ЛУЦЬКИЙ
НАЦІОНАЛЬНИЙ
ТЕХНІЧНИЙ
УНІВЕРСИТЕТ

ТОВАРОЗНАВЧИЙ ВІСНИК

Том 17, № 1

Заснований у 2009 році
Видається два рази на рік

Луцьк
2024

ISSN 2310-5283
e-ISSN 3041-1432

DOI: 10.62763/ef/1.2024

Засновники:
Луцький національний технічний університет, ТОВ "Наукові журнали"

Рекомендовано до друку та поширення
через мережу Інтернет Вченою радою
Луцького національного технічного університету
(протокол № 10 від 26 квітня 2024 р.)

**Свідоцтво про державну реєстрацію
друкованого засобу масової інформації:**
Національна рада України з питань телебачення та радіомовлення (Рішення № 40 від 11.01.2024).
Ідентифікатор медіа – R30-02530.

Науковий журнал включено до категорії «Б» Переліку наукових фахових видань України, у яких можуть публікуватися результати дисертаційних робіт на здобуття наукових ступенів доктора та кандидата наук зі спеціальностей: 076 – Підприємництво та торгівля; 132 – Матеріалознавство; 181 – Харчові технології; 182 – Технології легкої промисловості (наказ МОН України № 886 від 02.07.2020 р.)

**Журнал представлено у міжнародних наукометричних базах даних,
репозитаріях та пошукових системах**: Google Scholar, Index Copernicus, Crossref, Національна бібліотека України імені В. І. Вернадського, Dimensions, UC Santa Barbara Library

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https://c-bulletin.com.ua/uk

LUTSK NATIONAL TECHNICAL UNIVERSITY

COMMODITY BULLETIN

Volume 17, No. 1

Year of foundation: 2009
Frequency: 2 issues per year

Lutsk
2024

ISSN 2310-5283
e-ISSN 3041-1432

DOI: 10.62763/ef/1.2024

Founders:
Lutsk National Technical University, Scientific Journals LLC

Recommended for printing and distribution
via the Internet by the Academic Council
of Lutsk National Technical University
(Minutes 10 of April 26, 2024)

Certificate of state registration of the print media:
National Council of Ukraine on Television and Radio Broadcasting (Decision No. 40 of 11.01.2024).
Media identifier – R30-02530.

The scientific journal is included in category "B" of the List of scientific specialized publications of Ukraine,
in which can be published the results of dissertations for obtaining the scientific degrees of doctor and candidate of sciences in specialties: 076 – Entrepreneurship and Trade; 132 – Materials Science; 181 – Food Technologies; 182 – Light Industry Technologies
(Order of the Ministry of Education and Science of Ukraine No. 886 of 02.07.2020)

The journal is presented international scientometric databases, repositories and scientific systems: Google Scholar, Index Copernicus, Crossref, Vernadsky National Library of Ukraine, Dimensions, UC Santa Barbara Library

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ТОВАРОЗНАВЧИЙ ВІСНИК
Journal homepage: https://c-bulletin.com.ua/en
Том 17, № 1, 2024

Редакційна колегія

COMMODITY BULLETIN
Journal homepage: https://c-bulletin.com.ua/en
Vol. 17, No. 1, 2024

Editorial Board

ЗМІСТ

Content

COMMODITY BULLETIN
Journal homepage: https://c-bulletin.com.ua/en
DOI: 10.62763/ef/1.2024.09

Article's History: Received: 27.12.2023 Revised: 26.03.2024 Accepted: 26.04.2024

Vol. 17, No. 1, 2024, 9-16

UDC 677.11.021

Analysis of the properties of bast raw materials as a component of fabric for military uniforms

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Abstract. The relevance of the present research is determined by the need to replace imported raw materials for manufacturing military clothing with Ukrainian raw materials of industrial hemp and oilseed flax. The aim was to analyse the quality properties of bast raw materials and determine their potential for use in military uniforms. In the course of solving the set goals, the methods of complex analysis, synthesis, observation, measurement, comparison and generalisation of the obtained results and information were applied, as well as standard methods generally accepted in the light industry were implemented. It is noted that hemp cottonin and oilseed flax fiber, in contrast to other natural fibers, are more durable, resistant to abrasion, decay, and are characterised by sanitary, antistatic, hypoallergenic and antibacterial properties. It has been revealed that fabrics made of these fibers are durable, have high resistance to ultraviolet radiation, hold colour well, do not fade, etc. The academic paper analyses scientific studies on the use of this raw material for various types of military clothing, protective body armour, and gunpowder production. By determining the main properties of the bast raw materials under study, the possibility of using this raw material in some types of military uniforms was established. The main feature of the structure and components of the research was the systematic and comprehensive study of the quality properties of bast raw materials at all stages of its processing. It was proposed to use oilseed flax fibers and hemp cottonin instead of cotton fibers in fabrics for military purposes. This will reduce the state's material expenditures on the purchase of fabric for the defense sector and, at the same time, it will help bring the Ukrainian light industry to a new quality level and increase the competitiveness of Ukrainian manufactured goods in the global market. Knowledge of the properties of bast raw materials can help manufacturers improve the quality of fabrics for military purposes

Keywords: fibers; hemp; oilseed flax; properties; fabrics for military purposes

Introduction

The global market of the latest developments in modern military uniforms is evolving at a high pace, which creates unique challenges and opportunities for armies and manufacturers. This growing pace of development is explained by various factors, such as: the improvement of technologies, resulting in the rapid development of technical processes, in particular, information processes; the need to adapt to modern threats,

Suggested Citation:

Boyko, H., & Prokopchuk, V. (2024). Analysis of the properties of bast raw materials as a component of fabric for military uniforms. *Commodity Bulletin*, 17(1), 9-16. doi: 10.62763/ef/1.2024.09.

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increase the efficiency and security of military personnel due to automated systems and protection against various types of threats. The relevance of this research paper is explained by the fact that the study of the properties of Ukrainian bast crops for the purpose of their use in the military sphere will enable light industry companies to produce their own raw materials and supply the armed forces with superior quality uniforms.

The scientific work of L.M. Degenstein *et al.* (2021) is focused on the development and use of smart textile materials for camouflage in the visible and infrared (IR) spectrums. They considered "smart textiles", which include fabrics and materials containing embedded electronic components, sensors, or other advanced technologies. These textile materials can adapt and respond to changes in the environment, making them very valuable for camouflage applications.

E. Delihasanlar & A.H. Yuzer (2020) described the use of three-dimensional metamaterials, which makes it possible to fine-tune the electromagnetic properties of the material, create absorber characteristics according to specific requirements. This technology can be applied in the defense sector and military purposes to achieve stealth, in telecommunications for signal absorption and interference reduction, as well as in the development of advanced wearable devices to enhance communication capabilities and sensors. The integration of textiles with three-dimensional metamaterials opens up promising opportunities for creating unique materials with special electromagnetic properties that influence various fields of technology and industry.

Thus, as noted by T. Lim *et al.* (2020), scientific achievements and developments in the field of improving and enhancing military uniforms are constantly advancing. P.I. Dolez *et al.* (2018), S.G. Kalan *et al.* (2019) studied the features of using various fiber components for military purposes as well as developed special emulsions and sprays providing fabrics with new protective properties: waterproof, chemical, heat and frost resistance, masking and making the military invisible, providing the ability to withstand high-speed impact and retain shape during and after impact, etc.

V.M. Durach & L.G. Nikolaychuk (2021) have found that the production of military clothing for the armed forces is a promising sector in the Ukrainian market; however, the quality standards for such products are very high. It is necessary to use high-quality, natural materials, mainly of Ukrainian origin for the successful implementation of the technological process of sewing military uniforms and providing the army with high-quality products.

Moreover, it is necessary to have Ukrainian raw materials of high quality in order to obtain selected, natural, environmentally friendly military fabrics. T.N. Holovenko *et al.* (2019) argue that hemp and oilseed flax are examples of rapidly renewable resources that are becoming increasingly relevant in the world since the interest in sustainable and renewable materials has grown. Growing hemp and oilseed flax does not require large amounts of pesticides or water, and their roots help improve soil quality. A particularly important advantage is that these plants are widespread on Ukrainian land and can become an alternative to imported raw materials. The entire potential of plants can be used for military purposes. R.B. Malabadi *et al.* (2023) have established that the fibers of these plants can be used for the production of natural, environmentally friendly and high-quality clothing, body armour, gunpowder; the seeds of these bast crops can be used as a nutritious, healthy ingredient in the military diet; straw and bast as a material for composites that can be used as a construction and insulation material for military dugouts; bast as a material for the production of fuel briquettes that can be used for stoves and homemade stoves that are widely used by the armed forces.

The purpose of the research was to study the qualitative properties of bast raw materials and evaluate the possibility of using them in the field of military equipment.

Materials and methods

Studies on this scientific work began in 2021 and continue to the present day. The first studies of bast fiber raw materials were conducted at the research laboratory of Kherson National Technical University, and in 2024 the main studies are being conducted at the laboratories of Khmelnytskyi National University. In accordance with the objectives of the research, a breeding variety of monoecious hemp "Glyana" was selected for the experiments, with the following properties: straw yield is 64.2 c/ha, seed yield is 16 c/ha, total fiber content is 32.7%, long fiber content is 24.7%, average fiber diameter is 1, THC content is 0.001%. The variety is relatively resistant to lodging, shedding, drought, and disease and pest damage at the level of 8-9 points. The oilseed flax variety "Orpheus" was selected for these experiments for its quality indicators: average fiber length of 45 mm and fiber content in the stem of 21%.

The first stage of the research was aimed at determining the physical and mechanical properties of the obtained fibers. The fiber was obtained from industrial hemp straw at "Hemp Bio Group" LLC (the city of Irpin, Kyiv region) on the "CannaSystems" decorticator (Canada, New Zealand, Australia), which simultaneously collects and processes industrial hemp stems (Boyko *et al.*, 2020). It can be used both in the field and in stationary conditions. Oil flax fibers were obtained on a modernised flax tow scutching unit (KPAL) (modernisation of the KPAL was carried out according to the scientific work of H.A. Tikhosova (2011)) in the conditions of the Private Joint Stock Company (PJSC) "Flax Mill "Starosambirsky" (Ukraine). The fiber production process at the modernised KPAL consists of the following technological stages: raw material processing in the milling machine of the flax tow scutching unit, fiber separation

in the carding machine after pressing and their subsequent cleaning on the coarse carding machine.

Due to the absence of standard methods for evaluating the quality of hemp cottonin and oilseed flax fibers, the methods for assessing the quality of fibers specified in the regulatory documents for cottonised flax and cotton were used to determine the main physical and mechanical parameters: TU 17 U 00306710.079 2000. Cottonin made of short flax fiber. Technical conditions, TU.U.05495816.005-2000. Cottonised linen fiber. Technical conditions (Holovenko, 2019), DSTU GOST 3274.5:2009 (ISO 4913-81). Cotton fiber. Methods of length determination (2009). The study of the physical and mechanical characteristics of oilseed flax fibers was carried out according to DSTU 5015:2008. Short flax fiber. Specifications (2008).

The set objectives were achieved by using the methods of theoretical and experimental studies, which make it possible to obtain a complete picture of the physical and mechanical structure of hemp cottonin and flax fiber and formulate practical conclusions and recommendations for changing their properties, for further implementation of this raw material in the production of military garments.

As a result of a critical analysis of the current regulatory documents, it was recommended to evaluate hemp cottonin and oilseed flax fibers according to the following physical and mechanical parameters: tensile load, tensile elongation, linear density, fiber length and actual moisture content. These indicators make it possible to classify fibers by functional purpose. The length of hemp and flax fibers was determined in accordance with TU 17 U 00306710.079-2000. Cottonin made of short flax fiber. Technical conditions (Holovenko, 2019). In order to determine the linear density of hemp cottonin and flax fiber, the method of determining this indicator by cleavage is applied. This method characterises not only the thickness of the fibers but also their ability to further split. Strands of fibers of a certain length are prepared and cut into 20 mm long sections for the study with a total weight in mg. The total number of fibers cut in this way is then counted. A whole fiber and a fiber split by less than half its length are each considered one fiber, and a fiber split by more than half its length is considered as many fibers as the number of ends it has been split into, and then the linear density is calculated using the formula:

$$T_p = 1000 \frac{M_s}{L_s n}, \quad (1)$$

where T_p – linear fiber density, tex (g/km); M_s – weight of fibers, g; L – length of fibers, km; n – number of fibers in a strand, pcs.

Due to the lack of modern methods, existing textile laboratories propose to study the tensile properties of hemp and oilseed flax fibers according to the methodology given in GOST 3274.1-72 (ISO 3060-74, ISO 1973-76). Textiles. Cotton fibres. Determination of breaking tenacity of flat bundles (1976). The steaming of hemp cottonin fibers was carried out using a laboratory autoclave (the device was developed in the laboratory of Kherson National Technical University) under special conditions. In the laboratory conditions of Kherson National Technical University, samples of mixtures of natural (cotton, wool) and chemical fibers (lavsan, nylon, nitron) from 5% to 30% with oilseed flax fiber and hemp cottonin were made using a laboratory fiber mixer "Labormixer" (Hungary). The following modes were used to steam the bast fiber material, which are shown in Table 1.

Table 1. *Modes of steaming hemp cottonin*

Pressure		
heating, cooking – 1.2-7.1 kgf/cm^2	steaming – 1.8-2.3 kgf/cm^2	rinsing – 0 kgf/cm^2
Temperature		
heating, cooking – 90-160^{0}C	steaming – 140-121^{0}C	rinsing – 40°C
Duration of the operation		
heating, cooking – 30 min	steaming – 20 min	rinsing – 10 min

Source: *developed by the authors*

After steaming the hemp cottonin, according to the method described above, a second study was conducted to determine changes in the physical and mechanical properties of the test fiber. The main attention was paid to the relative tensile elongation of hemp cottonin.

Results and discussion

The main purpose of protective clothing is to provide optimal and comfortable conditions for people in difficult or extreme situations. Such clothing should be comfortable and practical, withstand contamination and heavy physical exertion, and effectively disguise the person using it.

In some situations, uniforms can save a soldier's life or help them complete a combat mission. The range of protective military clothing is growing every year. Time-tested fabrics are used for production, and new high-tech textile materials are being developed (Malbon & Carr, 2019). A range of military clothing and special-purpose equipment (weapon covers, backpacks, sleeping bags, tents, etc.) is made from various types of fabrics:

• Natural materials: wool, moleskin, "afghan" and profit, which are characterised by the highest level of comfort during wear. They provide breathability; they are resistant to dust; they absorb moisture and are easy to wash and maintain, but some of them wear out quickly, wrinkle and shrink after washing. Jackets, pants and overalls are often made of these materials, and cotton is used for thermal underwear.

• Synthetic fabrics: polyester and nylon, which are highly durable, elastic, lightweight, hydrophobic, windproof, and wear-resistant. Although these garments are compliant with and can be resistant to chemicals, they can melt and cause burns when burned. It is also prone to electrification and fading. It is recommended to dry such clothes at a low temperature and wash them in cold water. This type of fabric is used to make demi-season and summer clothing, as well as for backpacks, gloves, belts, bags, and cargo vests.

• Combined fabrics consisting of cotton and polyester and represented by such types as greta, raincoat, shirt fabric and ripstop. They combine the positive hygienic properties of natural materials with the high wear resistance of synthetic fibers.

Thus, modern textiles for military uniforms are mostly made of synthetic, artificial fibers and cotton fibers. For Ukraine, all these fibers are imported raw materials. In order to search for a Ukrainian raw material base for use in the defense sector, further studies in the present academic paper were conducted directly with natural raw materials – hemp cottonin and oilseed rayon fibers.

Fabrics made of bast fiber materials are characterised by high air permeability, which helps preserve oxygen in the structure of textile products. This prevents the development of anaerobic bacteria and their spread inside various types of clothing, knitwear and footwear. The use of such materials will not only provide high-quality products for the defense sector but also promote the use of Ukrainian raw materials.

Ensuring the high quality of materials for the defense industry is possible only if the quality of raw materials is constantly monitored at each stage of the technological process. The main feature of the structure and components of the studies to be conducted in this research work is the systematic and comprehensive study of the quality properties of bast raw materials at all stages of its processing. For this purpose, modern and updated methods of decortication of raw materials and methods for determining the physical, mechanical, sanitary and chemical properties of hemp and oilseed flax fibers were used.

