since 2023: Safety Gate) shows that the most frequently cited risks included non-compliance with chemical safety standards. Also, the risk of choking of small components such as decorative elements was cited. The notifications pertained to hazards arising from inappropriate shoe construction, which could potentially lead to foot deformities were a minority [https://ec.europa.eu/safety-gate-alerts].

There are no obligatory EU directives which are dedicated to children's footwear. As a result, it is not possible to apply the CE mark to children's shoes to indicate compliance with specific EU regulations, as is the case with toys. For consumers, the presence of the CE mark on a product typically implies compliance with stringent quality and safety standards.

The CE marking appears on children's footwear only when the product is classified as a Class I medical device. However, not all children's footwear qualifies under this classification. Polish manufacturers of children's shoes often pursue voluntary assessment procedures to obtain alternative, recognizable quality and safety labels that inform consumers of product compliance with safety standards-such as the 'Healthy Foot' label.

This complex regulatory situation is not unique to Poland but is observed throughout Europe. In most European countries, footwear certification is voluntary. Mandatory requirements are usually limited to hygiene parameters and the content of harmful substances [Mayerová & Kocourek 2012].

When discussing the safety aspects of children's footwear, it is essential to consider that children's feet are in contact with shoes for many hours daily. The absence of controls over dimensions, shapes, harmful substances, and hygiene--related properties of footwear materials poses a tangible risk to children's health and safety.

As previously noted, children's footwear is not subject to the same strict oversight as children's toys. The currently applicable Directive 2009/48/EC (commonly known as the Toy Safety Directive or 'TOYS') mandates that all toy manufacturers and importers selling to the EU market comply with harmonized regulations and standards aligned with this directive.

Under current legislation, children's footwear is only subject to mandatory assessment in terms of labeling requirements, as outlined in:

- The Regulation of the Council of Ministers of 19 October 2004 on additional labeling requirements for footwear intended for sale to consumers [Journal of Laws 2004 No. 240, item 2409].
- The Act of 12 December 2003 on General Product Safety [Journal of Laws 2003 No. 229, item 2275].

According to these documents, footwear is defined as a group of products 'with soles, intended to protect or cover the lower limbs, including the individual components comprising footwear'. The regulation governs the labeling of footwear with regard to the materials used in the upper, lining, insole, and outer sole components. Permissible markings include verbal descriptions or pictograms specified in the regulation.

Another binding legal document is Regulation (EC) No 1907/2006 (REACH), which aims to ensure a high level of protection for human health and the environment. Notably, the control of chemical substances in consumer products remains limited, despite these products being a significant source of chemical exposure [Ingre-Khans et al. 2010].

Importantly, both in Poland and across the European Union, there are no mandatory regulations specifying the internal shape or dimensions of children's footwear. This regulatory gap significantly impacts product safety. Improper footwear dimensions pose real risks to children's feet, including the development of toe deformities [González-Elena et al. 2021].

The only applicable, though non-binding, Polish regulation is the standard PN-O-91015:2000: 'Footwear for children up to 15 years of age. Material and construction requirements for shoe lasts and footwear, and test methods'. Other detailed standards that once regulated footwear interior dimensions-such as PN-O-91010:1987 (Footwear – Sizing) and PN-O-91055:1987 (Shoe lasts – Sizing) have been withdrawn. These are now used solely in voluntary certification procedures such as the 'Healthy Foot' program, which has been conducted for over 30 years by the Leather Industry Institute in Łódź (currently: Lukasiewicz Lodz Institute of Technology) [Rajchel-Chyla et al. 2012a].

Expanding the review to include ISO and European footwear standards, 124 ISO documents were identified covering general footwear terminology, sizing systems, and testing methods for components and finished footwear. However, no ISO standard was found to be exclusively dedicated to children's footwear. Nevertheless, the British research organization SATRA (Shoe and Allied Trades Research Association) recommends the use of selected EN 71 toy safety standards for assessing children's footwear.

Relevant examples include:

- EN 71-1: Safety of Toys – Mechanical and Physical Properties,
- EN 71-3: Safety of Toys – Migration of Certain Elements.

According to SATRA, elements of these standards may be suitably applied to test footwear and its components.

In light of the current regulatory environment, children's footwear manufacturers can only pursue voluntary certification for quality assessment. In Poland, two major institutions offer such certification:

- The Lukasiewicz Lodz Institute of Technology, through the 'Healthy Foot' label,
- The Institute of Mother and Child, which issues a positive opinion for suitable products.

In the Czech Republic, a comparable certification program exists through the Czech Footwear and Leather Association, which awards the 'Žirafa' (Giraffe) label.

This article presents a comparative overview of the voluntary assessment procedures for children's footwear in Poland and the Czech Republic, focusing on the 'Healthy Foot' and 'Žirafa' certification systems, respectively, and analyzes the broader regulatory and normative framework governing the safety and quality of children's footwear in the European Union.

1. MATERIAL AND METHODS

In this article, the documentation related to the certification procedures for awarding the 'Healthy Foot' and 'Žirafa' labels was subjected to detailed analysis. Each procedure was reviewed based on the available official documents.

In the case of the 'Healthy Foot' label, the following documents were examined:

- The Regulations for Awarding the 'Healthy Foot' label (hereinafter: the Regulations),
- Appendix 1 to the Regulations,
- Appendix 2 to the Regulations,
- Appendix 3 to the Regulations.

For the 'Žirafa' label, the analysis covered the following documents:

- The Certification Regulations (Zkušební předpis ČOKA 1-2013 Třídění a měření obuvi),
- The Technical Specification (Technická Specifikace TS ČOKA 2–2013).

The analysis focused on identifying differences in the requirements, procedures, and evaluation criteria of both systems, as well as highlighting areas of convergence and consistency between them.

2. RESULTS

2.1. Requirements for 'Healthy Foot' label

In Poland, one of the earliest labels applied to children's footwear was the 'Healthy Foot' label, awarded to footwear that supports the proper development of the foot. Today, the 'Healthy Foot' label remains one of the most recognizable quality labels for children's shoes. It has been granted for over 30 years by the Committee of Specialists for the Assessment of Children's Footwear, composed of experts in anthropology, footwear design, manufacturing technology, and material science at the Lukasiewicz – Lodz Institute of Technology. The 'Healthy Foot' label is presented in Figure 1.

- The mark applies to footwear designed for children up to the age of 15. To be eligible for certification, footwear must meet comprehensive construction, technological, and material requirements that ensure the proper development of children's feet. These include the provisions of the certification regulations and the following Polish standards:

- PN-O-91015:2000 Footwear for children up to 15 years of age. Material and construction requirements for lasts and footwear, and testing methods,
- PN-O-91055:1987 – Shoe lasts – Sizing,
- PN-O-91010:1987 – Footwear – Sizing.