Criteria are used that include length, thickness and breaking load to evaluate the suitability of fibers for further processing on spinning equipment. These parameters together determine the spinning ability of the fiber. For this purpose, the length, linear density, breaking load, elongation, and normalised moisture content were studied. Table 2 shows the physical and mechanical properties of the bast fibers under study.

Table 2. *Quality indicators of bast fiber components that can be used in protective clothing*

No.	Indicator	Oilseed flax	Hemp cottonin
1	Fiber length, mm	33-55	50-90
2	Relative breaking load, sN/tex	6-8	16.2-17.0
3	Relative tensile elongation, %	2.0-2.3	9.5-17.2
4	Linear density, tex	0.60-1.20	0.71-1.44
5	Standardised moisture content, %	8.5-15.0	12.0

Source: *developed by the authors*

The equipment of cotton processing enterprises using the carded spinning system utilises fibers with a linear density of 0.16-0.33 tex and a cross-sectional size of 15-19 microns (Slizkov *et al.*, 2007). As can be observed from Table 2, hemp cotton and oilseed flax fibers have a higher linear density, which exceeds the standard cotton fineness. The analysis of the data on the strength of hemp cottonin and oilseed flax fibers, which is one of the key indicators of their quality, presented in Table 2, makes it possible to conclude that the tensile load of these fibers is much higher than the maximum value of the tensile load of medium-fiber cotton fiber, which is 0.003 daN (Slizkov *et al.*, 2007). In addition, the relative tensile elongation of hemp cottonin, which is 9.5-17.2%, indicates that the manufacture of mold-resistant products from one hundred percent yarn is not recommended.

Taking into account all the advantages of this type of bast fiber components listed above, the main disadvantages of these fibers were highlighted in the present research. The main disadvantage of oilseed flax fibers is their low strength; therefore, it is not recommended to use them in 100% composition for yarns intended for military textiles. Hemp cottonin also has one significant drawback: due to its high fat content (up to 3%), it has a high tensile elongation; therefore, it is not recommended for use in form-resistant products.

In order to reduce the tensile elongation of hemp cottonin, the raw material was steamed in a laboratory autoclave. After steaming, repeated studies of the physical and mechanical properties of hemp fiber were carried out. The studies showed that the tensile elongation

decreased from 17% to 7.3%, which was due to changes in the chemical composition of hemp cottonin, namely a decrease in the content of fatty acids to 1.0-1.2%.

The strength of oilseed flax fibers was increased by mixing this type of fiber with various natural and chemical fibers up to 30%. This stage was not aimed at suppressing the naturalness of this fiber but rather at improving its quality properties. Compositional combinations with other fibers up to 30% were also carried out with hemp cottonin. Table 3 shows the properties of fiber components that are proposed to be added in an amount of up to 30% to the mixture with bast fibers.

Table 3. *Quality indicators of fiber components added to the compounds*

No.	Indicator	Fiber components of compounds				
		cotton	wool	lavsan	nitron	nylon
1	Fiber length, mm	35-50	45-190	100	35-150	65-90
2	Relative breaking load, sN/tex	24-36	10-14	32-40	25-34	35-46
3	Relative tensile elongation, %	7.0-9.0	20.0-67.0	43.0-55.0	25.0-31.0	45.0-65.0
4	Linear density, tex	0.66-0.22	0.20-5.00	0.55	0.11-2.50	0.40
5	Standardised moisture content, %	8.5	18.3	1.0	5.0	1.0-2.0

Source: *developed by the authors*

All the fibers listed in Table 3 had a positive effect on the resulting yarn to one degree or another, in different percentages in a mixture with oilseed flax and hemp cottonin fibers. According to the research results, after all these components were added at 5%-30% to oilseed flax fibers and hemp cottonin, it was found that the yarn strength increased, elongation decreased (in blends with hemp cottonin), spinning properties improved, and all the disadvantages of bast fibers were balanced, thereby increasing the possibility of using these mixed yarns in fabrics for military uniforms.

Thus, having data from previous studies of both raw materials and yarns for military fabrics, it is possible to compare them with existing studies on the use of bast fibers in military garments. There aren't many works like this one. It is evident from a comparison with the research by the Ukrainian scientists N.V. Ostapenko and L.G. Nikolaychuk that the former provides a more detailed description of the raw materials' qualities, highlighting both the benefits and drawbacks of the fibers and utilising a variety of techniques to address the shortcomings of the fibers under study. On the other hand, the research conducted by scientists N.V. Ostapenko *et al.* (2021) and L.G. Nikolaychuk (2021) is more focused on the known facts about hemp fiber and goes into great detail about the legal aspects of growing this kind of raw material. The joint work of the US Army Research, Development and Engineering Center and the Department of Defense is more informative in this area (Military uniform fabric produced with hemp fibers, 2021). According to the data of their study, a fabric made of hemp fibers for marines was produced and its properties were compared with those of cotton fiber fabric, which has been used in this area since 2022. The publication also highlighted the advantages of hemp fabric and the possibility of replacing cotton with hemp fiber in this type of fabric for military uniforms. However, the scientific work included studies with 100% use of hemp fibers in yarn for marine uniforms without indicating the disadvantages of the fiber and their elimination.

Scientists from many countries are studying and improving the properties of protective textiles for the armed forces. Many developments are devoted to special coatings for military textiles that provide unique protective properties (Pimenta *et al.*, 2021). For instance, scientists at the US Army Research, Development and Engineering Center, Natick, Massachusetts, Q.T. Truong & N. Pomerantz (2018) were engaged in improving the properties of military fabrics by applying an omniphobic coating that increases the durability of clothing, helps to self-clean, protects the armed forces from getting wet and protects them during missions in chemically and biologically contaminated environments. Scientists from the Federal University of Santa Catarina, Brazil, were engaged in the improvement and development of new technological processes in the production of military textiles (Steffens *et al.*, 2019). The study of the water-repellent and waterproof properties of protective textiles made of various fibers and materials for the purpose of conceptualising the distribution of special materials for different types of troops was carried out by C. Loghin *et al.* (2018) from the Defense Clothing and Textiles Agency, UK. The well-known company OTEX Specialty Narrow Fabrics (2023) is one of the largest manufacturers in the United States that produces high-performance textiles for the military with new fibers such as Kevlar, Nomex, Spectra, etc. using new technologies developed by leading state institutes.

I.I. Shuvo & P.I. Dolez's (2023) research focuses on the application of several unprocessed natural and synthetic materials in military apparel. The use of bast fibers in this kind of industry has not been the subject of many studies, which makes this area promising for further consideration. Some studies in this area have focused on the development of a homogeneous hemp fiber fabric with significant performance advantages over conventional textile fabrics intended for the Marine Corps (Military uniform fabric produced with hemp fibers, 2021). This fabric will have significant performance benefits, lower cost, lighter weight, and will be

stronger, more comfortable, and more environmentally friendly than the existing option. Additional desirable attributes of the fabric will be the ability to provide protection against vectors, such as protection against insects, improved flame retardancy, that is, the ability to self-extinguish, and camouflage protection that exceeds current requirements for visual and near-infrared rays. Chinese scientists have also been working in this area since China is the largest supplier of hemp fiber to European countries (Zhang *et al*., 2018; Liu *et al*., 2019). Ukrainian scientists have also made a major breakthrough in developing an improved variety of industrial hemp called "Sofia" (Ukrainian scientists have developed a new variety of hemp, which can be used to make body armor for the military, 2022). This type of plant will be used in the production of gunpowder, as well as raw materials for ropes and parachutes. After all, these fabrics are lighter than synthetic Kevlar, which has been used since the 60s to make bulletproof vests, which means that the armor plates that are made of them will withstand the impact of armor-piercing bullets. Ukrainian scientists such as L.V. Krasnyuk *et al. (*2019), V.M. Durach & L.G. Nikolaychuk (2021), O.V. Chepeliuk *et al.* (2021), in cooperation with specialists in production technologies, have developed new and improved traditional methods of manufacturing fabrics from natural fibers for the needs of the modern defense industry. The aforementioned techniques and technologies are all typically predicated on the application of unique solutions along with the utilisation of synthetic and artificial fibers. The drawbacks of all of these methods include high production costs, poor hygienic and sanitary standards, breathable fibers, and a deficiency of natural ingredients. As a result, there is a growing need to find high-quality natural components for the manufacturing of protective fabrics.

No scientific papers on the use of oilseed flax fibers for military fabrics were found. Therefore, based on the literature studies, it was concluded that this scientific area requires further research in order to more accurately predict the use of flax fibers in fabrics for military purposes. The use of such materials will help provide the defense industry with high-quality products as well as support Ukrainian raw materials.

Conclusions

Ensuring high quality materials for the defense sector is possible only if innovations are introduced, own resources are used and quality control is ensured at every stage of the technological process. For this purpose, modern and updated methods of decortication of raw materials and methods for determining the physical, mechanical, sanitary and chemical properties of raw hemp and oilseed flax were used in the research.

The analysis of literary sources has enabled the identification of primary scientific directions in improving military fabrics, indicating that the main materials for military gear are cotton and synthetic fabrics. Additionally, it has been pointed out that Ukrainian textile industry enterprises depend on imported raw materials. The fibers of oilseeds like hemp and flax, which are widely grown in Ukraine, may serve as the basis of the natural raw material base. A thorough examination of these raw resources' use patterns was done in order to ascertain their quality attributes.

The results of the experimental studies undertaken allowed for the identification of both benefits and drawbacks in the features of bast crops. Different natural (cotton, wool) and chemical (nylon, nitron, polyester) fibers were added in varying percentage ratios (5-30%) to the combination containing bast fibers in order to highlight the benefits and lessen the drawbacks. Moreover, steam treatment was conducted under certain regimes for hemp cottonin in order to reduce the relative elongation at break from 17.2% to 7.3%. Ukrainian raw materials, such as oilseed flax fibers and hemp cottonin, will allow for improving the quality and reducing the cost of clothing for armed forces' needs.

Therefore, conducting scientific research will reduce the state's material expenditures for purchasing quality environmentally friendly materials for the defense complex while simultaneously promoting the advancement of Ukrainian light industry productions to a new qualitative level, enhancing the competitiveness of Ukrainian products in the global market.

Further studies of the present scientific work will be directed towards examining the obtained fabrics for their use in various types of military equipment. As of 2023, the utilisation of domestic raw resources for Ukraine represents a highly promising direction in the light industry, especially when aimed at improving the properties of protective textiles intended for military equipment.

Conflict of interest

None.

Acknowledgements

We would like to express our gratitude for the invaluable technical assistance provided in obtaining oilseed flax fibers and hemp cotton to the following companies: "Hemp Bio Group" LLC (Irpin, Kyiv region); "Flax Mill "Starosambirsky".

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Аналіз властивостей луб'яної сировини як компонента тканини для військового обмундирування

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Анотація. Актуальність даної наукової роботи визначається потребою заміни імпортованої сировини для виготовлення військового одягу на українську сировину технічних конопель та льону олійного. Метою було провести аналіз якісних властивостей луб'яної сировини та визначити її потенціал для використання у військовому обмундируванні. В процесі вирішення поставлених завдань було застосовано методи комплексного аналізу, синтезу, спостереження, вимірювання, порівняння та узагальнення отриманих результатів та інформації, а також реалізовано стандартні, загальноприйняті у галузі легкої промисловості методики. Зазначено, що конопляний котонін та волокно льону олійного, на відміну від інших натуральних волокон, більш міцні, стійкі до стирання, гниття, в них переважають санітарно-гігієнічні, антистатичні, гіпоалергенні та антибактеріальні властивості. Визначено, що тканини з цих волокон довговічні, мають високий опір ультрафіолетовому випромінюванню, добре тримають фарбування, не вигорають та не вицвітають тощо. Проаналізовано наукові роботи, де вивчалися застосування даної сировини для використання різних видів військового одягу, захисних бронежилетів, у виробництві пороху. За рахунок визначення основних властивостей досліджуваної луб'яної сировини було встановлено можливість використання даної сировини в деяких видах військового обмундирування. Головна особливість структури та складових досліджень полягали у систематичному та комплексному вивченню якісних властивостей луб'яної сировини на всіх етапах її переробки. Було запропоновано замість бавовняних волокон в тканинах військового призначення використовувати волокна льону олійного та конопляний котонін. Це дасть змогу зменшити матеріальні витрати держави на закупівлю матеріалів для оборонного комплексу та водночас сприятиме виведенню українських виробництв легкої промисловості на новий якісний рівень, підвищить конкурентоспроможність українських виробів на світовому ринку. Знання властивостей луб'яної сировини може допомогти виробникам підвищити якість виробництва тканин для військового застосування

Ключові слова: волокна; коноплі; льон олійний; властивості; тканини військового призначення

COMMODITY BULLETIN
Journal homepage: https://c-bulletin.com.ua/en
DOI: 10.62763/ef/1.2024.17

Article's History: Received: 17.12.2023 Revised: 20.02.2024 Accepted 26.04.2024

Vol. 17, No. 1, 2024, 17-26

UDC 620.22:621.7(075.8)

Modification of the surface of titanium alloys by the synthesis of coatings by the PEO method in alkaline electrolytes saturated with diatomite

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Abstract. One of the most promising directions of modern materials science is the search for methods of improving the biocompatibility properties of metals used in implantology, which will allow to reduce the percentage of rejection of implants by the living organism. Therefore, it is promising to use processing methods to change the state of the surface of metals due to surface modification, which includes the method of plasma electrolytic oxidation. The main goal of this work was to develop a technological process for obtaining coatings with higher biocompatibility compared to the base metal due to the introduction of natural components into the coating. The presence of elements in biocoatings and their quantity was determined using a scanning electron microscope (SEM) and energy dispersive X-ray spectroscopy (EDS), which allowed for targeted analysis of the surface of the samples. The elemental composition of coatings synthesised on the basis of titanium alloy in alkaline electrolytes based on KOH, liquid glass of calcium hydroxide, sodium polyphosphate and sodium pyrophosphate with the addition of hydroxyapatite and diatomite was researched in the work. A direct relationship between the composition of the electrolyte and the Ca/P ratio was established. It has been proven that biocoatings synthesised in alkaline solutions by the PEO method satisfy the conditions of biocompatibility. It has been established that in an environment containing alkalis and phosphates, coatings are synthesised for which Ca/P = 1.21. The introduction of hydroxyapatite into the electrolyte leads to an increase in the Ca/P ratio to a value of 1.28, and an increase in the concentration of the electrolyte and the addition of diatomite increases this ratio to a value of 1.57. The obtained results establish the possibility of a wide range of regulation of the Ca/P ratio in the biocoating

Keywords: elemental analysis; biocompatibility; chemical properties; synthesis modes; coating composition

Introduction

Titanium alloys are utilised for fracture fusion and splicing, as well as for knee, hip, and shoulder prosthesis. J. Jakubowicz (2020) described that high biocompatibility is due to the ability of titanium to form a protective oxide layer on its surface in a fraction of a second, thanks to which it does not corrode and does not release free metal ions that can cause pathological processes around the implant, and the tissues surrounding the prosthesis remain free of metal ions. T. Hanawa (2022) note that the PEO coating on titanium alloys is characterised by high bioactivity and biocompatibility. They developed a new graphical method for evaluating the porosity of PEO oxide films, which helps predict their bioactivity. O. Povstyanoy *et al.* (2024) describe in his works the effective use of coatings with a wide range of porosity. Y. Gu *et al.* (2018) point out that the main disadvantages of titanium alloys are poor machinability, high coefficient of friction, relatively low modulus of elasticity, and for implantology, resistance to marginal corrosion, low chemical activity and low adhesion. These

Suggested Citation:
Imbirovych, N. (2024). Modification of the surface of titanium alloys by the synthesis of coatings by the PEO method in alkaline electrolytes saturated with diatomite. *Commodity Bulletin*, 17(1), 17-26. doi: 10.62763/ef/1.2024.17.

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facts can lead to bone resorption around them. M. Fazel *et al.* (2019) pay attention to the prospect of using compositions with antimicrobial properties of the surface of materials in implantology. An effective method of preventing this effect is the preliminary application of a bactericidal layer to the surface of the material.

J. Zhou *et al.* (2019) pointing on possible solution to this problem is superficial surface modifications that improve osseointegration of implants or reduce bacterial infection. Considering the above the use of compositions with antimicrobial properties in bone plastic is promising. N.Y. Imbirovych *et al.* (2023) examine the plasma-electrolytic oxidation (PEO) technique as a possible means of improving light alloy's surface characteristics. They found that as a result of a 4-fold increase in the concentration of electrolyte components and the addition of diatomite (20g/l), the coating synthesis process is stabilised and coatings with higher roughness (3-4 times) and porosity (1.9 times) are formed compared to coatings synthesised in an electrolyte without diatomite. T. Li *et al.* (2022) investigated PEO coatings corrosion properties synthesised on titanium alloys. The authors established that the change in the corrosion state is influenced by the coatings structural flaws and porosity caused by the peculiarities of the technological process. F. Malekmohammadi *et al.* (2020) determined the influence of nanoparticles on the thickness of PEO coatings. They observed that, in contrast to the coating that was synthesised in PEO electrolyte containing cerium (III) chloride, the nanostructured cerium dioxide/titanium composite formed from functions as a barrier to porosity growth from nitrate salt during the PEO process. It also shows improved corrosion resistance in 0.1 M HCl solution at ambient temperature and stronger impedance resistance at lower frequency.

X. Yang *et al.* (2019) imply that one aspect of the PEO technique is the ability to modify the electrolyte and working substance composition to regulate the mechanical and physical characteristics of coatings. To increase the biocompatibility of implants, it is important to form porous coatings with increased roughness on the surface. V. Subha *et al.* (2023) modified the surface of titanium alloys with diatomaceous earth. They showed that the introduction of diatomaceous earth particles leads to an increase in the mechanical and thermal properties of titanium alloys. Diatoms are naturally occurring silica and could be a potential source of silicon for the electrolyte used in the PEO method. That is why there is great interest in introducing such a natural component into the structure of oxide coatings on a titanium alloy.

The purpose of this work is to modify the surface of titanium alloys by applying coatings with high porosity and antimicrobial properties to their surface.

Materials and methods

In this work, a combination of SEM and EDS was used to investigate the elemental composition of the coatings produced on the surface of titanium alloys. With the help of SEM analysis, was got a qualitative image of the coatings. Under a microscope, specimens of Grade 5 titanium alloy were shaped like cylinders, measuring 25 mm in diameter and up to 10 mm in thickness. The goal used EDS was research composition of coatings that are synthesised into various electrolytes such as: 20 g/l KOH+20 /l liquid glass+20 g/l sodium pyrophosphate+20 g/l sodium polyphosphate+20 g/l diatomite, 5 g/l KOH+5 g/l liquid glass+5 g/l sodium pyrophosphate+5 g/l sodium polyphosphate+5 g/l hydroxyapatite and 5 g/l KOH+5 g/l liquid glass+5 g/l sodium pyrophosphate+5 g/l sodium polyphosphate. The current density from the anode to the cathode (Ia/Ic) was equal to 5/5 A dm^2. The time of the PEO process was 10 min.

Titanium alloys of Grade 2 and Grade 5 were used in the work. The coating was synthesised by the PEO method in the anode-cathode mode, where the sample was the anode and the bath with the electrolyte was the cathode. The IMPELOM installation, which works in alternating anode-cathode mode, was used as a power source. The current is applied alternately to the anode and cathode. Spark discharges that result from the current flowing through the sample in the electrolyte solution guarantee a high temperature in the surrounding area. Temperature influences the introduction of electrons into the oxide layer at the spark plug locations. J. Jovović *et al.* (2012) studied the temperature of the plasma channel and noted that it varies from 4000 K to 33000 K. These thermodynamic circumstances cause electrons to be injected into the oxide layer from the electrolyte.

The synthesis of coatings on titanium alloys was carried out in three environments: 5 g/l KOH+5 g/l liquid water (l.g.)+5$Ca(OH)_2$+5 g/l $Na_4P_2O_7$+5 g/l $Na_6P_6O_{18}$, 5 g/l KOH+5 g/l l.g.+5$Ca(OH)_2$+5 g/l $Na_4P_2O_7$+5 g/l $Na_6P_6O_{18}$+1 g/l HPA and 20 g/l KOH+20 g/l l.g.+20 g/l $Ca(OH)_2$+20 g/l $Na_4P_2O_7$+20 g/l $Na_6P_6O_{18}$+20 g/l diatomite. The ratio of current densities and processing time for all the studied systems were the same, respectively: Ia/Ic = 5/5 A/dm^2, t = 10 min. A Phenom XL scanning electron microscope (SEM) with automatic measurement, equipped with a backscattered electron detector (BSED) and 3D roughness reconstruction, was used to analyse the coatings that were manufactured in various modes. Additional Elemental Mapping and Line Scan software allows for further elemental distribution analysis. The technique of energy dispersive spectroscopy (EDS) analyses the X-ray radiation produced by electrons from an electron beam interacting with a sample. Combination of SEM and EDS makes it possible to assess the surface of the studied samples in detail and determine their elemental composition. Samples of Grade 5 titanium alloy, which were viewed under a microscope were cylindrical in shape, measuring 25 mm in diameter and up to 10 mm in thickness.

Results

The chemical composition of the coating created by plasma-chemical reactions is crucial for guaranteeing the coating's biocompatibility. This depends on the base on which the coating is synthesised, alloy grade, and electrolyte components. For the development of coatings characterised by high biocompatibility, a necessary condition is that the composition of the coatings is as close as possible to bone. Bone consists of minerals, organic substances and water (Fig. 1). Therefore, the working electrolytes were saturated with phosphates and calcium salts. Thus, polyphosphate is an inorganic polymer, which, due to its biocompatibility and low toxicity, is a biomedical compound of hydroxyapatite, the main component of bone tissue. To saturate the electrolyte with calcium components, calcium hydroxide was introduced into the working environment, which is soluble in water and loses moisture at temperatures above 580°C, turning into calcium oxide.

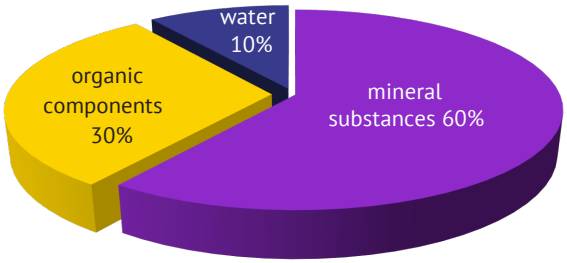


Figure 1. *The components that make up a bone*

Source: *developed by the author*

Diatomite is a non-metallic clay mineral, the main chemical composition of which is amorphous silica (80-95%), which consist small amounts of montmorillonite, kaolinite, quartz and other clay impurities and organic substances. In an aqueous solution (electrolyte) in the presence of alkalis KOH or $Ca(OH)_2$, a neutralisation reaction occurs:

$$SiO_2+2KOH \rightarrow K_2O(SiO_2)+H_2O; \quad (1)$$

$$SiO_2+CaOH_2 \rightarrow CaSiO_3+H_2O. \quad (2)$$

As a result, potassium and/or calcium silicates are formed. Due to its high porosity, diatomite has good absorption. In addition, diatomite has antibacterial properties.

To establish the biocompatibility of coatings, the Ca/P ratio is used, which in hydroxyapatite $Ca_5[OH(PO_4)_3]$ (the main component) is 1.67. M. Tzaphlidou (2005) shows that there is a small variation in the Ca/P ratio between the bones of men and women between the ages of 15 and 55. In adults (from 21 to 120 years old), the Ca/P ratio in bones is 0.79…1.65%. For children, this ratio slightly increases. In general, the difference varies within 0.34…2.14%. So, elemental analysis of bio-coatings makes it possible to establish the interaction of the sample surface with the components of the electrolyte and understand the reactivity under thermodynamic conditions. Therefore, the amount of phosphorus and calcium in the electrolytes used in this work was first determined.

Electrolyte composition 5 g/l KOH+5 g/l r.s.+5 $Ca(OH)_2$+ +5 g/l $Na_4P_2O_7$+5 g/l $Na_6P_6O_{18}$ contains phosphorus:

$$n = \frac{m}{M}. \quad (3)$$

The content of phosphorus in sodium polyphosphate, which is contained in this electrolyte, was calculated in the amount of 5 g/l. The volume of distilled water in the bath is 20 liters, therefore, sodium polyphosphate is contained in the electrolyte 100 g.

$$n(P) = \frac{100\ g}{102\frac{g}{mol}} = 0.9804\ mol. \quad (4)$$

The amount of phosphorus in sodium pyrophosphate is equal to:

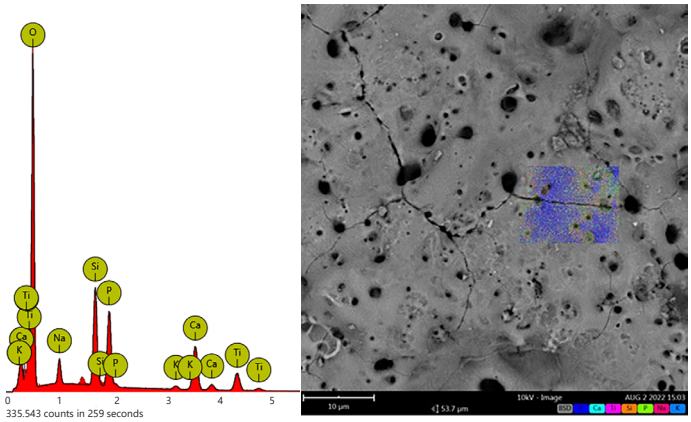
$$n(P) = 2n(Na_4P_2O_7); \quad (5)$$

$$\frac{m(P)}{266\frac{g}{mol}} = \frac{200\ g}{266\frac{g}{mol}} = 0.7519\ mol. \quad (6)$$

Therefore, 1.7323 mol of all phosphorus is contained in this electrolyte. The amount of calcium in $Ca(OH)_2$ is:

$$n(Ca) = \frac{100\ g}{74\frac{g}{mol}} = 1.3514\ mol. \quad (7)$$

Therefore, the Ca/P ratio in the electrolyte is 0.5 g/l KOH+0.5 g/l r.s.+0.5$Ca(OH)_2$+0.5 g/l $Na_4P_2O_7$+0.5 g/l $Na_6P_6O_{18}$ according to calculations is 1.3514/1.7323 = 0.7801. Based on the ratio of current densities Ia/Ik=5/5 A/dm^2, Figure 2 presents the elemental analysis results of the coatings produced in the electrolyte of 5 g/l KOH+5 g/l r.s.+5Ca(OH)2+5 g/l $Na_4P_2O_7$+5 g/l $Na_6P_6O_{18}$. The results were obtained using a scanning electron microscope. According to the presented elemental analysis, coatings were obtained that contain the largest amount of oxygen (69.72 at.%), which is released from water, which in turn is ionised in the place of intense spark formation (or arc discharge plasma) (Table 1).



a *b*

Figure 2. *Elements in the coating synthesised on a titanium alloy (a); arrangement of elements present on the surface of the coating synthesised (b)*
Note: *synthesis mode: 5 g/l KOH+5g/l l.g.+5Ca(OH)$_2$+5 g/l $Na_4P_2O_7$+5 g/l $Na_6P_6O_{18}$, Ia/Ic = 5/5 A/dm^2, t = 10 min*
Source: *developed by the author*

Table 1. *Quantitative content of elements in the coating synthesized in the electrolyte 5 g/l KOH+5 g/l l.g.+5Ca(OH)$_2$+5 g/l $Na_4P_2O_7$+5 g/l $Na_6P_6O_{18}$, Ia/Ic = 5/5 A/dm^2, t = 10 min*

Element Symbol	Atomic Conc.	Weight Conc.
O	69.72	51.28
Ca	8.18	15.07
Ti	4.97	10.94
Si	7.50	9.69
P	6.74	9.60
Na	2.38	2.51
K	0.51	0.91

Source: *developed by the author*

It should also be noted that in a sufficient electrolyte, the potassium content becomes:

$$n = \frac{100\ g}{39\ \frac{g}{mol}} = 2.57\ mol. \quad (8)$$

Comparing the amount of calcium in the electrolyte with the amount of potassium, a value of 1.9 was determined, which represents a larger proportion of potassium ions. However, elemental analysis showed that the coating contains 16 times more calcium ions than potassium, which is explained by the higher water solubility of KOH. In turn, Ca ions are heavier and less soluble in water, and therefore, being in the boundary region, they are introduced into the surface, thereby modifying it. Studies of the phasing of the PEO process have established that the system, which does not contain calcium hydroxide, but only consists of KOH and liquid glass in the weight equivalent of 5 g/l each, requires a voltage of approximately 40 V to ensure the process of stable synthesis of the titanium alloy's surface oxide layer, while to ensure the synthesis of a bio-coating in an electrolyte containing KOH, sodium silicate (liquid glass) and Ca(OH)$_2$, respectively, 5 g/l, the system requires an increase in the operating voltage, which ensures uniform growth of the oxide on the surface to a value of 140 V, which on 100 times more than the coating synthesis in an electrolyte with a lower concentration.

Thus, this fact indicates that the system needs a larger reserve of energy to ensure the state to which the system tends according to the principle of Le Chatelier-Brown (Gibbs, 1878), who proved that every system tends to balance. A slightly different effect was obtained when analysing the content of sodium ions in the electrolyte and in the coating synthesised in it. According to calculations of the amount of sodium ions in the electrolyte, the following was found: sodium ions are contained in liquid glass, which is sodium silicate $Na_2O(SiO_2)n$, sodium pyrophosphate, and sodium polyphosphate. Therefore, n(Na) (liquid glass) = 4.35 mol, n(Na) ($Na_4P_2O_7$) = 1.07 mol, n(Na) ($Na_6P_6O_{18}$) = 1.45 mol. Its total amount in the working electrolyte is 6.87 mol. While the coating of sodium ions contains only 2.38 at.%. Sodium dissolves quite well in water. However, comparing the obtained values of the amount of such components in the electrolyte and in the coating as potassium and sodium, it can be noted that the potassium in the coating is 5 times less than in the electrolyte, and the amount of sodium deposited

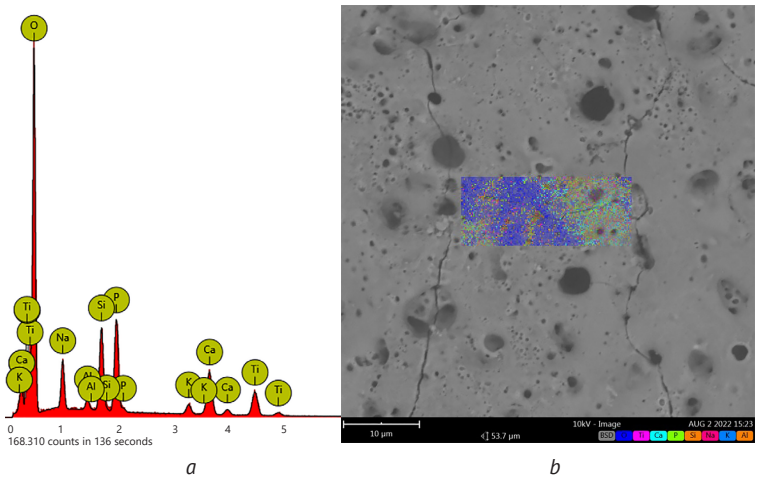
on the modified surface by the PEO method is almost three times smaller.

The amount of silicon is related in the following way. The number of silicon ions in the electrolyte is:

$$n = \frac{100\ g}{28\ \frac{g}{mol}} = 3.57\ mol. \quad (9)$$

According to the carried out elemental analysis, its amount in the coating is 7.50 at.%. Unlike sodium and potassium ions, silicon is present in the base of the produced metal, which is why its abundance in the coating has increased. From the obtained result, it was established that the coating mainly contains oxides, which upon interaction with the titanium matrix form TiO_2 in various crystal modifications. The resulting titanium-based ceramics also contain a sufficient amount of calcium and phosphorus, the ratio of which in the coating is Ca/P = 1.21.