Figure 1. 'Healthy Foot' mark

Source: Lukasiewicz – Lodz Institute of Technology.

- The 'Healthy Foot' label is intended for footwear used by children with normally developed feet; therefore, it does not require the use of orthotic insoles. The specific criteria that a footwear model must fulfill in order to be awarded the mark are detailed in the Regulations for the Award of the 'Healthy Foot' Label.
- Since its inception, the Lukasiewicz – Lodz Institute of Technology has certified 4,421 models of children's footwear.
- The 'Healthy Foot' label informs consumers that the footwear they are choosing is *prophylactic*, i.e., physiologically designed with shapes and dimensions consistent with those of a healthy, properly developed foot. Prophylactic footwear supports the natural development of children's feet under specific climatic and societal conditions and protects the feet from various disorders and deformities.

- In an effort to ensure consumer protection, the Lukasiewicz – Lodz Institute of Technology has developed a detailed list of requirements for children's footwear. Compliance with these requirements is mandatory in the voluntary footwear assessment process.
- In the first stage of evaluation, the shoe last (form) used for manufacturing the footwear is assessed, along with the internal dimensions of the shoe. Next, the construction and aesthetics of the product are reviewed. Subsequently, all footwear components are assessed for compliance with the material and construction requirements specified in the certification regulations.
- The list of construction requirements is formulated clearly and includes the following features:
  - The insole length must be at least 1 cm longer than the foot (functional allowance),
  - A wide and high toe box allowing free movement of the toes,
  - A low heel ensuring proper physiological foot positioning (0–20 mm for younger children; 25–35 mm for older girls with feet longer than 220 mm),
  - A stiffener in the heel counter to maintain correct alignment of the heel relative to the leg axis,
  - Flexible outsoles to enable natural foot roll-off during walking,
  - Lightweight, slip-resistant soles with appropriate tread patterns,
  - Upper construction that avoids pressure on the area of the big toe joint and the fifth toe joint,
  - Use of soft, hygienic materials that conform easily to the shape and size of the foot and facilitate moisture absorption and evaporation,
  - Secure attachment of decorative elements and safe finishing of lace tips to eliminate the risk of detachment and ingestion by small children,
  - Footwear assortment tailored to the age and size group of the intended users (see Table 1).

Table 1. Range of footwear permitted within specific size groups

Group Name and symbol	Metric Size Range	User Age	Allowed Types of Footwear
1. Infant and post-infant	9.5–14.5	2	Protective footwear for non-walking infants, first walking shoes, ankle boots, high-top shoes, winter boots, rain boots
2. Early childhood	15–17	3–4	Ankle boots, high-top shoes, winter boots, rain boots, low shoes, sandals with closed heel or heel cup
3. Preschool	17–19.5	5–6	Ankle boots, high-top shoes, winter boots, rain boots, low shoes, sandals with closed heel or heel cup
4. School-age	20–22	7–10	Ankle boots, high-top shoes, winter boots, rain boots, low shoes, sandals, sandals with closed heel or heel cup
5. Girls	22–25	11–15	Ankle boots, high-top shoes, winter boots, rain boots, low shoes, sandals, sandals with closed heel or heel cup, dress shoes
6. Boys	22.5–26	11–15	Ankle boots, high-top shoes, winter boots, rain boots, low shoes, sandals, sandals with closed heel or heel cup

Source: Certification Requirements for the 'Healthy Foot' Mark [Lukasiewicz – Lodz Institute of Technology].

In the certification procedure for awarding the 'Healthy Foot' label, the hygienic properties of the materials used in the footwear uppers and linings are assessed in accordance with the standards listed in Table 2.

Table 2. List of applicable standards for testing the hygienic properties of materials used in uppers and linings

No.	Standard	Test parameter	Material
1.	PN-EN ISO 105-X12 Textiles –Tests for colour fastness	Color fastness to rubbing	- Natural leather - Textile materials
2.	PN-EN ISO 3376 Leather - Physical and mechanical tests – Determination of tensile strength and percentage elongation	Tensile strength Elongation at break (maximum)	- Natural leather (upper)
3.	PN-EN ISO 3377 Leather – Physical and mechanical tests – Determination of tear load	Tear strength	- Natural leather
4.	PN-EN ISO 5402 Leather – Determination of flex resistance	Flex resistance at room temperature	- Natural leather (upper)
5.	PN-EN ISO 11640 Leather –Tests for color fastness –- Color fastness to cycles of to-and-fro rubbing	Color fastness to rubbing (reciprocating motion)	- Natural leather - Textile materials

cont. Table 2

No.	Standard	Test parameter	Material
6.	PN-EN ISO 13934 Textiles – Tensile properties of fabrics	Tensile strength Elongation at break (maximum)	- Textile materials (upper)
7.	PN-EN ISO 13937 Textiles –Tear properties of fabrics	Tear strength	- Natural leather - Textile materials
8.	PN-EN ISO 17700 Footwear - Test methods for upper components and insocks – Color fastness to rubbing and bleeding	Color fastness to rubbing and water spotting	- Natural leather - Textile materials
9.	PN-EN ISO 20344 Personal protective equipment - Test methods for footwear	Water vapour permeability (sec. 6.6) Water vapour absorption (sec. 6.8) Abrasion resistance (sec. 6.12)	- Natural leather (lining) - Textile materials (lining)

Source: requirements for the Lukasiewicz – Lodz Institute of Technology Healthy Foot mark.

Material safety is also determined by the content of elements with proven harmful effects on the human body. Table 3 presents detailed requirements for the content of harmful substances in footwear materials.

Table 3. Acceptable levels of harmful substances in footwear materials and corresponding test methods