The results of research into the elemental composition of coatings in hydroxyapatite environments are shown in Figure 3.



a *b*

Figure 3. *Elements in the coating synthesised on a titanium alloy (a); distribution of elements on the surface of the coating synthesised (b)*

Note: *synthesis mode: 5 g/l KOH+5 g/l l.g.+5Ca(OH)$_2$+ 5 g/l $Na_4P_2O_7$+5 g/l $Na_6P_6O_{18}$+1 g/l HPA, Ia/Ic = 5/5 A/dm^2, t= 10 min.*

Source: *developed by the author*

Already from the obtained spectrogram, an increase in the number of potassium elements. Following a quantitative examination of the calcium and phosphorus contents in the hydroxyapatite working electrolyte, it was discovered that in the salt $Ca(OH)_2$:

$$n(CaOH_2) = \frac{100\ g}{40+16\cdot2+1\cdot2\left(\frac{g}{mol}\right)} = 1.3514\ mol. \quad (10)$$

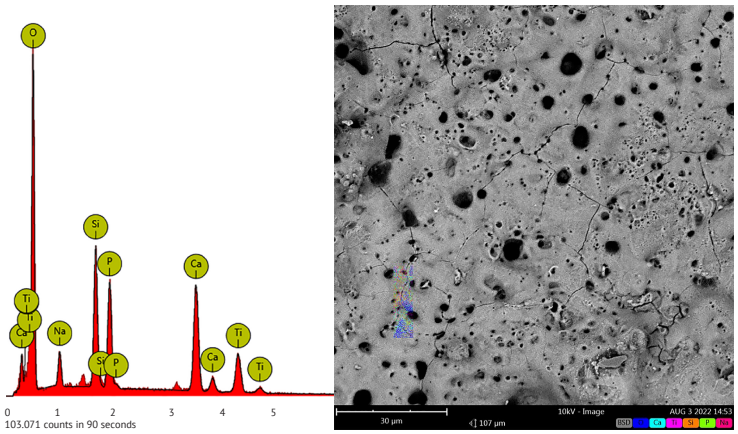
The calcium content in the electrolyte with hydroxyapatite is 1.5506 mol. In the coating, its content is 7.06 at.% and 12.87 wt.% (Table 2). Furthermore, by comparing the calcium and phosphorus contents of the coating that formed in the electrolyte with and without hydroxyapatite, it was found that the phosphorus content increased to 7.17 at.% against 6.74 at.% in the electrolyte that has 0.2 mol more calcium due to the introduction of hydroxyapatite, while the calcium content in the coating decreased by approximately 1 at.%. At the same time, the phosphorus content in the electrolyte without hydroxyapatite is 5.37 mol, and in the electrolyte containing HPA is 5.97 mol. Calculations showed that the Ca/P ratio in these coatings is 1.28.

Table 2. *Quantitative content of elements in the coating synthesised in the electrolyte 5 g/l KOH+5 g/l l.g.+5Ca(OH)$_2$+5 g/l $Na_4P_2O_7$+5 g/l $Na_6P_6O_{18}$+1 g/l HPA, Ia/Ic = 5/5 A/dm^2, t = 10 min*

Element Symbol	Atomic Conc.	Weight Conc.
O	68.12	49.53
Ti	5.95	12.95
Ca	7.06	12.87
P	7.17	10.09
Si	5.62	7.17
Na	4.05	4.23
K	1.24	2.21

Source: *developed by the author*

Analysis of the elemental composition of coatings that were synthesised in the composition electrolyte 20 g/l KOH+20 g/l l.g.+20g/l $Ca(OH)_2$+20g/l $Na_4P_2O_7$+20g/l $Na_6P_6O_{18}$+ 20g/l diatomite for 10 minutes is presented in Figure 4. The presence of oxygen ions under this regime is 61.61 at.%, while a slight decrease in oxygen ions in the coating is observed (Table 3).



a *b*

Figure 4. *Elements in the coating synthesised on a titanium alloy (a); distribution of elements on the surface of the coating synthesised (b)*

Note: *synthesis mode: 20 g/l KOH+20 g/l l.g.+20Ca(OH)$_2$+20 g/l $Na_4P_2O_7$+20 g/l $Na_6P_6O_{18}$+20 g/l diatomite, Ia/Ic = 5/5 A/dm^2, t = 10 min.*
Source: *developed by the author*

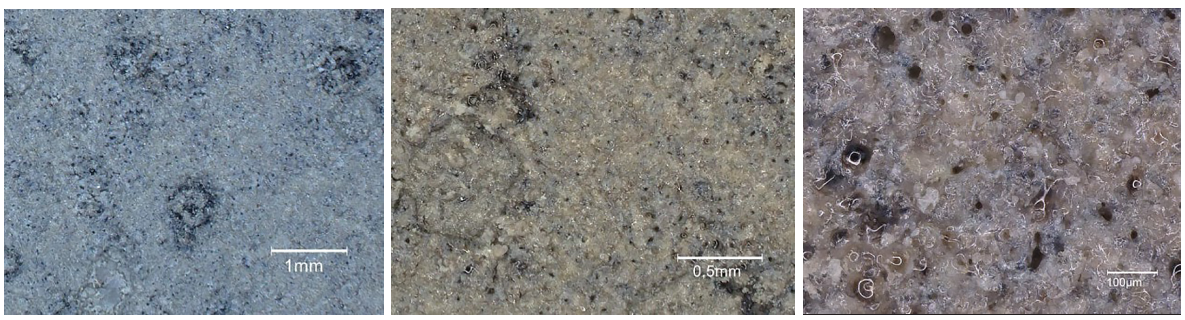
Table 3. *Quantitative composition of the coating's components made in the electrolyte 20 g/l KOH+20 g/l l.g.+20Ca(OH)$_2$+20 g/l $Na_4P_2O_7$+20 g/l $Na_6P_6O_{18}$+20 g/l diatomite, Ia/Ic = 5/5 A/dm^2, t = 10 min*

Element Symbol	Atomic Conc.	Weight Conc.
O	61.61	41.9
Ca	13.95	23.36
Ti	7.82	15.64
Si	7.65	8.98
P	6.62	8.57
Na	2.35	2.26

Source: *developed by the author*

It is also worth noting that the coating synthesised in these modes consists of almost twice as much calcium with an almost unchanged amount of phosphorus. This effect confirms the fact of higher absorption of coatings synthesised in an electrolyte with diatomite.

The biocompatibility of coatings generated in an electrolyte of 20 g/l KOH+ 20 g/l l.g.+20$Ca(OH)_2$+ + 20 g/l $Na_4P_2O_7$+ 20 g/l $Na_6P_6O_{18}$+ 20 g/l diatomite is evaluated by analysing the ratio of Ca/P elements, which is 1.57.



a *b* *c*

Figure 5. *The coating synthesised in the electrolyte 20g/l KOH+20g/l l.g.+20g/l Ca(OH)$_2$+20g/l $Na_6P_6O_{18}$+20g/l $Na_4P_2O_7$+20g/l diatomite*
Source: *developed by the author*

This result is the most acceptable for the conditions of biocompatibility. As Figure 5 illustrates, the addition of diatomite to the electrolyte causes coatings with increased porosity and roughness to form on the titanium alloy's surface.

Discussion

The properties of the surface of materials have a decisive influence on the working properties of the product. L. Markashova *et al.* (2019) indicate the modification of the metal surface with metal-ceramic coatings by spraying. Studies were conducted into the structural-phase state of cumulative-detonation sprayed coatings. The dislocation density of these coatings is found to be uniformly distributed in their matrix, the substructures are significantly dispersed, and a nano-sized strengthening phase is formed. V. Korzhyk *et al.* (2024) determined the regularities in the interrelation between the strength and crack resistance characteristics of functional metal-ceramic coatings on metal parts and their structural and phase properties, taking into consideration the structural requirements that provide the necessary combination of strength and crack resistance properties. Is relevant to study the factors and reasons behind how technological modes of the processing method (PEO) affect specific product attributes, specifically the material's surface layer under study. The authors researched the mechanism of formation of hydroxyapatite coating on Grade 5 titanium alloy under combined treatment. It is noted that this treatment aids in the expansion of the hydroxyapatite phase, which leads to an increase in the biocompatibility of the surface of the titanium alloy.

A. Azmat *et al.* (2023) believe that modification of the titanium alloy surface can significantly affect the process and quality of osseointegration. P. Pesode & S. Barve (2021) note that the biological aspect of the interaction of the vitality of the organism's tissue with the non-biological environment depends on the modification of its surface, for example, extending the oxide film's thickness, giving the surface of the material roughness and texture. X. Li *et al.* (2018) found that coatings obtained under potentiostatic conditions show better wear resistance. They found that the wear rate of such coatings is approximately 10 times lower than that of galvanostatic coatings due to the formation of low porosity coatings, because when the size of the microdischarges can be controlled in the potentiostatic mode. Ł. Maj *et al.* (2024) determined the electrolyte's influence, electrical modes on the microstructures and composition of the resulting layers. In their work, the authors discussed in detail the properties of the obtained coatings and gave examples of their applications.

M. Molaei *et al.* (2021) highlight the importance of figuring out why specific coating qualities are impacted by PEO technology modes. The authors discovered that enhancing solutions with specific sized particles can help PEO coatings perform better. The addition of ZrO_2 particles to the electrolyte was found by the researchers to have a good influence on mechanical and chemical properties, including resistance to oxidation of PEO oxide coatings formed on titanium and its alloys, biological processes, wear and corrosion.

G. Montes-Hernandez & F. Renard (2020) note that integration with bone tissue can be improved and enhanced by the presence of bioactive materials on the surface, which also include calcium phosphate-containing materials. The authors research identifies unique chemical pathways to help better explain the creation of amorphous calcium phosphate phases and their subsequent transition into brushite or hydroxyapatite nanocrystals under abiotic circumstances. These paths have relevance in both natural settings and a wide range of technology applications. I. Zglobicka *et al.* (2019) think that diatom frustules are ideal model systems for manufacturing materials and gadgets using biomimicry. They used nano-X-ray computed tomography (XCT) to non-destructively visualise the diatom *Didymosphenia geminata's* frustule structure. The authors' biomimetic strategy serves as a proof of concept for upcoming advancements in production scaling based on the unique characteristics of microorganisms. The research of M. Ghobara *et al.* (2024), showed that diatom frustules are characterised by a high ability to absorb the environment due to a highly porous structure. They determined through a combined theoretical and experimental approach their mechanical properties, such as Young's modulus, which was estimated at 31.8 GPa. Research results obtained by L. Li *et al.* (2019) indicate the promotion of early osteogenesis and osseointegration of porous surfaces. They point out that this kind of structure might promote early in vivo bone integration and strengthen the link between implants and bone. V. Subbotina *et al.* (2022) research of a synthesised coating on an aluminium alloy makes it possible to determine the impact of adding hexametaphosphate to an alkaline silicate electrolyte on coating thickness. The thickness formation rate, according to the authors, is 0.9 μm/min when hexametaphosphate is present and 0.7 μm/min when it is not. Regarding the phase composition, no discernible impact was found. It was discovered that adding aluminium sodium aluminate-silicate electrolytes up to 13 g/l had an impact on the phase composition of the coating but had no discernible effect on the coating's thickness.

Therefore, the experimental studies of the above-mentioned authors made it possible to reasonably develop new bioenvironments for the synthesis of coatings characterised by high biocompatibility.

Conclusions

It was feasible to determine from the analysis of the content of PEO coatings synthesised in three different electrolytes that the addition of diatomite to the

electrolyte produces a highly developed surface and positively affects the composition of the produced coating. Taking into account the conditions of surface compatibility, the Ca/P ratio was calculated in all synthesised coatings. The obtained results show that the introduction of hydroxyapatite into the composition of the electrolyte makes it possible to increase such a ratio from the value of 1.21, which is set for the coating synthesised in the electrolyte without hydroxyapatite, to the value of 1.28. Increasing the electrolyte concentration and adding diatomite instead of hydroxyapatite leads to an increase in the Ca/P ratio to 1.57. The broad development of coatings formed on a titanium base by plasma-electrolytic oxidation was established with the aid of scanning electron microscopy. As a result, a significant number of pores of various sizes were discovered on the coatings final surfaces.

Therefore, in further research, it is important to determine the size of these pores and identify their presence in the coating layer, as well as their type. The obtained results will make it possible to predict the time of osseointegration of the synthesised coatings by PEO method in vivo, and the combination of the results obtained in this work will open the possibility of regulating a wider range of predicted properties of biocoatings on titanium alloys.

Conflict of interest

None.

Acknowledgements

The author N. Imbirovych is grateful to Dr. K.J. Kurzydlowski for his help in the definition of elemental analysis of the coatings and the opportunity to use the equipment for conducting microstructural studies.

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Модифікація поверхні титанових сплавів синтезом покриттів методом ПЕО в лужних електролітах, насичених діатомітом

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Анотація. Одним із перспективних напрямків сучасного матеріалознавства є пошук методів покращення властивостей біосумісності металів, які використовуються в імплантології, що дозволить зменшити відсоток відторгнення імплантатів живим організмом. Тому перспективним є використання методів обробки для зміни стану поверхні металів за рахунок поверхневої модифікації, до яких належить метод плазмового електролітичного оксидування. Основною метою даної роботи була розробка технологічного процесу отримання покриттів з підвищеною біосумісністю порівняно з основним металом за рахунок введення до складу покриття природних компонентів. Наявність елементів у біопокриттях та їх кількість визначено за допомогою растрового електронного мікроскопа (SEM) та енергодисперсійної рентгенівської спектроскопії (EDS), що дозволило провести прицільний аналіз поверхні зразків. У роботі досліджено елементний склад покриттів, синтезованих на основі титанового сплаву в лужних електролітах на основі KOH, рідкого скла гідроксиду кальцію, поліфосфату натрію та пірофосфату натрію з додаванням гідроксиапатиту та діатоміту. Встановлено пряму залежність між складом електроліту та співвідношенням Ca/P. Доведено, що біопокриття, синтезовані в лужних розчинах методом ПЕО, задовольняють умови біосумісності. Встановлено, що в середовищі, яке містить луги та фосфати, синтезуються покриття, для яких Ca/P = 1,21. Введення в електроліт гідроксиапатиту призводить до збільшення співвідношення Ca/P до значення 1,28, а підвищення концентрації електроліту та додавання діатоміту збільшує це співвідношення до значення 1,57. Одержані результати свідчать про можливість широкого діапазону регулювання співвідношення Ca/P у біопокриттія

Ключові слова: елементний аналіз; біосумісність; хімічні властивості; режими синтезу; склад покриття

COMMODITY BULLETIN
Journal homepage: https://c-bulletin.com.ua/en
DOI: 10.62763/ef/1.2024.27

Article's History: Received: 20.11.2023 Revised: 10.01.2024 Accepted: 26.04.2024

Vol. 17, No. 1, 2024, 27-35

UDC 674.022:621.715

The development of glutin-based biocomposite materials with advanced hydrophobicity

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Abstract. Biocomposite materials, which contain components of natural origin, have low resistance to water absorbtion due to high lyophilicity of components. It leads to quick destruction of biocomposite products under the conditions of high humidity exploitation that defines the necessity and importance of conducting scientific research in this sphere. The aim of the article is to research the hydrophobic additives influence on the compressive strength and hygroscopicity of biocomposite materials consisting of glutin matrix (100 parts by weight) and wood flour (100 parts by weight). The technology of forming biocomposite materials includes a step-by-step pressing the composition at a pressure of 10-15 MPa and a heat treatment of the product in a press mold at a temperature of 140°C. Experimental methods of investigating the biocomposite materials compressive strength and hygroscopicity were used in the work. It was experimentally determined that the modifying additive (paraffin) optimal content is 4 parts by weight per 100 parts by weight of biopolymer matrix. At this content, there is an increase compressive strength by 2.8-4.6 times of the biocomposite materials compared to biocomposites with different paraffin content. As a result of the state analysis of biocomposite samples which were destroyed under the static loading influence, the features of the cracks occurrence and propagation in biocomposites depending on different modifying additive content, the conduct of the composition preliminary processing or biocomposites additional processing in a thermal field were determined. The use of protective hydrophobic coatings on the biocomposite samples surface provided an increase in the biocomposites resistance to the moisture negative influence. The most effective were coatings based on a paraffin solution, which provided a reduction in water absorption by 45-50% compared to biocomposites coated with wax, drying oil Oksol, and sunflower oil. The complex use of hydrophobic substances as modifying additives and protective coatings has practical significance, as they positively affect the processes of forming the structure, increasing the strength and hydrophobicity of biocomposite materials used in a humid environment

Keywords: wood flour; sunflower oil; drying oil Oksol; paraffin solution; wax melt; compressive strength; thermal field

Suggested Citation:
Kashytskyi, V., Sadova, O., & Shehynskyi, V. (2024). The development of glutin-based biocomposite materials with advanced hydrophobicity. *Commodity Bulletin*, 17(1), 27-35. doi: 10.62763/ef/1.2024.27.

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Introduction

A biocomposite materials significant drawback is their high hydrophilicity, which is caused by the plant-based fillers ability to absorb moisture and water in significant quantities. This leads to the proliferation of microorganisms and biocomposite materials intensive degradation over a short period of product use. Therefore, it is relevant to research and determine the modifying additives impact on the physical, mechanical and operational properties of biocomposite materials, as the use of hydrophobic substances results in the interaction deterioration between the polymer matrix and the filler surface.

Polymer composite products contain a polymer matrix obtained through the petroleum products processing. Petroleum is a finite raw material source. This poses a problem related to the search for alternative raw material sources, the solution to which lies in the use of renewable resources. R.A. Ilyas & S.M. Sapuan (2020) noted that such raw stuff sources include materials of plant or animal origin which are able to regenerate under favourable conditions of the natural environment.

The use of natural materials as fillers in polymer composites has a history of decades, but their exploitation is limited to the use of synthetic polymer matrices. In the works of S.A. Albab *et al.* (2019), K.R. Sumesh *et al.* (2024), the research results on biocomposite materials based on polyether, polyurethane, epoxy, phenol-formaldehyde, and urea-formaldehyde resins were analysed, focusing on the feasibility of developing biocomposites with high physical, mechanical and operational characteristics. These resins have a high adhesive ability to form strong physical and chemical bonds with the plant-based fiber surface.

In the N. Uppal *et al.* (2022) study, the feasibility of forming biocomposite materials based on epoxy resins and fillers in the form of discrete flax fibers, industrial hemp, ramie and kenaf, as well as the sisal, pineapple, and banana leaves, was determined. Such composites have high economic profitability and satisfactory mechanical characteristics. The proposed fillers, after special treatment, are environmentally safe and potentially suitable raw stuff for new biocomposite materials.

Polymer composite materials based on synthetic polymers are widely used in the automobile industry as they provide high specific strength to constructions. Such polymer composites contain carbon and glass fibers, which are resistant to atmospheric factors, hence their disposal through natural means is complicated. In the M. Zwawi (2021) work, a high risk of waste accumulation in the form of discarded polymer composite parts and environmental pollution is identified. Consequently, there arises a need for the development of new biocomposite products containing environmentally safe fillers of natural origin that can be utilised in natural conditions without harming the environment.

The process of forming polymer composite materials using molten binders poses a significant danger to workers and the environment, as harmful substances emitted under the heating influence can evaporate. To mitigate the synthetic resins harmful impact is possible while using another binder type that allows the formation of polymer composite products without heating. M.A. Shamsudin *et al.* (2020) have developed a technology for forming such materials based on silicone rubber or epoxy resins containing kenaf fibers.

In the M.A. Paglicawan *et al.* (2021) study, the hybrid-type polymer composites production is practiced with the combined use of synthetic and natural origin fibers. Such fibers include aramid fibers, glass fibers, abaca fibers, and kenaf fibers. Synthetic fibers possess higher strength, resulting in biocomposites exhibiting better mechanical properties, as glass fibers withstand higher loads and ensure the integrity of the polymer matrix. This approach allows to replace a part of the synthetic polymer with another phase, represented by some material of natural origin, thereby improving the polymer composites mechanical properties. In the work of R. Chaturvedi *et al.* (2022), a biocomposite material containing granite particles and jute fibers was developed. This reduced the biocomposite products water absorption to 0.1% and enabled the mineral waste reuse, which poses significant environmental hazards. As a result of organic and mineral fillers hybrid use, an optimal balance between economic indicators and operational characteristics is achieved.

From 2004 to 2024, research on using materials of plant origin as matrices has been actively conducted. Polylactic acid (PLA) is widely used in global science as a biopolymer matrix for forming biocomposite materials. Particularly, in the work of R. Scaffaro *et al.* (2021), fine-dispersed fillers obtained from marine and agricultural waste were used for forming biocomposite materials based on PLA. Plant-derived powder fillers allow replacing up to 20% of the biopolymer matrix without significant changes in technological and operational properties. The interaction between the biocomposite material components can be improved with the use of modifying additives and coupling agents, thereby enhancing the resistance to biocomposite materials thermomechanical degradation and expanding the application scope of products based on natural components.

F. Ortega *et al.* (2021) established that biocomposite materials consisting solely of natural origin components exhibit high biodegradability. This determines their high susceptibility to degradation under the influence of the atmospheric factors and microorganisms. Such an approach to forming biocomposites ensures their ability for processing through composting or controlled application of fertilisers, positively affecting environmental safety and addressing the waste accumulation problem.

The aim of the study was to determine the influence of the hydrophobic additive content paraffin on the compressive strength and the influence of the

hydrophobic coating type on the water absorption resistance of biocomposite materials based on natural components.

Materials and methods

Biocomposite materials samples based on a glutin matrix and a wood flour were prepared. A 60% concentration glutin solution was obtained by dissolving bone glue granules in water, the physicochemical properties of which corresponded to the technical data specified in the Official website of Kremer Pigmente. 63000 Bone glue granules (2016). Preparation of the glutin solution began with soaking a measured amount of bone glue granules in an airtight container for 12-15 hours. The next stage involved soaking water-saturated bone glue granules in a drying oven at 50°C for 2.5-3.0 hours to intensify the dissolution process. To achieve high solution uniformity, it was periodically stirred. Wood flour was obtained by further mechanical grinding of fine-dispersed wood particles, which are waste products from lumber production. After grinding, the raw material was dried at 80-90°C for 1-2 hours with periodic mixture mixing. The prepared mixture was separated into fractions using a set of sieves, and the fraction with particle sizes of 0.5-0.7 mm was separated. The paraffin solution was obtained by dissolving paraffin flakes in drying oil, the physicochemical properties of which corresponded to DSTU 4153-2003 (2004).

The composition was prepared by mechanically mixing components in a ratio of 100 parts by weight of wood flour to 4 parts by weight of paraffin solution per 100 parts by weight of glutin solution. Mixing was carried out using a laboratory mill with a high-frequency rotation (20 kHz) of the hammer-type working element. A measured amount of the composition was placed into the matrix cavity of a cylindrical mold press form. The press form end holes were closed, and uniaxial pressing was performed with a 50 kN force. The punch was fixed in the press form to prevent elastic aftereffects. The composition in the press form was subjected to heat treatment at 140°C for 90 minutes with additional composition pressing. After cooling, the samples were removed from the press form and coated using hydrophobic environmentally friendly materials of natural origin: paraffin solution, beeswax, refined sunflower oil, drying oil Oksol. The coating was applied thinly to the cylindrical samples surface with subsequent stepped holding of the samples in a drying oven at 100°C for 20 minutes.

The compressive strength was determined according to ASTM D695-23 (2023) on cylindrical samples with a 30 mm height and a 20 mm diameter. The compression of the biocomposite samples was carried out under conditions of the approach of the lower traverse at a 2 mm/min speed with the fixation of the maximum load at which the biocomposite samples were destroyed. Hygroscopicity was determined by the weight method according to ASTM D3201/D3201M-20 (2020) on cylindrical samples with a holding time of 24 hours in a desiccator. Weighing was performed on WPS 110/C/1 3rd class laboratory scales with a measurement accuracy of up to 0.5 mg.

Results and discussion

Experimental results indicate that the biocomposite materials compressive strength limit without the modifying additive (paraffin) is 22-24 MPa (Fig. 1). The modifying additive introduction in an amount of 2 parts by weight does not lead to a change in the biocomposites compressive strength limit, indicating insufficient additive content. The paraffin uses in amounts ranging from 4 parts by weight to 12 parts by weight results in a decreasing the mechanical characteristics by 26-39%, attributed to the paraffin plasticising effect. Paraffin molecules penetrate the biopolymer matrix, leading to a reduction in the resistance to movement of the glutin amino acids macromolecule segments under static loading. In the of M.H. Mulla *et al.* (2023) work, it is noted that the application of inhibitors (wax, pectin) additionally reduces interfacial interaction, so their quantitative content needs to be limited in the process of developing biocomposite materials.

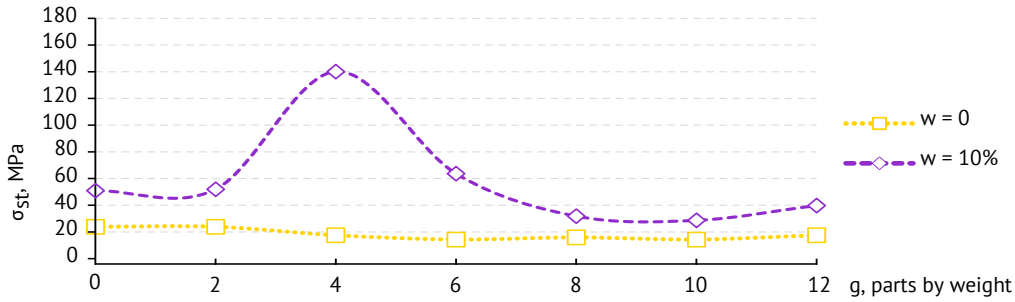


Figure 1. *The relationship between compressive strength limit and the content of the modifying additive (paraffin) at different degrees of composition moisture (W)*

Source: *developed by the authors*

Authors V.P. Kashytskyi *et al.* (2023b) have determined that using a composition without prior heat treatment results in the formation of biocomposite materials with reduced compressive strength due to the

residual moisture content in the composition components. The water is mainly contained in the glutin amino acid chains, as it serves a technological function in preparing the glutin solution. Conducting heat treatment during the biocomposite material formation ensures the removal of a significant moisture amount; however, some water molecules remain in the biopolymer matrix volume and are also adsorbed by wood flour particles.

The composition pre-treatment in a drying cabinet for 20-30 minutes at a temperature of 50-55°C leads to a 10% reduction in the mass of the composition due to moisture removal. The compressive strength limit of biocomposite materials that do not contain paraffin increases by 50-55% (51 MPa) since a rigid structure of the biopolymer matrix is formed. In the case of using paraffin in an amount of 2 parts by weight per 100 parts by weight of glutin, there is no decrease in the biocomposites strength, indicating insufficient additive content. At this content of paraffin, the biocomposite material structure remains unchanged. However, with a paraffin content of 4 parts by weight, the compressive strength limit of biocomposite materials increases by 2.6-2.8 times due to the modifying effect of the additive on structure formation. In this case, there is an even paraffin molecules distribution in the biopolymer matrix volume. It ensures increased packing density of the biocomposite material components by the lubricating additive presence, reducing the resistance to macromolecule segments microdisplacement and wood flour particles. At the level of the biopolymer matrix fine structure, paraffin molecules increase the flexibility of amino acids macromolecule segments, reducing intensive growth of stress in local areas of the biocomposite material. The use of modifying additives improves the properties of materials. For example, authors M. Huda *et al.* (2008) and A. Mohd *et al.* (2021) conducted chemical treatment of the natural fibers surface using silanes or alkali. This provides moisture content regulation and mechanical characteristics improvement of developed biocomposites based on polylactic acid (PLA) matrix compared to biocomposites containing untreated fibers. This is due to the natural fibers surface modification, resulting in improved interphase interaction and adhesion between the biocomposite material components serves a technological function in preparing the glutin solution. Conducting heat treatment during the biocomposite material formation ensures the removal of a significant moisture amount; however, some water molecules remain in the biopolymer matrix volume and they are also adsorbed by wood flour particles.

Increasing the paraffin content to 4-12 parts by weight leads to a decrease in the biocomposite materials compressive strength limit to values of 30-40 MPa, as the excess additive content provides intensive biopolymer matrix plasticisation. As a result, the resistance to static loading decreases due to the reduction in the number of physicochemical bonds between the biocomposite material components.

The biocomposite samples destruction after static loading occurs at different levels of plastic deformation degree. The degree of biocomposite materials deformation that do not contain the modifying additive (paraffin) and have excess moisture in the composition is 8-11%. Cracks are present on the cylindrical sample lateral surface, some of which are located at an angle of 42-47° to the sample end surface, while others are parallel to the end surface (Fig. 2a).

The numerous delaminations presence is associated with the low biocomposite material resistance to static loading under low levels of plastic deformation. The ruptures are related to the water molecules presence within the biopolymer matrix volume, which facilitate the glutin macromolecule segments movement. Consequently, during compression of biocomposite samples with compositions that have lost 10% of their moisture content, rupturing occurs with the fewer cracks formation compared to biocomposite samples containing moisture (Fig. 2b). This indicates a better biocomposites ability to resist static loading due to the formation of a stiffer framework within the biopolymer matrix.

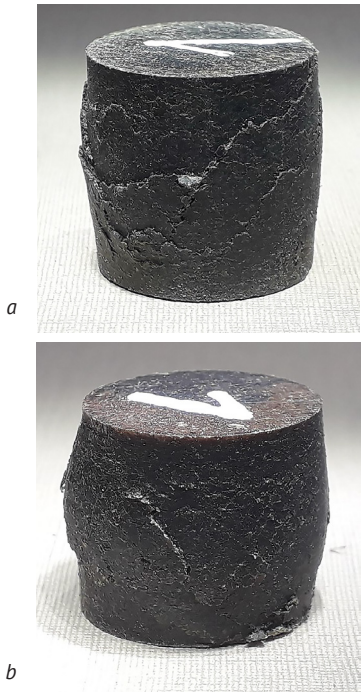
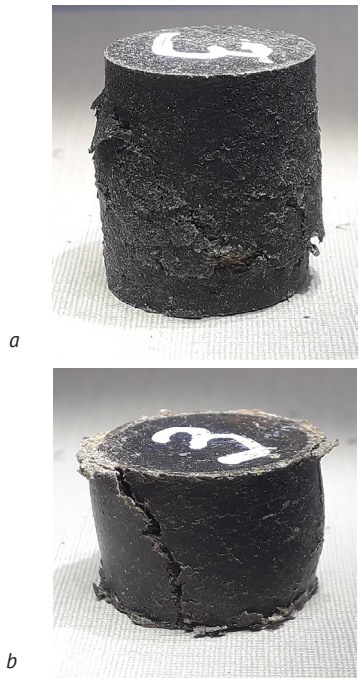


Figure 2. *General view of biocomposite samples without modifying additive after compression*
Note: *a – without heat treatment of the composition; b – loss of 10% of moisture by mass of the composition*
Source: *developed by the authors*

The propagation of a main crack during the biocomposite materials compression with 4 parts by weight of modifying additive fraction occurs at an angle of 43-47° to the sample end face (Fig. 3a). The interface between sample parts is less distinct compared

to the main cracks appearance in biocomposite samples without the modifying additive. This suggests the paraffin plasticising effect on the processes of forming the biopolymer matrix structure, where under the static loading influence, redistribution of normal and tangential stresses occurs. Additionally, local movements of biopolymer matrix macromolecule segments lead to the appearance of stress concentrators followed by material failure. Consequently, during a biocomposite sample compression with 4 parts by weight of paraffin content, whose composition was treated in a thermal field to remove 10% moisture content, a clearly defined main crack is formed, which is located at an angle of 57-62° to the end face surface (Fig. 3b). A single crack presence with a clearly defined shape indicates the predominant influence of normal stresses on crack development. In the biopolymer matrix volume, elastic deformations of local areas prevail, as a structure with amino acid macromolecule segments increased flexibility is formed due to the optimal paraffin molecules content.



a

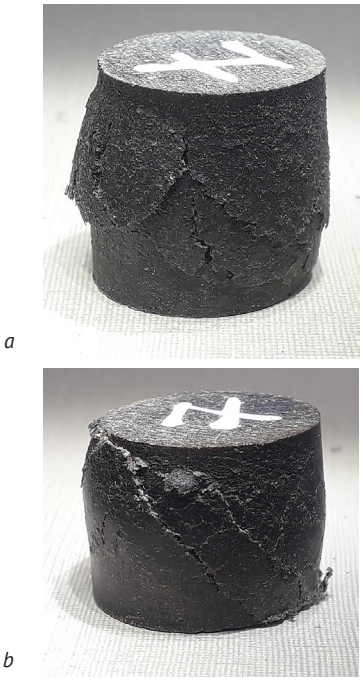
b

Figure 3. *General view of biocomposite samples with 4 parts by weight of the modifying additive (paraffin) content after compression*

Note: *a – without heat treatment of the composition; b – loss of 10% of moisture by mass of the composition*

Source: *photo by the authors*

The paraffin use in an amount of 12 parts by weight per 100 parts by weight of biopolymer matrix leads to the cylindrical samples lateral surface destruction with the numerous flake-like shape areas formation as a result of some biocomposite material local areas displacement in relation to others (Fig. 4a). This indicates the dominant influence of tangential stresses due to significant glutin matrix plasticisation, which contains an excessive moisture and modifying additive amount. In the case of biocomposite samples compression, the compositions of which were treated in a thermal field until the of moisture loss reached 10%, several cracks are formed (Fig. 4b). These cracks are located at an angle of 47-50° to the cylindrical sample end face plane, indicating even normal and tangential stresses distribution. The tangential stresses appearance is caused by the plasticising additive presence, the function of which is performed by paraffin. The appearance of normal stresses is caused by the glutin matrix formation with a lower moisture content, as the composition was treated in a thermal field until the moisture loss reached 10%. The composition contains less moisture, therefore, the ability of the biopolymer matrix macromolecules segments to move without the stress concentrators appearance is reduced.



a

b

Figure 4. *General view of biocomposite samples after compression with 12 parts by weight of the modifying additive (paraffin) content*

Note: *a – without heat treatment of the composition; b – loss of 10% of moisture by mass of the composition*

Source: *photo by the authors*

During the biocomposite materials development, it is necessary to achieve an increase in mechanical properties that ensure the strength and reliability of structural products. In the case of using plant-based fibers, there is a need to consider the fibers' ability to absorb moisture, which leads to deterioration of mechanical properties.