No.	Name of harmful substance *(material types in which it may be present)*	Acceptable content	Test method
1.	Aromatic amines *(in dyed natural leather and textile materials)*	< 30 mg/kg	PN-EN ISO 17234-1:2015-07 PN-EN ISO 17234-2:2011 PN-EN ISO 14362-1:2017-04 PN-EN ISO 14362-3:2017-04
2.	Formaldehyde *(in natural leather and textile materials)*	< 20 mg/kg for children under 3 years (sizes 18–23 EU) < 75 mg/kg for children over 3 years (size 24 EU and up)	PN-EN ISO 14184-1:2011 PN-EN ISO 17226-1:2019-05 PN-EN ISO 17226-2:2019-05
3.	PCP and its salts *(in natural leather, natural fiber-based materials)*	Not detectable	PN-EN ISO 17070:2015-04
4.	Chromium VI *(in natural leather)*	Not detectable	PN-EN ISO 17075-1:2017-05

cont. Table 3

No.	Name of harmful substance *(material types in which it may be present)*	Acceptable content	Test method
5.	*Antimony (Sb) (in natural leather, coated leather, textiles, plastics, printed surfaces)*	< 30 mg/kg	PN-EN ISO 17072-1:2019-07 (*content in natural leather, coated leather, textiles, plastics, prints on materials)
	Arsenic (As), Lead (Pb)	< 0.2 mg/kg	
	Cadmium (Cd)	< 0.1 mg/kg	
	Chromium (Cr), Cobalt (Co), Nickel (Ni)	< 1 mg/kg	
	Copper (Cu)	< 25 mg/kg	
	Mercury (Hg)	< 0.02 mg/kg	
6.	Nickel *(in metal components)*	< 0.5 μg/cm²/week	PN-EN 1811+A1:2015-09
7.	Phthalates: DEHP, BBP, DBP, DIBP *(in coated leather, plastics, printed materials)*	Not detectable	ISO 16181-1:2021
8.	Organotin compounds: DBT, TBT, TPhT, DOT *(in leather, textiles, plastics, printed surfaces)*	< 1 mg/kg	ISO/TS 16179:2012
9.	Dimethylfumarate *(in finished footwear and all components)*	< 0.1 mg/kg	PN-EN ISO 16186:2021-11
10.	Nonylphenol, ethoxylated nonylphenol, ethoxylated octylphenol *(in leather and textiles)*	< 100 mg/kg in leather < 25 mg/kg in textile materials	PN-EN ISO 18218-2:2019-10 PN-EN ISO 18254-1:2016-06
11.	Polycyclic aromatic hydrocarbons (PAHs) *(in coatings on textiles and leather, plastics, synthetic rubber)*	< 0.5 mg/kg per single PAH for children under 3 (sizes 18–23 EU) < 1 mg/kg for total 18 PAHs for children under 3 < 1 mg/kg per single PAH for children over 3 (size 24 EU and up) < 10 mg/kg for total 18 PAHs for children over 3	PN-EN ISO 16190:2022-04

Source: The Regulations of awarding The Healthy Foot Mark, [Lukasiewicz – Lodz Institute of Technology].

What is important, when assessing the content of harmful substances in footwear, if production takes place in the EU, a signed declaration regarding the content of harmful substances is required. If the footwear is manufactured in a country other than the EU, test results from an accredited laboratory or one with a quality management system in accordance with the ISO 9001 standard must be submitted.

The footwear assessment procedure for the 'Healthy Foot' Label also includes testing of children's shoe soles. In addition to organoleptic tests performed during the footwear construction assessment, durability parameters are also examined (Table 4).

Table 4. Requirements and testing methods for soles for children's footwear

No.	Parameter	Test method
1.	Tear resistance	PN-EN 12771:2002
2.	Abrasion resistance	PN-ISO 4649:2007
3.	Resistance to repeated bending at temperatures of +20°C and -15°C	PN-EN ISO 20344:2012
4.	Slip resistance	Procedure of IPS (KR)- BJ- 017

Source: The Regulations of awarding The Healthy Foot Mark [Lukasiewicz – Lodz Institute of Technology].

Documentation analysis revealed that not only the hygienic properties of materials or the content of harmful substances are assessed. The durability and strength of individual components and systems are also examined. The concept of durability encompasses a set of characteristics that determine the uniform wear of individual shoe components during prolonged use. This includes the durability of the connections between individual upper components, the upper-sole system, and the physicomechanical properties of the materials used [Rajchel-Chyla et al. 2012b]. In the case of children's footwear, durability, meaning the longest possible service life, is not paramount. Children's foot length increases significantly at certain stages of ontogeny, resulting in a short shoe life (which prevents complete destruction of the shoe). In this case, it is more important whether the durability of the connections between individual upper components and the upper-sole components lasts the expected life of the footwear and whether individual components wear evenly over time. In the final stage, the material connections are thoroughly assessed. Any unevenness or bulges inside the footwear are unacceptable.

These can cause discomfort and even injury to children's feet. During the shoe interior inspection, special attention is paid to areas of the foot that are particularly susceptible to pressure and strain – the so-called sensitive areas. The method of attaching small elements (discs, rivets, eyelets, hooks) is assessed. Poorly attached decorations are unacceptable, as they increase the risk of swallowing small elements by a child.

The shoe quality inspection also examines technological defects (wrinkles in linings, insoles, adhesive residue, etc.). Subsequent stages of evaluation include the assessment of individual shoe components: the toe cap, the heel counter, the lining, the insole, the sole, and the upper.

Fulfillment of all requirements specified in the Healthy Foot Label Award Regulations is confirmed by a Healthy Foot Label Award Certificate.

2.2. Requirements for 'Žirafa' label

In the Czech Republic, footwear manufacturers are obliged to sell footwear that meets the quality requirements specified in two documents that indirectly present the applicable criteria based on the following standards: ČSN 79 5600 Obuv – Pozadavky a skusebni metody (Footwear – Requirements and test methods) and ČSN 79 5790 Obuv – Prijatelne odchylky (Footwear – Acceptable Deviations). Both documents, along with Decree No. 84/2001 of the Minister of Health (Collection of Laws on Hygienic Requirements for Toys and Products for Children Under 3 Years of Age (including Footwear)), are among the criteria required for the voluntary evaluation of footwear for the 'Žirafa' label.

The 'Žirafa' label was registered in the Czech Republic in 1998. Similar to the 'Healthy Foot' label, it was a response by the Czech Footwear and Leather Association (ČOKA) to the mass import of children's footwear from abroad that did not meet the requirements for children's footwear. The 'Žirafa' label informs consumers about the safety of footwear, both in terms of harmful substance content and the prevention of lower limb defects and deformities. It is intended for footwear for children under 3 years of age, with an insole length of 105–165 mm, and for older children (up to an insole length of 235 mm, which corresponds to size 36 in the French numeration). The 'Žirafa' label is shown in Figure 2.

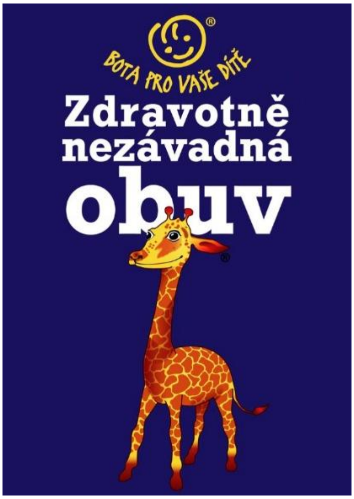

Figure 2. 'Žirafa' label

Source: ČOKA.