In works by authors E. Munoz & J.A. Garcia-Manrique (2015), L. Chen *et al.* (2022), satisfactory resistance to water absorption of biocomposite materials based on

epoxy or urea-formaldehyde polymers is achieved due to the high degree of the fiber surface wetting by the polymer binder and the hydrophobic barrier formation. However, the problem remains in eliminating the polymer matrix components harmful effects during material formation and disposal of used products. N. Ramli *et al.* (2018) analysed natural fibers used in the automobile industry to achieve ecological efficiency in car manufacturing. They pointed out that the materials used in production do not always meet environmental standards.

In the A. Shahzad (2013) work, a high susceptibility to water absorption of biocomposite materials containing natural hemp fibers was identified. V.A. Alvarez *et al.* (2006) established high biocomposite materials biodegradability during product disposal, but this also leads to rapid deterioration of such products during use. Therefore, the modifying additive (paraffin) usage is justified by the need to improve the biocomposite materials mechanical properties and increase the hydrophobicity of products containing natural components. As a result of experimental studies, it was found that the biocomposite materials ability to absorb moisture, with an optimal paraffin content (4 parts by weight), varies depending on the additional biocomposite materials heat treatment. V.P. Kashytskyi *et al.* (2023a) developed a heat treatment, which is biocomposites exposure in a thermal field at temperature of 50-55°C for 2.0-2.5 hours. This ensures the residual moisture removal from the biocomposite samples surface layers. The highest hygroscopic moisture content (1.4%) was recorded for biocomposite samples without hydrophobic coating and without additional heat treatment (Fig. 5). In the case of the composition pre-heat treatment, which was treated in a thermal field until a 10% moisture loss by mass, the hygroscopic moisture content is 1.27%. With the additional biocomposite samples heat treatment, the hygroscopic moisture content is 0.85-0.86%. This is 35-37% less than in biocomposite samples that were not additionally treated in the thermal field, as the heat treatment in the thermal field ensures a denser structure formation of the biopolymer matrix. At the same time, it is more difficult for water molecules to penetrate into the globules of the glutin amino acid matrix.

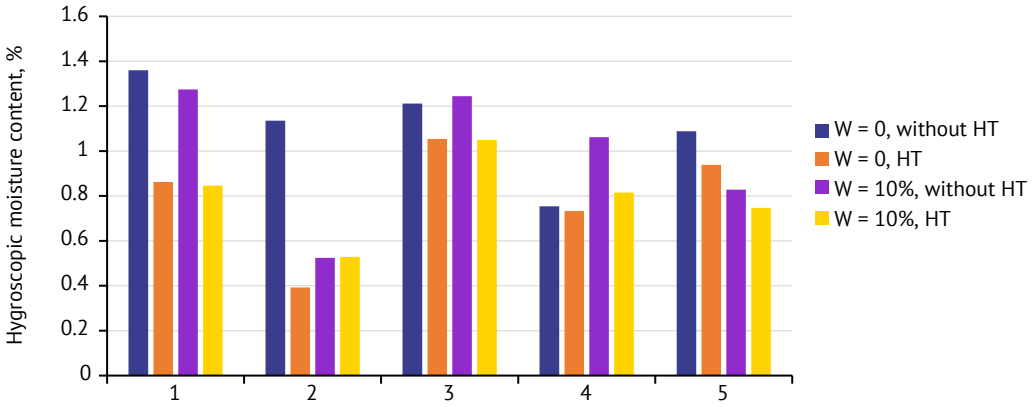


Figure 5. *Hygroscopic moisture content of biocomposite samples with applied hydrophobic coatings*
Note: *1 – without coating; 2 – paraffin solution; 3 – wax melt; 4 – drying oil Oksol; 5 – sunflower oil*
Source: *photo by the authors*

Hydrophobic paraffin coating application on the biocomposite samples external surface allowed achieving a hygroscopic moisture content of 1.13% in the case of using compositions that were not heat-treated. Such biocomposite materials contain excess moisture, which hinders the paraffin molecules adsorption. As a result, the ability to form a quality continuous coating is lost, and water molecules can penetrate into the biocomposite material interior. If additional biocomposite samples heat treatment is performed, the hygroscopic moisture content is minimal (0.39%). This is due to the water molecules removal from the biocomposite samples surface layers and the formation of a solid protective coating. In the case of applying a protective paraffin coating on the samples surfaces whose compositions were heat-treated before losing 10% moisture, the hygroscopic moisture content is 0.52%, that is slightly higher compared to biocomposites whose compositions were additionally heat-treated. However, these values are 52-55% lower compared to biocomposite materials whose compositions were not additionally heat-treated in thermal field. The paraffin coating formation provides the highest degree of biocomposite materials surface hydrophobic protection due to additional surface saturation with paraffin molecules, part of which is inside the material in the form of modifying additive.

Application of hydrophobic coating using melted wax does not provide effective biocomposite material protection from moisture. The hygroscopic moisture content for biocomposites whose compositions were not additionally heat-treated is 1.21-1.25%. This is

0.06-0.15% lower compared to similar samples without protective coating. Biocomposite samples absorb less moisture (1.04-1.05%) when additional heat treatment is carried out. However, this indicator is 0.2% higher compared to the hygroscopic moisture content of biocomposites without protective hydrophobic coating. This can be explained by the wax ability to hydrolyse in a humid environment, forming products capable of allowing water molecules to penetrate.

Biocomposite materials coated with drying oil provide better resistance to moisture absorption. Their hygroscopic moisture content is 0.73-0.82%, which is 0.23-0.32% lower than biocomposites with wax coatings. A similar situation is observed when using sunflower oil to form a hydrophobic coating. In this case, applying drying oil coating provides better hydrophobicity compared to oil coating. This is explained by the ability of drying oil to form a layer on the material surface, which provides better protection against moisture. Compared to drying oil, oil coatings do not always form such a protective barrier, so water molecules penetrate more easily through the oil coating.

Conclusions

Biocomposite materials containing plant-based fillers have a high tendency to absorb moisture. The use of hydrophobic additives allows to increase the biocomposite products hydrophobicity, but in most cases, it leads to the mechanical properties deterioration. The introduction of an optimal paraffin solution amount (4 parts by weight per 100 parts by weight of glutin matrix) allowed to obtain a biocomposite material with high compressive strength values of 138-141 MPa. The modifying additive acts as a lubricant during the composition compression, which contains fine-dispersed wood flour particles coated with a thin layer of biopolymer matrix. Preheating the composition ensures a 10% moisture loss by mass, which further complicates the particles movement during pressing. Therefore, the use of paraffin allows achieving higher biocomposite material density, which improves its resistance to static loads. The paraffin addition ensures the biopolymer matrix equilibrium structure formation as a result of residual stresses relaxation that occurs during the composition pressing and heat treatment in the process of forming biocomposite products.

Biocomposite materials with an optimal modifying additives content are destroyed without visible plastic deformation signs, forming a main crack located at an angle of 57-62° to the cylindrical sample end surface. This indicates the material's resistance to tangential stresses that cause plastic deformation. Consequently, the material is capable of withstanding higher compressive loads compared to biocomposites with a different composition.

Applying a paraffin solution to the biocomposite samples surface ensures the protective layer formation. In this case, biocomposite materials that underwent heat treatment to remove 10% moisture have the lowest hygroscopic moisture content (0.39%). Increasing the biocomposites hydrophobicity is associated with the paraffin molecules adsorption on the wood flour particles surface, which have minimal moisture content. The excess moisture presence in the composition or the use of other hydrophobic additives does not effectively increase the biocomposite materials hydrophobicity.

Further research is planned to investigate the effect of other hydrophobic additives on the formation processes, structure and mechanical properties of biocomposite materials based on natural components.

Conflict of Interest

None.

Acknowledgements

None.

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Розробка глютинових біокомпозитних матеріалів з підвищеною гідрофобністю

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Анотація. Біокомпозитні матеріали, що містять компоненти природного походження, мають низьку стійкість до водопоглинання через високу ліофільність компонентів. Це призводить до швидкого руйнування біокомпозитних виробів в умовах експлуатації підвищеної вологості, що визначає необхідність та важливість проведення прикладних досліджень в даній галузі. Метою роботи є дослідження впливу гідрофобних добавок на міцність при стисненні та гігроскопічність біокомпозитних матеріалів, що складаються з глютинової матриці (100 мас. ч.) та деревного борошна (100 мас. ч.). Технологія формування біокомпозитних матеріалів полягає у поетапному проведенні операції пресування композиції за тиску 10-15 МПа та термічної обробки виробу у прес-формі за температури 140°С. У роботі використано експериментальні методи дослідження міцності при стисненні та гігроскопічності біокомпозитних матеріалів. Експериментально встановлено оптимальний вміст модифікуючої добавки (парафін) в кількості 4 мас. ч. на 100 мас. ч. біополімерної матриці. За такого вмісту відбувається підвищення межі міцності при стисненні біокомпозитних матеріалів у 2,8-4,6 разів порівняно з біокомпозитами з іншим вмістом парафіну. В результаті аналізу стану зруйнованих під дією статичного навантаження біокомпозитних зразків визначено особливості виникнення та поширення тріщин в біокомпозитах з різним вмістом модифікуючої добавки, а також залежно від проведення попередньої обробки композиції або додаткової обробки біокомпозитів у тепловому полі. Використання захисних гідрофобних покриттів на поверхні біокомпозитних зразків забезпечило підвищення стійкості біокомпозитів до негативного впливу вологи. Найбільш ефективним виявилися покриття на основі розчину парафіну, які забезпечили зниження водопоглинання на 45-50 % порівняно з біокомпозитами, що покриті розплавом воску, оліфою та олією соняшниковою. Комплексне використання гідрофобних речовин як модифікуючих добавок та захисних покриттів мають практичне значення, оскільки позитивно впливають на процеси формування структури, підвищення міцності та гідрофобності біокомпозитних матеріалів, які експлуатуються у вологому середовищі

Ключові слова: деревне борошно; олія соняшникова; оліфа оксоль; розчин парафіну; розплав воску; міцність при стисненні; теплове поле

COMMODITY BULLETIN
Journal homepage: https://c-bulletin.com.ua/en
DOI: 10.62763/ef/1.2024.36

Article's History: Received: 30.11.2023 Revised: 13.02.2024 Accepted: 26.04.2024

Vol. 17, No. 1, 2024, 36-43

UDC 664.1:543

The analysis of approaches to assessing the sugar content of fruit and vegetable products

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Abstract. The relevance of this study is due to the growing interest of modern consumers in healthy eating, where fruit and vegetables play an important role, which should not only be aesthetically pleasing but also have high taste potential. The purpose of the article is to analyse and compare different approaches to assessing the sugar content of fruit and vegetable products, their effectiveness, and to substantiate areas for improvement. For this purpose, the author analysed the literature and regulatory and technical documents. Traditional methods for determining the sugar content are considered: total content, soluble solids content, and total soluble solids content. It has been established that the soluble solids content and the total soluble solids content of fruits cannot be equated and should be adjusted using an appropriate coefficient based on the percentage of sugars. It has been shown that the content of total soluble substances does not always correctly reflect the sugar content and does not correlate with the taste of sweetness of fruit and vegetables. The necessity of taking into account acidity, which significantly affects the perception of sweet taste, has been established. High acidity can inhibit the sweet taste of fruit and vegetables, even with a very high sugar content. It is proposed to use the ratio of sugar content to titratable acidity for a comprehensive assessment of the sugar content and taste of products. The necessity of using the BrimA and sweetness indices, which combine the indicators of sugars and acidity, as well as reflect the contribution of a single carbohydrate to the total sugar content of the product, is substantiated. These indices allow for a comprehensive assessment of sugar content and predict the sensory perception of fruit and vegetable raw materials. The absence of a single standardised approach and the need for comparative analysis to select optimal methods for measuring the sugar content of fruit and vegetable products are noted, so there is an urgent need to standardise such approaches to improve data comparison. The results of the article can be used to select the most informative methods of sugar content analysis. This will optimise quality control procedures and standardisation of measurements in the food industry

Keywords: carbohydrates of fruit and vegetable raw materials; sugar content; acidity; sugar content indices; sensory perception of sugar content

Introduction

Modern consumers are increasingly focused on healthy eating and consuming more fruit and vegetables. They are looking for products that not only look attractive, but also have high flavour potential. Assessing the quality of fruit and vegetables by their appearance can help identify batches of products with signs of damage or defects before they reach store shelves. This will help to avoid loss of marketable weight and reduce waste. The ability of fruit and vegetable producers to manufacture products with an attractive appearance and high-quality taste can have a positive impact on their competitiveness in the market.

N. Sameshima & R. Akamatsu (2023) noted that various aspects of the appearance of fruit and vegetables influence their primary consumer choice, particularly in the context of their quality and aesthetic characteristics.

Suggested Citation:
Moroz, I. (2024). The analysis of approaches to assessing the sugar content of fruit and vegetable products. *Commodity Bulletin*, 17(1), 36-43. doi: 10.62763/ef/1.2024.36.

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Typically, consumers evaluate the quality of fruit and vegetable products by their appearance, colour, shape, and size. However, the decision to make further purchases will be determined by the taste and quality of the fruit, which cannot be assessed by appearance. K. Jürkenbeck *et al.* (2020) found that the flavour characteristics of fruit are directly related to the sugar and acid content of the fruit, its acidity, and texture. The sugar content of fruit and vegetables is determined by the content of sugars, mainly fructose and glucose. This characteristic is key to determining the quality and flavour of plant products.

The sugar content is an important indicator of the nutritional value of fruits and vegetables. In their study, M. Prada *et al.* (2021) notes that sugars are a source of energy and healthy carbohydrates for the human body. This is especially important in diets that emphasise natural and unaltered foods. Fruit and vegetables high in sugars add flavour and satisfaction and provide important nutrients to the human body. A.O. Bawajeeh *et al.* (2020) argues that consumers most often choose foods that satisfy their taste buds. High sugar content plays a key role in shaping a positive perception of taste at any age. The natural sugars (fructose and lactose) found in fruits and vegetables exist in combination with other nutrients such as vitamins, minerals, antioxidants, and fiber. This contributes to their slow absorption, avoiding a rapid rise in blood sugar levels and improving their metabolic effects (Zaitoun *et al.*, 2018). Therefore, natural sugars included in a diet with a varied and balanced diet can be part of a healthy lifestyle.

The sugar content of fruit and vegetable raw materials is a highly desirable characteristic for food producers, so it is regulated by adding sucrose or other sugars to the finished food product. With this in mind, quantifying the sugar content of foods of plant origin is extremely important. Usually, the content of natural sugars fructose, glucose, and sucrose is determined by physicochemical methods, as well as organoleptically (Dudarev & Kuzmin, 2023).

Assessing sugar content is an important aspect for producers and consumers, as it affects the quality and flavour of products. The relationship between the chemical composition of fruits, in particular their sugar content, and their flavour profile is an important aspect for understanding consumer perception of products. Among the publications related to the study of the relationship between sugar content and sensory perception of sweetness for fruits, it is worth noting the study by H.H. Wang *et al.* (2022). The paper presents an analysis of the relationship between the chemical composition of fruit, in particular sugars, and the perception of sweetness using sensors or flavour profile analysis.

The publication by K.B. Mejía-Correal *et al.* (2023) investigated the sugar content of fruit and vegetable products based on traditional indicators: soluble solids content and total soluble solids content. The work of M. Trius-Soler *et al.* (2020) describes the effect of acidity of fruit and vegetables on the perception of sweet taste, as well as the feasibility of using indices that allow to assess the effect of organic acids on the sugar content of fruit and vegetable products.