The general requirements included in the voluntary assessment procedure for the 'Žirafa' label include provisions regarding product quality, both at the design and production stages. Footwear marked with the 'Žirafa' label must meet the footwear quality requirements of Czech technical standards (ČSN). Furthermore, the manufacturer is obligated to ensure production conditions that guarantee consistent product quality. The association allows for inspections and audits, including random ones.

According to the association's declaration, the footwear design principles and assessment criteria were developed by a team of experts and are subject to ongoing updates.

The assessment procedure documentation, in addition to the mandatory standards mentioned above, includes: the ČOKA ZP Regulations – 1-2013 and the ČOKA TS Technical Specifications – 2-2013.

The Regulations are a document that provides a detailed classification of footwear based on intended use, shoe assembly system, and upper height.

ČOKA divides children's footwear in the foot length range of 105–225 mm into 4 groups (differently than in the Polish procedure) – Table 5.

Table 5. Classification of footwear sizes according to ČOKA

Group symbol	Group name	Foot lenght range [mm]
0	Infant	105–140
1	Toddler	145–165
2	Preschool	170–190
3	Early school age	195–225

Source: ČOKA.

The design requirements for children's footwear, contained in the Regulations, primarily concern last dimensions, taking into account the division into metric and French size numbers for all four shoe size groups (number range 105–225 mm).

The technical specifications cite 17 standards (5 national ČSN, 3 European EN, and 9 EN ISO standards). These standards cover both the determination of harmful substance content in materials and footwear, as well as the classification and measurement method for footwear.

Furthermore, general requirements for footwear safety (orthopedic, hygienic, and usability) are presented, along with hygiene, design, and material requirements. The final stage of the footwear certification procedure is the evaluation of the aesthetics of the footwear. The individual requirements are discussed below.

1. Footwear Safety

Fulfillment of this criterion is assessed based on the provisions of the ČOKA ZP Regulations – 1-2013, Czech technical standards ČSN 79 5600, ČSN 79 5600 and ČSN EN ISO 19952 and ČSN EN 71-1, as well as Regulation C. 84/2001 Coll., § 16 of Decree No. 84/2001 Coll. (Article 10 of Decree No. 84/2001 Coll.). Additionally, the voluntary certification procedure for the 'Žirafa' label includes a safety check of:

- Materials used for shoe uppers (in footwear for children under 3 years of age, synthetic materials are permitted up to 20% of the shoe upper surface),
- Materials used for shoe soles (in accordance with the Czech technical standard ČSN 12 770),
- Use: small parts (hooks, rivets, discs) must be attached in a way that minimizes the risk of cuts or lacerations, as well as detachment and swallowing.

2. Assessment of the aesthetics of the footwear.

Footwear should be made with due care, free of material bulges, lining wrinkles, or traces of glue. The stitching and joining of materials should be smooth and free of bulges.

3. DISCUSSION

Footwear is one of the most significant external factors influencing foot morphology and shaping gait patterns in children [Breet & Venter 2022; Wegener et al. 2011; Wolf et al. 2008]. Because footwear is used for several hours a day, its quality should be closely monitored. Currently, manufacturers or importers of footwear into EU countries are required by law to ensure the quality of children's footwear by properly labelling and monitoring the content of harmful substances. However, the scope of current regulations should be expanded to include quality control of footwear, including shoe construction, quality assessment of shoe components, and assessment of the fit of the shoe's interior dimensions to the child's foot.

To the authors' knowledge, voluntary assessment of children's footwear is currently being conducted in the Czech Republic and Poland. Analysis of the available documentation for the 'Healthy Foot"' and 'Žirafa' labels revealed numerous similarities between the two procedures:

1. Assessment of shoe last dimensions and shape.

The quality of shoe lasts determines the correctness of the shoe's internal dimensions and size. Both procedures involve direct last measurements and an assessment of the shoe's last's bedding structure in relation to standards. The internal dimensions of shoes are an extremely important characteristic of shoe quality for the prevention of foot deformities in children. Many authors point out that children's feet are particularly susceptible to ill-fitting footwear [González-Elena et al. 2019]. Incorrect design of the front part of footwear may increase the risk of hallux valgus and varus deformity of the fifth toe [González-Elena et al. 2021; Hettigama et al. 2016; Puszczałowska-Lizis et al. 2020]. Correct shoe size marking is another important safety feature of footwear, closely correlated with the shape of the shoe's last. Size provides information about the shoe's dimensions (primarily the length of the shoe in the French numbering system). Correct sizing includes not only foot length but also the so-called functional allowance in the shoe and is one of the most important criteria for assessing the quality of children's footwear [Pavlackova et al. 2015]. Functional allowance is the space in the forefoot-usually 5-10 mm-that allows for free toe positioning and proper mobility while walking [Pavlackova et al. 2015; Rajchel-Chyla et al. 2012b]. Shoes that are too short can cause abrasions and cuts, and in long-term use, lead to toe deformities [Alfamege-Garcia et al. 2024]. Research also indicates the unfavorable effect of footwear that is too long and too wide in relation to the dimensions of the feet, causing a reduction in the longitudinal arch of the foot, as well as problems with maintaining balance [Alfamege-Garcia et al. 2024; Puszczalowska-Lizis et al. 2020; Puszczalowska-Lizis et al. 2022].

2. Assessment of footwear construction

Shoe construction method: the design of the shoe upper and the shoe sole and heel. Physiological footwear should be as flexible and soft as possible so as not to restrict the natural mobility of the foot [Alfamege-Garcia 2024; Buckland et al. 2014; Morrison et al. 2018; Staheli 1991].

The requirements for the 'Healthy Foot' label include the use of a heel support that ensures proper foot alignment. Data regarding the design and maximum permissible heel height for specific age groups are also provided. The Czech procedure is similar – the heel must be low to ensure physiological foot alignment.

3. Assessment of the safety and quality of materials used.

According to EU regulations, footwear manufacturers and importers are required to monitor the quality of materials used for harmful substances. Some elements, even in trace amounts, are carcinogenic or may adversely affect the hormonal or reproductive systems, as well as increase the risk of allergies [Adams & Marshall-Battle 2012; Petrliki et al. 2016]. Children's bodies are particularly sensitive to the toxicity of these substances [Møller et al. 2020]. The REACH regulation is mandatory for footwear manufacturers and importers in the EU market. The 'Healthy Foot' label provides detailed requirements for the test method and threshold values for over 18 harmful substances. For the Czech 'Žirafa' label, the technical specifications only include four standards of the Czech Technical Committee for testing formaldehyde and chromium (VI) content.

Material quality encompasses not only the content of harmful substances, but also the hygienic properties of the materials. The soles of the feet contain a large number of sweat glands, which produce sweat intensively. Materials used for linings and insoles must therefore have good water absorption and water vapor permeability properties. The footwear evaluation procedure for the 'Healthy Foot' Label references the water vapor absorption and permeability test methods specified in the PN-EN ISO 20344:2022-04 p.6.6 Standard – the English version 'Personal protective equipment – Footwear test methods'. For the Czech 'Žirafa' mark, the technical specifications include the identical standard ČSN EN 20344 p.6.6, and additionally ČSN EN 12746 and ČSN EN 13515.

4. Assessing the Aesthetics of Shoemaking

The aesthetics of children's footwear are an important aspect of its quality. The choice of materials, the design of the upper, and the soles should all form a harmonious whole. Of course, children's footwear, especially for girls, is full of decorations. Any decorations should be attached in a way that prevents a child from removing and swallowing them. It is recommended to use colorful materials (free from harmful substances) instead of decorations.

Particular attention is paid to the construction of the interior of the footwear to protect delicate children's feet from injury.

The presented voluntary children's footwear assessment procedures highlight the many aspects of footwear safety that must be met for high-quality children's footwear to be considered. A growing child's body is extremely susceptible to harmful factors, such as ill-fitting footwear or poor-quality materials used in footwear production. With consumer well-being in mind, Lukasiewicz – LIT and ČOKA have developed footwear certification procedures that appear to be pioneering in Europe. Furthermore, Lukasiewicz – LIT, in collaboration with the Krakow University of Economics, is conducting research to update the standard regarding shoe last dimensions for children's footwear. Thanks to the actions undertaken by both entities, the quality of children's footwear is expected to improve in terms of the fit of the internal dimensions to children's feet.

CONCLUSIONS

The voluntary footwear certification procedures in place in the Czech Republic and Poland are pioneering on a European scale. According to the authors, it is necessary to develop common requirements and standards for children's footwear across Europe, and to make them mandatory for manufacturers and importers of children's footwear, at least on a scale equivalent to toy regulations.

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QUALITY ASSESSMENT OF KEFIRS PRODUCED FROM DIFFERENT MILK TYPES WITH CINNAMON

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Abstract

Kefir belongs to the group of fermented milk beverages, which are among the most frequently consumed functional foods by consumers. There is little variation among kefirs on the market in terms of flavor variants and raw materials used. The aim of this study was to evaluate the quality of kefir made from goat's milk and kefir with added cinnamon. The study was conducted for products stored under refrigeration for 1 and 7 days. Changes in the physicochemical properties of the kefirs varied. During storage, organoleptic changes occurred, as observed in the sensory evaluation results. The color and texture of both beverages changed after the addition of cinnamon and glucose. The goat's milk beverages contained a higher dry matter content. The beverages differed in taste, aroma, and consistency. The highest acceptance was achieved by cow's kefir with cinnamon and glucose, natural cow's kefir, and goat's kefir with cinnamon and glucose.

Keywords: kefir, goat milk, cow milk, cinnamon, storage.

INTRODUCTION

Milk is the secretion from the mammary glands of female mammals. Milk is an important part of the early life of all mammals, including humans. It provides the substrates necessary for animal development. It meets basic energy needs thanks to its appropriate content of macronutrients – carbohydrates, protein, and fat. A unique macronutrient is lactose, a disaccharide composed of galactose and glucose. It is the main source of energy in human milk [Schaafsma 2002]. The presence of micronutrients in milk – B vitamins, vitamins C and A, and minerals (including calcium, sodium, and potassium) – supports proper development during adolescence. In later life, despite the exclusion of human milk from the diet, animal milk and its derivatives continue to be consumed [Fox 2008; Mosca & Giannì 2017]. The chemical composition and nutritional value of milk influence its functional properties and technological suitability. The nature and quantity of micro- and macronutrients in milk vary depending on the breed, lactation stage, and animal husbandry system. It is possible to obtain a raw material with the desired chemical composition by manipulating the animals' diet. The use of feeds with a higher fat content in the goat diet increased fat concentration and changed the fatty acid structure of the milk [Roy et al. 2006]. The quantitative chemical composition of cow's and goat's milk is similar: protein 2.9–3.16%, fat 3.01–5.1%, lactose 4.1–1.85%, dry matter 11.5–13.63%, and ash approximately 0.8% [Pełczyńska 1995].

Goat milk has exceptional organoleptic properties. The characteristic aroma of goat milk, often appreciated in cheeses, influences the palatability of the products. This aroma results from the increased content of volatile, short-chain fatty acids compared to cow's milk. The intensity of the aroma can be reduced by dietary manipulation, using corn silage instead of hay, or ensuring a sufficiently high energy intake. The lack of carotene in goat milk is responsible for its white color. Genetic predispositions of goats influence the type of casein fraction and the amount of protein present in the milk. Breeding goats with favorable conditions, in terms of technological suitability, is possible thanks to Mendel's rules of trait transmission [Krzyżewski 2014].

The Food and Agriculture Organization and the World Health Organization (FAO/WHO) define fermented milk beverages as products obtained from milk that have been fermented by specific microorganisms that, by fermenting lactose, lower the milk's pH and can cause it to coagulate. Fermented milk beverages include yogurt, sour milk, kefir, and buttermilk. Kefir is a beverage obtained by fermenting a carrier medium with kefir grain bacterial cultures. We distinguish between dairy and non-dairy carriers for the growth of kefir grain bacteria. Products of the fermentation process influence the organoleptic profile of the products and their resistance to pathogenic microorganisms. During lactic and alcoholic fermentation, compounds of carbon dioxide, ethyl alcohol, and lactic acid are formed. High acidity and increased ethyl alcohol concentration result in coagulation of the protein contained in the milk. The fermentation products of kefir grains make kefir a drink with high acidity, a distinct refreshing taste and a density higher than the original product [Azizi 2021].