The purpose of this article is to review the carbohydrates of fruit and vegetable raw materials that determine their sweet taste, analyse and compare the main approaches to assessing the sugar content of fruit and vegetables; to establish indicators that allow the most informative and comprehensive assessment of the sugar content of fruit and vegetable products. In preparing the article, modern and fundamental works on the subject of research, data from experimental studies of fruit and vegetable sugar content assessment were processed. The following methods were used: search and analysis of scientific and technical information, systematisation and comparative analysis of literature data, analysis of regulatory documents (DSTU ISO 2173:2007).

Carbohydrates and their role in photosynthesis and nutrition

The sweet taste of plant material is mainly due to natural carbohydrates. Plants produce carbohydrates during photosynthesis. Plants can use carbohydrates either to obtain the energy necessary for vegetation and growth or as precursors in the processes of biosynthesis, synthesis of lipids, proteins, polysaccharides and other substances (Shanmugavelan *et al.*, 2013). Simple sugars (monosaccharides) are quite common and are found in almost all fruits and vegetables. The main monosaccharides in fruit and vegetables are glucose and fructose. Glucose is the most common natural monosaccharide. It is the main sugar in honey and is also found in large quantities in fruit, vegetables and legumes. It is most abundant in grapes, black currants, quince, and pears (BeMiller, 2018).

Fructose is considered to be the sweetest sugar among natural sugars and is found mainly in fruits, especially in persimmons, figs, mangoes, and cherries (BeMiller, 2018). Fructose is about 1.5-2 times more sweet than glucose (Merino *et al.*, 2019). This is due to the peculiarities of its chemical structure and interaction with taste buds, in particular, fructose has higher solubility, lower crystallisation capacity, and binds better to taste buds than glucose, which leads to its higher sweetness. Monosaccharides are the basic building blocks of most natural di-, oligo- and polysaccharides. Due to their ability to form glycosidic bonds, monosaccharides can be linked together in chains to form complex carbohydrates of various lengths and structures.

In contrast to monosaccharides, oligosaccharides, especially the disaccharides sucrose and lactose, are much more common in nature (Lim & Pullicin, 2019). Sucrose, which consists of glucose and fructose residues, is synthesised by plants during photosynthesis and is a source of energy for them, so it is present in edible

parts of plants in various concentrations. In addition to imparting a sweet taste to fruit and vegetables, sucrose performs a number of technological functions in food products, in particular during caramelisation and canning processes. Raffinose and stachyose are oligosaccharides found in some fruit and vegetables. Raffinose is found mainly in legumes such as peas, beans, and soybeans. It can also be found in small amounts in onions, cabbage, and carrots. Stachyose is present in cereals such as wheat, barley, rye, and in small amounts in some vegetables. Jerusalem artichoke rhizomes contain the most stachyose. Raffinose and stachyose are inferior to sucrose in terms of sweetness, with a sweetness of 40-50% of sucrose (Ibrahim, 2018).

In their work, N.C. Kim & A.D. Kinghorn (2002) noted that the sweet taste of vegetables and fruit is mainly due to carbohydrates such as glucose, fructose and sucrose, which are formed either directly as a result of photosynthesis in plants or as products of hydrolysis of polysaccharides. In the work of H. Zheng *et al.* (2016) stated that sucrose, fructose, and glucose are the main sugars in grapefruit and account for 80% of the total soluble solids. In the work of Z. Li-Jing *et al.* (2015), while studying the content and composition of soluble sugars in apple fruits of different varieties, it was found that the main sugars in apples are fructose, glucose and sucrose. The sucrose content in oranges and grapefruits is predominant and the ratio of sucrose to glucose and fructose in all citrus fruit is almost constant and amounts to approximately 2:1:1 (Yu *et al.*, 2012).

The sweet flavour of plant material is therefore the result of natural carbohydrates that plants produce through photosynthesis, and these carbohydrates can be used for energy or as building blocks for the synthesis of other nutrients. Monosaccharides, such as glucose and fructose, are known for their widespread occurrence in fruit and vegetables, with fructose in particular being considered one of the sweetest sugars in nature, slightly surpassing glucose in its sweetness. Naturally occurring disaccharides, such as sucrose and lactose, not only impart a sweet taste to fruit and vegetables, but also perform important technological functions by assisting in preservation and caramelisation processes.

Traditional indicators for assessing the sugar content of fruit and vegetables

The traditional indicator used to assess the sugar content of fruits and vegetables is the total sugar content. It indicates the total weight of sugars (glucose, fructose, sucrose, etc.) in 100 g of the product. This indicator is generally accepted for comparing the sugar content of food products in accordance with the national standard of Ukraine (DSTU ISO 2173:2007, 2007), which is based on the International Organization for Standardization's ISO 2173:2003. This document establishes a refractometric method for determining the mass fraction of soluble solids in processed fruit and vegetables and allows estimating the content of natural and added sugars in grams per 100 grams of finished food product. The total sugar content indicator makes it easy to compare the sugar content of fruit and vegetable raw materials and food products, as well as to control the amount of added sugar in them.

The term "soluble solids content" or SSC is quite common in the modern (Guo *et al.*, 2019; Huang *et al.*, 2022). This indicator is a complete correspondence to the total content of sugars (glucose, fructose, sucrose) in fruit and vegetable raw materials and indicates their mass fraction (%). Along with the SSC indicator, another one is used – TSS (total soluble solids) – the total content of all soluble substances, including sugars, organic acids, vitamins, proteins, pigments, phenolic substances and minerals (de Brito *et al.*, 2021; Valverde-Miranda *et al.*, 2021; Mejía-Correal *et al.*, 2023). The total dissolved solids content is usually measured refractometrically or with an areometer and expressed in degrees Brix (Jaywant *et al.*, 2022). One Brix degree is equal to 1 g of sucrose in 100 g of solution (1°Brix = 1% sugar).

Table 1 shows the ranges of change in soluble solids and total soluble solids for some fruit and vegetables. The terms are very similar and closely correlated for most fruit and vegetables, as the majority of soluble solids are sugars. However, TSS is a more general indicator and it should be noted that for some fruits, natural sugars will not be the main component of all soluble substances. Citrus fruits are characterised by a high content of organic acids and, accordingly, sugar values will be lower, ranging from 25% of total soluble solids for lime to 85% for other citrus fruits (Wu *et al.*, 2021). Therefore, the SSC and TSS values for these fruits cannot be equated; the TSS value needs to be adjusted with an appropriate factor based on the percentage of sugars. The TSS value does not always correspond to the sensory perception of sweetness of fruit and vegetables (Kader, 2008). The results of this study show that the TSS value does not reflect the actual sugar content, so it should not be used as the sole indicator of sugar content for fruit and vegetable products.

Table 1. *Soluble solids content (SSC) and total soluble solids content (TSS) for some fruit and vegetables*

Products	Soluble solids content (SSC, %)	Soluble solids content (TSS, ◦Brix)	Source SSC/ TSS
Oranges	8-12	9-13	G. Suszek *et al.* (2017)
Lemons	5-8	6-10	S. Wu *et al.* (2021)/M.G. Aguilar-Hernández *et al.* (2020)
Grapefruits	8-10	10-13	J. Zhang *et al.* (2020)/B.S. Buslig (2018)

Table 1. Continued

Products	Soluble solids content (SSC, %)	Soluble solids content (TSS, ◦Brix)	Source SSC/ TSS
Cherries	13-22	14-25	I. Ivanova *et al.* (2021)/R.R. Pullanagari & M. Li (2021)
Strawberries	7-10	8-11	P. Abeytilakarathna *et al.* (2013)
Apples	10-16	11-17	L.M. Yuan *et al.* (2016)
Tomatoes	4-6	5-7	A.A. de Brito *et al.* (2021)/X. Hong *et al.* (2014)
Onions	8-12	9-13	G.A. Chope *et al.* (2012)/S.A. Shehata *et al.* (2017)

Source: *compiled by the author*

In the practice of determining the sugar content of fruit and vegetables, the indicator of total sugars is usually used. The terms "soluble solids content" (SSC) and "total soluble solids" (TSS) are used to assess the sugar content of fruit and vegetables, but the difference between them is that TSS takes into account not only sugars but also other substances that may affect the flavour of the product. Although TSS can be a useful indicator for some products, such as citrus fruits, where the presence of organic acids changes the ratio of sugars, it should be noted that this indicator does not always accurately reflect the sweet taste of a product and cannot be the only criterion for assessing its sugar content.

Sugar indices based on the acidity of the raw material

The organic acid content has a significant impact on the flavour of fresh fruit and vegetables. Sweet fruit do not necessarily have a high sugar content, but their acidity level is usually low (Zhang *et al.*, 2020). The contribution of different organic acids to the perception of sour taste is ranked relative to citric acid (weighting factor 1.0). The weighting factors for malic and tartaric acid are 0.9 and 0.8, respectively (Kader, 2008). Some amino acids, such as aspartic and glutamic acids, can also increase the acidity of fruit and vegetables. A.A. Kader (2008) states that the acidity of fruit and vegetables, in addition to organic acids, can be caused by some amino acids (aspartic and arginine), as well as by the products of the interaction of calcium, phosphorus and potassium with organic acids, which change the buffering capacity of the product and, accordingly, the perception of acidity. Higher acidity reduces the perception of sweetness, even with the same sugar content (Trius-Soler *et al.*, 2020). This is due to the masking of sweet flavour by sour flavour. The article by T.M.M. Malundo *et al.* (2001) states that at a threshold value of acidity (about 0.9%), the sweetness of taste is significantly suppressed. E.A. Baldwin *et al.* (2008) found that when 0.2% of organic acids were added to tomato puree, the sweetness sensation was significantly reduced.

The acidity of fruit and vegetable products is assessed by the titratable acidity in percentage terms, recalculated to malic, citric or other dominant acid in the product under study. Titratable acidity is a key factor in determining the perceived sweetness of fruit in combination with the sugar content. That is why the ratio of soluble solids to titratable acidity is often used to assess the perception of sweetness. J. Zhang *et al.* (2020) stated that the ratio of sugar content to titratable acidity is more informative than the total sugar content of fruit and vegetables to assess the sugar content and taste perception.

However, it should be noted that the soluble solids and titratable acidity values depend on many factors and can change as fruit and vegetables ripen (Song *et al.*, 2019). As the fruit ripens, the soluble solids content increases, the acid content decreases, and the ratio of soluble solids to titratable acidity will increase. That is why this ratio is used as a measure of fruit and vegetable maturity in many countries around the world (Gecer *et al.*, 2020).

Although the aforementioned indicator is quite common for assessing the sensory perception of sugar content of fruit and vegetables, there are some caveats to its use. The same ratio of soluble solids to titratable acidity can be obtained by varying the sugar and acid content. Therefore, with the same ratio of sugars to titratable acidity, there will be a different perception of the taste of fruit and vegetables.

In the work of A. Ikegaya *et al.* (2019) proposed to use the BrimA index to assess the sugar content of fruit and vegetables, which allows to establish a balance between the sugar content of raw materials and their acidity. This index is based on the difference between the total soluble solids content and the acid content, not on their ratio. BrimA can be calculated as follows:

$$\text{BrimA} = SSC - k \cdot TK, \quad (1)$$

where *SSC* – soluble solids content; *TK* – titratable acidity index; *k* – constant that reflects the contribution of acid to sensory sensitivity compared to sugars.

The sensitivity constant *k* can take on values from 2 to 10 depending on the type or variety of fruit or vegetables. The value of the constant depends on the ratio and type of organic acids and sugars in certain types or varieties of fruit and vegetables. L. Chen & U.L. Opara (2013) note that the sensory sensitivity constant can be as high as 2 for pomegranate and 5 for citrus and grapes.

Taking into account that the BrimA index correlates well with the flavour characteristics of fruit and vegetables, it can be used as a better indicator than the traditional sugar-to-acidity ratio (Ikegaya *et al.*, 2019). This index is used as an indicator of the maturity and sweetness of fruit and vegetables and their suitability for long-term storage (Gupta *et al.*, 2021). The authors point to the prospects of using the BrimA index in the food industry and horticulture. However, the index has a number of drawbacks that limit its widespread use. In particular, the calculation of the index requires the adjustment of the constant *k* in equation (1) for different types and varieties of fruit and vegetables and additional validation for new hybrids and varieties. The BrimA index does not take into account the contribution of individual sugars to sweetness and needs to be compared with other methods of sweetness assessment.

M.A. Rosales *et al.* (2011) describes the use of the sweetness index (SI) as a measure of the sugar content of horticultural products. The essence of the sweetness index is the specific contribution of individual sugars (glucose, fructose and sucrose) to the total sugar content of the product (2):

$$SI = 2.3 \cdot C_{fructose} + 1.35 \cdot C_{sucrose} + 1.0 \cdot C_{glucose}, \quad (2)$$

where *C* – molar concentration of glucose, fructose and sucrose.

The coefficients in equation (2) reflect the contribution of a single carbohydrate to the total sugar content of the product. The choice of these coefficients is due to the fact that, according to the authors' study, fructose and sucrose are 2.30 and 1.35 times sweeter than glucose, respectively.

There is another approach to assessing the contribution of individual sugars to the total sweetness of fruit and vegetable raw materials. The contribution of each carbohydrate to the total sweetness of the product is estimated relative to sucrose as a reference sugar, which is assigned an arbitrary value of 1, and for fructose and glucose the weighting factors are 1.5 and 0.76 (Beckles, 2012). However, different studies have used different sucrose concentrations as a reference. In the work of M. Carocho *et al.* (2017), a sucrose solution containing 30g of this substance in 1 liter at 0°C was used as a reference and assigned a sweetness of 1. Other researchers, such as M. Grembecka (2015) and S. Chattopadhyay *et al.* (2014) used a 10% sucrose solution as a reference and also indicated its sweetness as 1. Similarly, the relative sweetness of natural sugars compared to sucrose was determined differently in the above works: for glucose 0.5 or 0.75; for fructose 1.5-1.8 or 1.1-1.5; for lactose 0.2-0.4 or 0.15, etc.

In the work of A.A. Kader (2008), the coefficients reflecting the contribution of each carbohydrate to the total sugar content of products are different and amount to 1.20, 1.0, 0.64 for fructose, sucrose and glucose, respectively. In the work of Z. Li-Jing *et al.* (2015) found that the weighting coefficients of fructose, glucose and sucrose in the total sugar content of fruits are 1.75 for fructose, 1.0 for sucrose and 0.7 for glucose.

The issue of the optimal choice of coefficients that reflect the contribution of individual carbohydrates to the total sugar content is controversial. The analysis of scientific publications leads to the conclusion that there is no unified approach to the numerical values of the weighting coefficients of individual carbohydrates in the calculation of the sweetness index. Further research is needed to more accurately determine SI and assess sugar content, clarifying the contribution of each sugar for different types of fruit and vegetable products. However, in combination with other sugar content indicators, the sweetness index (SI) provides a comprehensive assessment of the sweetness of a product and is convenient for practical use.

Conclusions

The sweet taste of fruit and vegetable products is mainly due to natural sugars such as glucose, fructose and sucrose. Their content and ratio determine the sweetness of different types of fruit and vegetables. Traditionally, sugar content is assessed by total sugars, soluble solids content (SSC) and total soluble solids (TSS). However, these indicators have limitations related to the content of other components. It has been established that standard methods of sugar content assessment, in particular, total sugars, soluble solids, and total soluble solids, do not allow a comprehensive assessment of the sugar content of fruit and vegetables. Their values are not always consistent with the sensory perception of the sweetness of fruit and vegetables. Therefore, they should not be used as the only indicators of sugar content for fruit and vegetable products.

It has been proven that acidity significantly affects the perception of the sweet taste of fruits. Therefore, for a comprehensive assessment of the sweet taste of vegetables and fruits, it is proposed to use the ratio of soluble solids to titratable acidity and the BrimA index, which allow to establish a balance between the sugar content and their acidity. The use of the sweetness coefficient as an optimal indicator for assessing sugar content is described. The sweetness coefficient takes into account the contribution of individual sugars to the total sweetness of fruit and vegetable raw materials, but the values of the weighting coefficients in the works of different scientists vary significantly. The analysis of scientific publications leads to the conclusion that there is no unified approach to the numerical values of the weighting coefficients of individual carbohydrates when calculating the sweetness index.