Kefir, valued for its sensory and health benefits, is consumed worldwide. Its origins are attributed to the nomadic Caucasian peoples, who, by transporting milk from cows, goats, sheep, and camels, among others, in leather bags, obtained a beverage with an extended shelf life and a distinctive flavor. According to Sekkal-Taleb [2016], kefir was brought to Poland by a professor from Gliwice who, while in India, developed liver cancer. He was cured by an Indian monk using kefir grains. Upon returning to Poland, he began treating patients at his clinic with kefir grains [Sekkal-Taleb 2016]. Kefir grains are small, gel-like particles of microorganisms that resemble cauliflower florets, measuring 2 to 15 mm. Kefir grains are formed during fermentation. They are insoluble in water and most solvents. Depending on their origin, kefir grains consist of 90% water, 10% dry matter, including 3.5% fat, 32% protein, 56% non-nitrogenous extractable substances, and 8.5% ash. The microbiological profile of the grains is diverse. The microbial population consists primarily of lactic acid bacteria from the *Lactobacillus* group, *Lactococci*, and kefir yeast [Sekkal-Taleb 2016; Witthuhn 2005]. A unique macronutrient for kefir is kefirate. This saccharide is composed of 44% D(–)glucose and 56% D(+)galactose, whose complex chemical structure makes it resistant to enzymatic digestion. Water absorption, the ability to form gels in the presence of ethyl alcohol and resistance to hydrolysis make it a valuable technological, health, and sensory component of kefir [Sekkal-Taleb 2016]. Kefir consumption is associated with a wide range of benefits. The following health-promoting properties can be distinguished: increased nutrient absorption, synthesis of B vitamins, alleviation of lactose intolerance symptoms, combating undesirable intestinal microflora, and probiotic activity. This increased nutrient absorption is due to lactic acid bacteria. They initiate protein breakdown and fat hydrolysis, resulting in increased nutrient absorption. Increased production of saliva and digestive juices due to lactic acid improves intestinal function. The alleviation of lactose intolerance symptoms is associated with a decrease in lactose concentration in kefir. During lactic acid fermentation, nearly 50% of the lactose is utilized, and partial degradation occurs. Undesirable intestinal microflora is combated by the acids formed during fermentation. As a result of the sudden decrease in intestinal pH, the environment becomes suboptimal for the growth of pathogenic bacteria [Brodziak & Król 2016].

Cinnamon is known as an aromatic spice, but for centuries it has been used in folk medicine as a medicine. Modern cinnamon consumption has proven to be just as, if not more, beneficial for health than previously thought. Cinnamon has properties that soothe digestive ailments thanks to its ability to stimulate the secretion of bile and digestive juices and improve nutrient absorption. Cinnamon's potential in the treatment of type 2 diabetes has been observed. Its consumption results in reduced blood glucose levels. Studies have also indicated its anticancer properties and potential in the prevention and treatment of cardiovascular disease. Cinnamon consumption affects key indicators of cardiovascular disease, including lowering blood pressure and normalizing blood glucose levels, total cholesterol, and LDL and HDL cholesterol levels. Cinnamon oils also have strong antiseptic and anti--inflammatory properties. The essential oils in cinnamon, in particular, are of interest because of their antioxidant, anti-microbial, anti-inflammatory, antifungal, and hypocholesterolaemic effects, in addition to their ability to stimulate digestive enzymes in the gut [Ali et al. 2021; Błaszczyk et al. 2021; Kaławaj & Lemieszek 2015; Tan et al. 2025].

The use of additives derived from food sources has increased due to the growing concern and demand from consumers for natural compounds in food. Given that cinnamon can enrich fermented products and increase their sensory appeal, the aim of this study was to evaluate the quality of kefirs made from goat's milk and, for comparison, from cow's milk with added cinnamon. Inulin was added to the kefirs to enrich them with dry matter in the form of a prebiotic. Additionally, it was decided to add a simple sugar (glucose) to one variant, which can affect both the dry matter content, the flavor of the products, and the fermentation process.

1. MATERIAL AND METHODS

The research material consisted of six kefir samples produced under laboratory conditions using the Thermomix TM6 device and a laboratory incubator. The kefirs were made from 3.2% Mlekovita cow's milk and raw goat's milk from a local supplier in the Pomeranian Voivodeship. The goat's milk was pasteurized at 85°C for 10 minutes. After cooling to 23°C, inulin (17g/L) and Vito kefir starter (in the amount recommended by the manufacturer, 0.3g/L of milk) were added with constant stirring. The milk was then divided into three parts. Part one was incubated; part two was added cinnamon (6g/L) and incubated; and part three was added cinnamon (6g/L) and glucose (25g/L) and incubated. The detailed composition of the products is presented in Table 1.

Table 1. Composition and symbols of the produced kefirs

Symbols	Composition	Symbols of product stored for 1 day	Symbols of product stored for 7 days
CN	cow milk, kefir starter, inulin	C1N	C7N
CC	cow milk, kefir starter, inulin, cinnamon	C1C	C7C
CCG	cow milk, kefir starter, inulin, cinnamon, glucose	C1CG	C7CG
GN	goat milk, kefir starter, inulin	G1N	G7N
GC	goat milk, kefir starter, inulin, cinnamon	G1C	G7C
GCG	goat milk, kefir starter, inulin, cinnamon, glucose	G1CG	G7CG

Source: own study.

The mixtures were poured into sterilized 1-liter glass jars and incubated in a laboratory incubator at 24°C for 24 hours. The resulting beverages were cooled to 4°C and stored at this temperature. The tests were conducted on one-day-old kefir and on the product stored for seven days. All production and testing were conducted in the laboratories of the Department of Quality Management at Gdynia Maritime University.

A sensory profiling method for palatability was used. The method assumes that palatability is a complex of individual attributes that can be separated, identified, and their intensity and order of occurrence determined. An eleven-point linear hedonic scale, the LHS [Lim 2011], was used for the assessment. The sensory profiling method requires the use of a properly trained team of evaluators [Babicz-Zielińska et al. 2016]. Sensory quality assessment was performed by two teams. The team used in the kefir study consisted of 13 employees of Gdynia Maritime University, who declared in the initial interview that they specialize in the organoleptic assessment of food products. This team was assembled twice, to evaluate one- and seven-day--old products. The same sensory analysis questionnaire was used in both evaluations. Kefir samples prepared for evaluation were coded with a three-digit code and presented for evaluation at the station. The study took place in a laboratory at

Gdynia Maritime University. The assessors assessed the intensity of the following attributes: sweet taste, sour taste, bitter taste, foreign taste; fermented odor, foreign odor; consistency (thin or thick); structure (homogeneous or grainy); color (white or light brown).

A physicochemical evaluation of the milk and kefir was also conducted. The quality of the cow's and goat's milk used in the study included determining the active acidity (pH) using a HI 110 pH meter. Potential acidity (°SH) was determined according to the PN-68/A-86122 standard by sampling 50 ml of the product and titrating it with 0.25N sodium hydroxide solution until pink, using phenolphthalein as an indicator. Fat content was also measured in triplicate according to the PN-ISO 488:2002 standard using a Gerber fat meter. The testing methodology for the six products included qualitative testing of the kefir after 1 and 7 days of storage. Potential acidity was determined, as was the case for milk, along with density (using the pycnometric method), viscosity (using a Brookfield viscometer), and water content (using the oven method at 105°C to dry samples to constant mass). All determinations were performed in triplicate, and the arithmetic mean of the measurements was taken as the final result.

2. RESULTS AND DISCUSSION

Before kefir production, milk quality was assessed. Cow's milk had a fat content equal to that declared by the manufacturer, 3.2%, while goat's milk contained 3.4% fat. The active acidity (pH) of cow's milk was 6.91 and the potential acidity was 6.35°SH. The active acidity (pH) of goat's milk was 6.85 and the potential acidity was 6.00°SH. The PN-A-86003 and PN-A-86002 milk standards were used in the study. The results of milk and kefir acidity determinations are presented in Table 2. Active acidity (pH) was the basic parameter tested during the production of fermented milk beverages. As the number of lactic acid bacteria increases, the amount of lactic acid they produce increases, leading to a decrease in pH [Birollo et al. 2000]. Danków et al. [2013] found that the pH value in beverages fermented with yeast decreased less than in beverages fermented with yeast-free inoculums. Therefore, it was concluded that 7 days was insufficient to detect significant changes in the active acidity of kefirs. Similar pH values for 7-day kefir produced with yeast were observed in the study by Teichert et al. [2015].

Table 2. Active and potential acidity of milk and kefir

Acidity	Cow milk	Goat milk	Kefirs						
			Storage time [days]	CN	CC	CCG	GN	GC	GCG
Active acidity (pH)	6.91	6.85	1	3.69	3.81	4.06	3.16	3.30	3.48
			7	4.26	4.27	4.20	4.12	4.06	4.00
Potential acidity (°SH)	6.35	6.00	1	37.20	39.00	37.20	38.80	39.47	39.47
			7	38.27	39.20	39.73	39.07	42.27	39.47

Source: own study.

In the present study, a lower pH was found for kefirs made from goat's milk, and similar values and a lower pH for kefirs made from goat's milk than from cow's milk were obtained in the study by Saygili et al. [2021]. The titratable acidity (°SH) of the tested samples did not change significantly during storage. The GCG sample did not show any increase in potential acidity over the seven-day period. Danków et al. [2000] found a significant effect of storage time on the titratable acidity of goat milk yogurts. According to Cais-Sokolińska and Pikul [2001], changes in the acidity of fermented milk during refrigerated storage are caused by the activity of microorganisms contained in the vaccines, which continuously degrade lactose at 4°C. However, this occurs at a slower rate than at temperatures optimal for the growth of lactic acid bacteria.

Recent years have seen a dynamic increase in the production of fermented beverages from cow's and goat's milk. Beverages with a thick consistency are very popular. In addition to taste and aroma, texture determines the acceptability of fermented milk beverages. Textural defects such as syneresis, poor consistency, and viscosity reduce the attractiveness of beverages [Domagała & Wszołek 2008; Kücükcetin et al. 2003; Savello & Dargan 1995]. Textural characteristics such as hardness, consistency, cohesiveness, and viscosity significantly influence the perception of products in the consumer's mouth [Bonczar et al. 2002; Park & Guo 2006; Moatsou & Park 2017; Teichert et al. 2015]. There are three characteristics of consistency: density, smoothness, and viscosity. In this study, density and viscosity were determined analytically (Table 3) and general consistency was determined during sensory evaluation (Figure 2, Figure 3).

Table 3. Density and viscosity of kefirs

Storage time (days)	Density [g/cm³]					
	CN	CC	CCG	GN	GC	GCG
1	1.02	1.01	1.00	1.03	1.02	1.03
7	1.01	1.01	1.00	1.02	1.01	1.01
Storage time (days)	**Viscosity [cP]**					
	CN	CC	CCG	GN	GC	GCG
1	1191.00	1275.00	1485.00	1268.00	1389.00	1605.00
7	1108.00	1256.00	1398.00	1246.00	1378.00	1543.00

Source: own study.

In this study, a decrease in density and viscosity was observed in stored kefirs, with both higher viscosity and density observed in goat milk kefirs. This could be due to the higher dry matter content in these kefirs (Figure 1). Similarly, Danków et al. [2013] found that the density and viscosity of fermented beverages decreased during refrigerated storage. Teichert et al. [2015] in their study found a statistically significant decrease in kefir cohesiveness after two weeks of storage. In the study by Bonczar et al. [2002], significant changes in the textural characteristics of goat milk yogurt were observed after the first week of refrigerated storage. The decrease in density resulted from the presence of higher CO_2 levels and a more effervescent structure in the 7-day-old kefirs. In the study by Bonczar and Wszołek [1997], the viscosity of the produced kefir decreased with the passage of six days of storage. Teichert et al. [2015] also found a statistically significant reduction in viscosity during 21-day storage. Güzeler et al. [2019] obtained kefir with the following properties: pH 3.96, viscosity 1272 cP, values similar to those obtained in this study for kefirs with added inulin. The apparent viscosity of kefir made from goat milk was lower than that of kefir made from cow milk, according to Saygili et al. [2021], but it could be affected by the acidity, fat content, and composition of milk and final products.

The dry matter content of the kefirs tested depended on the recipe and additives used, as well as the type of milk. The dry matter content of the kefirs increased with storage time (Figure 1). Kefirs made from cow's milk had a lower dry matter content, which may have been due to the dry matter content of the milk (primarily fat, protein, and carbohydrates). The addition of both cinnamon and glucose increased the dry matter content of the kefirs.

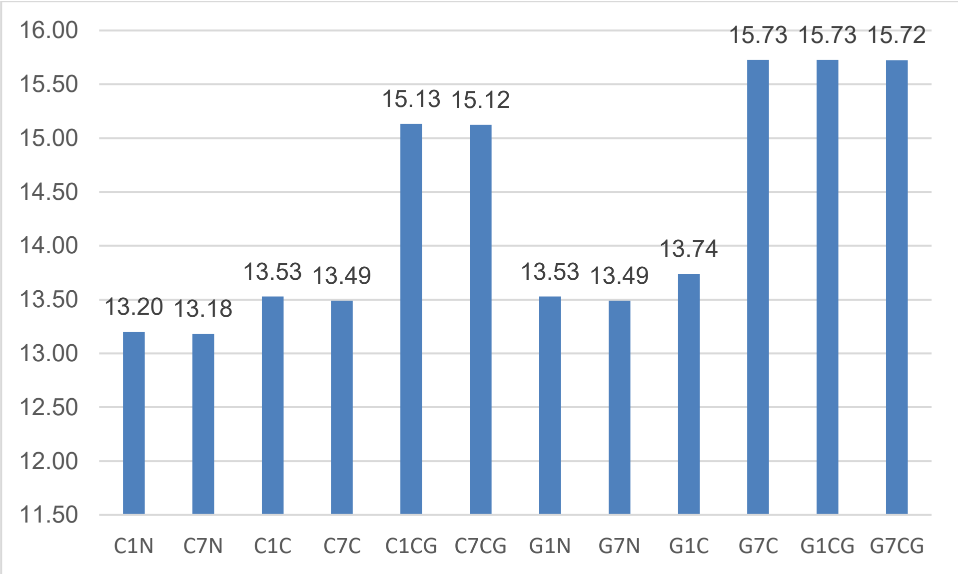

Figure 1. Dry matter content in kefirs

Source: own study.

In their study, Ziarno and Truszkowska [2005] reported that beverages fermented from goat's milk are less dense than products fermented from cow's milk. This inequality can be reduced by using appropriate starter cultures or by increasing the dry matter content in the processed milk. Najgebauer et al. [2014], examining the basic chemical composition of twelve commercial kefirs available on the Polish market, determined a dry matter content of up to 13%. Similar values were found in kefirs with added inulin: the KO0 sample made from goat's milk contained more dry matter (13.53%) than the KR0 sample made from cow's milk (13.20%). Goat's milk kefirs had a higher dry matter content than cow's milk products. The increase in dry matter was most influenced by the addition of glucose in the KO2 (15.73%) and KR2 (15.13%) samples. The dry matter content of cow's milk kefirs in the study by Barukčić et al. [2017] was 10.8%, so the addition of inulin certainly influenced the dry matter value in kefirs with this addition only. Similarly, to the study by Najgebauer et al. [2014], the composition of kefirs influenced their sensory quality, as the evaluators gave higher ratings to products with a higher dry matter content (Figure 2, Figure 3).

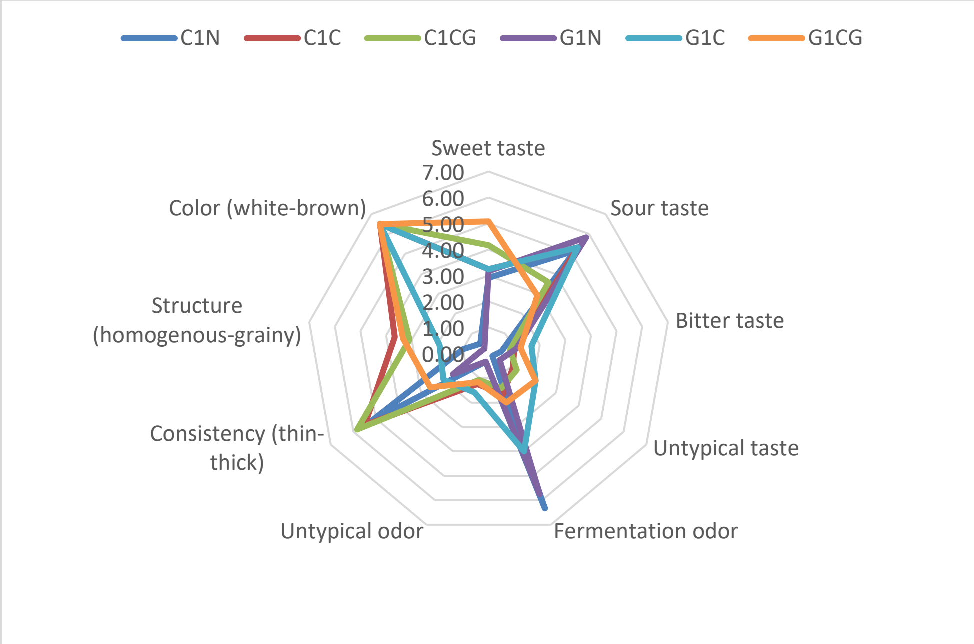

Figure 2. Sensory evaluation of kefirs after 1 day of storage

Source: own study.

Kefirs made from cow's milk were rated slightly better than those made from goat's milk. Goat's milk kefirs were slightly sweeter than cow's milk kefirs and slightly more acidic, as confirmed by the acidity test results. A bitter taste was also more noticeable in goat's milk kefirs. According to the panelists, they also had a more noticeable unusual taste and odor. The consistency of cow's milk kefirs was rated much better than that of goat's milk kefirs; no differences in color were found between kefirs made from different types of milk; this parameter was influenced only by the addition of cinnamon. Sweet, sour, and bitter tastes were rated higher after 7 days of storage, indicating that these characteristics become more pronounced during storage. Fermentation odor was rated differently after 7 days of storage;

in most samples, it was not as noticeable as at the beginning of storage. The consistency of all samples improved during storage.

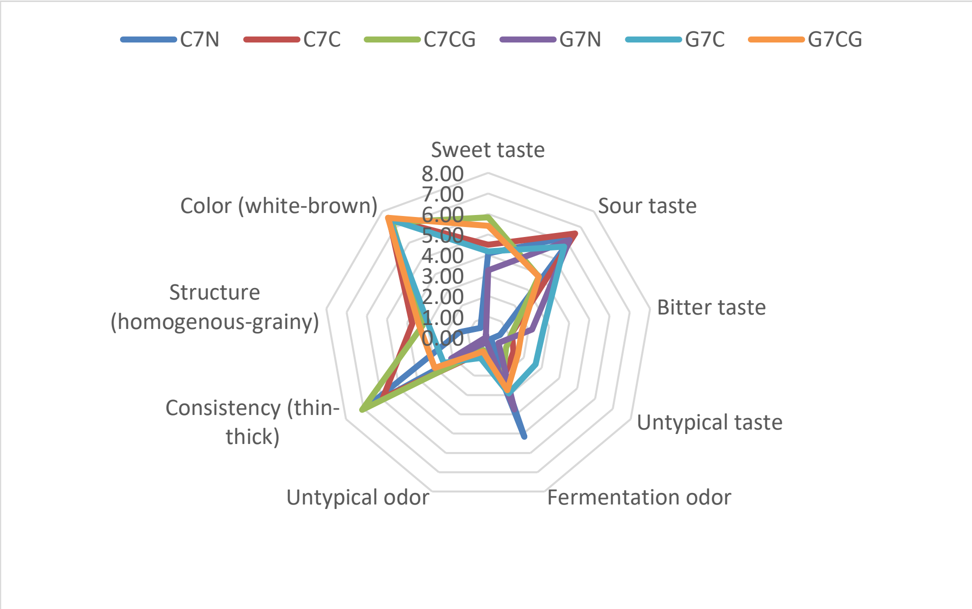

Figure 3. Sensory evaluation of kefirs after 7 days of storage

Source: own study.

CONCLUSIONS

Based on the conducted research, it was found that the sensory characteristics of cow's milk kefir were better evaluated. Goat's milk is a very good type of milk for producing kefir, and the addition of cinnamon and glucose improves its characteristics in terms of both sensory and physicochemical properties. Thanks to the addition of cinnamon and inulin, the health-promoting properties may be very valuable, therefore, further research into the functional properties of this type of product is recommended.

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