As of 2024, there is a lack of comparative analysis in available sources of information on the effectiveness of different sweetness indices for evaluating

fresh and processed fruit and vegetable products. The use of multiple indices makes it difficult to compare results and points to the need for standardisation of measurement and analysis methods to facilitate data comparison between industry and academia. Further research could focus on clarifying the contributions of the major sugars in raw fruit and vegetables to total sweetness and investigating the optimisation of methods for estimating the sugar content of fruit and vegetables.

Conflict of interest

None.

Acknowledgements

None.

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Аналіз підходів до оцінки цукристості плодоовочевої продукції

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Анотація. Актуальність даного дослідження зумовлена зростаючим інтересом сучасних споживачів до здорового харчування, де важливу роль відіграють фрукти та овочі, які мають бути не лише естетично привабливими, але й мати високий смаковий потенціал. Метою статті є аналіз та порівняння різних підходів до оцінки цукристості плодоовочевої продукції, їх ефективності та обґрунтування напрямків вдосконалення. Для цього було проведено аналіз літературних джерел та нормативно-технічних документів. Розглянуто традиційні методи визначення вмісту цукрів: загальний вміст, вміст розчинних сухих речовин та вміст загальних розчинних речовин. Встановлено, що показники вмісту розчинних сухих речовин та вмісту загальних розчинних речовин фруктів не можна ототожнювати та потрібно коригувати за допомогою відповідного коефіцієнту, що базується на відсотковому вмісті цукрів. Показано, що вміст загальних розчинних речовин не завжди коректно відображає вміст цукрів і не корелює зі смаковими відчуттями солодкості плодів та овочів. Встановлено необхідність врахування кислотності, яка значно впливає на сприйняття солодкого смаку. Висока кислотність може пригнічувати солодкий смак овочів та фруктів, навіть за дуже високого вмісту цукрів у них. Запропоновано використовувати співвідношення вмісту цукрів до титрованої кислотності для комплексної оцінки цукристості та смаку продуктів. Обґрунтовано потребу використання індексів BrimA та індексу солодкості, що поєднують показники цукрів і кислотності, а також відображають вклад окремого вуглеводу у загальну цукристість продукту. Ці індекси дозволяють комплексно оцінити цукристість та передбачити сенсорне сприйняття плодоовочевої сировини. Констатовано відсутність єдиного стандартизованого підходу та необхідність порівняльного аналізу для вибору оптимальних методів вимірювання цукристості плодоовочевої продукції, тому нагальною постає потреба в стандартизації таких підходів для поліпшення зіставлення даних. Результати статті можуть бути використані для вибору найбільш інформативних методів аналізу цукристості. Це дозволить оптимізувати процедури контролю якості та стандартизації вимірювань в харчовій промисловості

Ключові слова: вуглеводи плодоовочевої сировини; вміст цукрів; кислотність; індекси цукристості; сенсорне сприйняття цукристості

COMMODITY BULLETIN
Journal homepage: https://c-bulletin.com.ua/en
DOI: 10.62763/ef/1.2024.44

Article's History: Received: 29.10.2023 Revised: 20.01.2024 Accepted: 26.04.2024

Vol. 17, No. 1, 2024, 44-54

UDC 637.05

Comprehensive assessment of the quality of Ukrainian-made sour-milk cheese

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Abstract. Comprehensive research of food products, as well as compliance with the rules and regulations in the food industry, are necessary to provide consumers with quality and safe products. The purpose of this article is to provide a comprehensive analysis of the quality and safety of sour-milk cheese, including the evaluation of organoleptic characteristics, physicochemical properties, and microbiological indicators. The study was conducted with one of the largest producers of milk powder and fermented milk products on the Ukrainian market, BIAGR LLC as its basis. To achieve the set goal, the following methods were used: organoleptic, physicochemical, microbiological, and measurement of the content of toxic elements (cadmium, arsenic, lead). At the beginning of the measurement of quality indicators, packaging and labelling were evaluated, which complied with the requirements of the national standard. During the study of the organoleptic quality indicators of sour-milk cheese with a fat content of 5%, it was found that its consistency is soft, without whey separation; distinctive fermented milk smell and taste are without extraneous odour and favour; the colour of the sample is uniformly white. At the second stage of the research, the mandatory physicochemical quality indicators were measured and evaluated, namely: mass fraction of fat – 5.0%; mass fraction of protein – 14.6%; mass fraction of moisture – 68.0%; titratable acidity – 176°T; phosphatase was absent. Since food safety is now an urgent issue in Ukraine, the following safety indicators were measured during the research: the number of lactic acid bacteria, which was 2×106 CFU per 1 g; Escherichia coli bacteria were not detected; the number of mould fungi was 1×101 CFU per 1 g; the amount of yeast was 1×101 CFU per 1 g; pathogenic microorganisms, including *Salmonella, Staphylococcus aureus, Listeria monocytogenes* were not detected. Thus, in terms of organoleptic,

Suggested Citation:
Remizova, N., Korsun, A., Kalashnyk, O., & Moroz, S. (2024). Comprehensive assessment of the quality of Ukrainian-made sour-milk cheese. *Commodity Bulletin*, 17(1), 44-54. doi: 10.62763/ef/1.2024.44.

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physicochemical and safety indicators, sour-milk cheese with a fat content of 5%, produced by BIAGR LLC, meets the requirements of regulatory documents. The results of the research can be used for quality control of dairy products and improvement of production processes

Keywords: organoleptic, physicochemical, microbiological indicators; standardisation; safety; Hazard Analysis and Critical Control Points

Introduction

Regardless of the level of socio-economic development, every country aims to solve the problem of providing its population with food. In developed countries, the production of agricultural products, their processing and storage is a key condition for food stability. The level of availability of quality food affects not only the socio-economic situation in the country, but also the well-being of citizens.

Current trends of the global market dictate the need to address the challenges of ensuring food quality and safety. Preventing products that do not comply with regulations and are unsafe from entering circulation is becoming one of the most pressing issues in Ukraine and worldwide (Puhach, 2019). Food quality and safety affect health, living standards, activity, demographics, morbidity, and ultimately the economy of Ukraine. This aspect is especially evident today, when the military aggression has destroyed raw materials, industrial enterprises, logistics links, changed the structure of demand, etc. In addition, consumers are decreasing their trust in the quality and safety of food products offered by manufacturers on the market. Therefore, the issue of assessing the safety of such a popular food product as sour-milk cheese is relevant (Remizova *et al*., 2023).

It is known that sour-milk cheese is a traditional food product in Ukraine, therefore the works of Ukrainian and foreign authors are devoted to the evaluation of organoleptic, physicochemical, microbiological quality and safety indicators of sour-milk cheese. In their work, V.P. Lyasota *et al.* (2020) investigated organoleptic, physicochemical and microbiological quality indicators of sour-milk cheese required by the national standard. The researchers studied sour-milk cheese samples with different fat content and produced by different manufacturers, including sample No. 2 with a fat content of 5% (produced by PJSC "Kremenchuk Dairy Plant"), which is similar to the object of this study.

The study of A.A. Samoilenko & O.P. Yudicheva (2019) is devoted to the establishment of stability at different seasons and compliance of organoleptic and physicochemical indicators of samples of Ukrainian-made sour-milk cheese with the requirements of regulatory documents. The advantage of their study is the determination of safety indicators, namely microbiological indicators and the content of toxic elements.

M.T. Khatun *et al.* (2019) evaluated and compared the physical (smell and taste, consistency, texture and colour), chemical (content of fat, moisture, proteins, carbohydrates, ash, total dry matter) and microbiological quality indicators of different types of cheese made from skimmed milk (0.1% fat) and partially skimmed milk (1%, 2% and 3% fat). The researchers also evaluated the shelf life of a cheese sample at room temperature. However, the study did not investigate microbiological quality indicators and the content of toxic elements, which are mandatory for assessing food quality and safety.

The monograph by M.D. Kukhtin & Y.V. Horiuk (2023) highlights the issues of hygiene of whole cow's milk and fermented milk products sold on the agro-food market. Experimental studies resulted in the establishment of microbiological safety criteria for sour-milk cheese, based on *Enterococcus* bacteria content. In their study, C.-R. Stefanou *et al.* (2022) reported the presence of *Listeria monocytogenes*, *Salmonella spp.*, lactic acid bacteria, and coliforms. It should be noted that these microorganisms were not detected in the samples of sour-milk cheese. The physicochemical quality indicators measured included the content of proteins, fats, carbohydrates, ash, and water. The samples of sour-milk cheese were also tested for contamination with heavy metals. High nutritional value of the research object was found.

It is important to note that in the work of Y.V. Horiuk (2023), sour-milk cheese, which is sold on the agro-food markets of Ukraine, was chosen as the object of study. As a result of the conducted research, it was found that in sour-milk cheese made from whole cow's milk, the normal microflora consists of lactic acid microorganisms and enterococci (with *E. faecalis* being the dominant species among enterococci). In addition, the author presented the results of studies on various species and genera of microorganisms isolated from sour-milk cheese. In 97.7% of cases, its permanent microflora may include lactic acid bacteria and enterococci, fungi and spore-forming microorganisms; in 73.8% – it is contaminated with Escherichia coli group (BSCG); in 29.4% – it is contaminated with E. coli bacteria. *Staphylococcus aureus* was detected in approximately 20% of the sour-milk cheese samples, as well as the pathogenic microorganisms *Listeria monocytogenes* and *Salmonella spp.* were detected in 4.8% and 1.6% of the samples, respectively. Thus, this study is devoted only to microbiological quality indicators and aimed at improving the veterinary and sanitary control of the research object.

According to the list of toxic elements (Methodical Guidelines 4.4.4-108-2004, 2004), heavy metals and

arsenic are mainly subject to hygienic control. Among the toxic elements, lead, mercury and cadmium are of particular importance, as they are characterised by high toxicity and the potential for accumulation during long-term entry into the human body with food products. Therefore, emphasis is placed on the necessity of systematic monitoring and control of the levels of lead, mercury, and cadmium in food products in order to avoid negative impacts on human health.

According to the researchers N.V. Chuyen *et al.* (2022), arsenic is a chemical contaminant that deserves special attention due to its toxicity and bioaccumulation in food. In their study, the authors also provided the minimum, maximum, and average concentrations of arsenic in milk and dairy products. It was found that the average arsenic concentration for cheese is 221.38 ppb.

The team of authors N.B. Sarsembayeva *et al.* (2020) conducted a study to determine the amount of heavy metals and toxic elements in samples of milk and sour-milk cheese to monitor their quality and safety. As a result, it was found that the sour-milk cheese samples contained 0.0519 mg/kg of cadmium, 0.0117 mg/kg of lead, and no mercury or arsenic. In the work of researchers from Poland, M. Sujka *et al.* (2019), it is noted that the toxicity of heavy metals and their ability to accumulate in the human body necessitate monitoring their concentration in food. Therefore, the objectives of this study were to determine the amount of lead, cadmium, copper, and zinc in milk and dairy products such as kefir, sour-milk cheese and others, which are produced in different regions of Poland. The results of the study showed that the amount of lead ranged from 0.030 to 0.380 mg/kg, and cadmium – from 0.0010 to 0.0026 mg/kg. This paper also outlined the regions of Poland with low and high concentrations of these toxic elements.

Summarising the research data, we can conclude that researchers around the world are focusing on the issues of quality and safety of milk and dairy products, which are widely consumed food products. Therefore, the purpose of this research is to assess the quality level of sour-milk cheese according to the mandatory quality indicators of the national standard.

Materials and methods

The research was conducted in the laboratories of the Research and Testing Centre for Food Products of the SE Poltava Regional Research and Technical Centre of Standardization, Metrology and Certification. A comprehensive assessment of the quality of sour-milk cheese with a fat content of 5% was carried out at the end of September 2023 in accordance with the requirements of the regulatory document (DSTU 4554:2006, 2007).

The study covered products of the Ukrainian market, in particular, sour-milk cheese with a fat content of 5% produced by BIAGR LLC, one of the producers of sour-milk cheese in Poltava oblast (Fig. 1).

Figure 1. *Packaging of sour-milk cheese with a fat content of 5% produced by BIAGR LLC*
Source: *photo by the authors*

Modern analytical, organoleptic, physicochemical, and microbiological methods were used to conduct the research. The organoleptic evaluation was carried out according to the following indicators: texture and appearance, taste and smell, colour in accordance with DSTU 4554:2006 (2007).

Among the physicochemical indicators, the following were determined: mass fraction of fat according to Poltava Regional Research and Technical Centre of Standardization, Metrology and Certification (2022a); mass fraction of protein according to Poltava Regional Research and Technical Centre of Standardization, Metrology and Certification (2022b); mass fraction of moisture according to DSTU 8552:2015 (2017); acidity titrated according to Poltava Regional Research and Technical Centre of Standardization, Metrology and Certification (2021); phosphatase according to DSTU 7380:2013 (2014). The following equipment was used to study the physicochemical indicators of the quality of sour-milk cheese: laboratory balance VLR-200 manufactured by Gosmer (russia), titration unit – digital burette Solarus manufactured by Hirschmanm laboratory (Germany), laboratory universal centrifuge CLU-1 orbit manufactured by Impulse (Ukraine), drying cabinet SNOL 58-350 manufactured by AB Umega (Lithuania), Kjeldahl unit manufactured by Plurima (Ukraine).

The microbiological study was carried out according to the indicators recommended as the number of lactic acid bacteria according to DSTU ISO 15214:2007 (2009). Kessler's medium was used for the indication of E. coli bacteria in accordance with DSTU 7357:2013 (2014). The number of moulds and yeast was determined on Sabouraud agar in accordance with DSTU 8447:2015 (2017). Pathogenic microorganisms, including *Salmonella,* were determined on brilliant green agar and bismuth sulfite agar in accordance with DSTU IDF 93A:2003 (2005); *Staphylococcus aureus* was detected in accordance with DSTU ISO 5944:2005 (2007) on Baird-Parker agar, and *Listeria monocytogenes* was determined on Oxford agar and PALCAM agar in accordance with DSTU ISO 11290-1:2003 (2004). The microbiological study was carried out using the following equipment: dry-air thermostat TS-

80M-2 manufactured by Medlabortechnika (Ukraine), thermostat TGU 02-200 manufactured by Impulse (Ukraine), scales A500 manufactured by Axis (Poland), homogenizer BagMixer manufactured by Interscience (France), microscope XY B-2 ULAB manufactured by ULAB (China). The content of toxic elements was studied according to the following regulatory documents: cadmium, arsenic according to Poltava Regional Research and Technical Centre of Standardization, Metrology and Certification (2022c); lead according to Poltava Regional Research and Technical Centre of Standardization, Metrology and Certification (2022d) using Avio 200 Inductively Coupled Plasma Optical Emission Spectrometer (ICP-OES) manufactured by PerkinElmer (the USA).

Results and discussion

One of the largest producers of milk powder and fermented milk products on the Ukrainian market is BIAGR LLC, located in Bilotserkivka, Poltava oblast. This enterprise starts preparatory processes in agricultural complexes with primary processing (cleaning, cooling, and reserving). In the work of O.A. Savchenko *et al.* (2018), it is stated that one of the most important operations of the preparatory process is cooling of milk – a raw material that affects the continuation of the bactericidal phase, and, accordingly, the quality, grade, and suitability for processing into sour-milk cheese. For the production of sour-milk cheese, BIAGR LLC uses extra-grade milk.

The first control point of the HACCP (Hazard Analysis and Critical Control Points) system at BIAGR LLC begins with strict incoming milk control. Then it is purified and sorted. For the production of sour-milk cheese, the enterprise uses milk – a raw material with a high protein content, which undergoes technological processing (Fig. 2).

Figure 2. *Equipment preparation at BIAGR LLC*
Source: *photo by the authors*

To prepare the equipment for the technological process at BIAGR LLC, an automated washing station is used, two-level control of the efficiency of sanitary treatment and the cleanliness of the surface of the technological equipment is carried out (express tests and parallel sowing by the cup method). The pasteurised mixture arrives at the cheese-making section, where another set of measures and techniques for the production of sour-milk cheese begins to be applied, such as fermentation, curdling, curd cutting, curd processing and boiling, curd grain cooling, curd grain dehydration, sour-milk cheese post-cooling, pre-packaging and packaging of sour-milk cheese, post-cooling of the packaged product, storage, and sale.

BIAGR LLC uses one of the two known methods for making sour-milk cheese, namely the acid method. This method involves the coagulation of protein with lactic acid, which is formed as a result of the activity of lactic acid bacteria added in the starter culture, and subsequent heat treatment, usually performed by boiling. Each operation performed in the sour-milk cheese production and packaging departments has a direct impact on the appearance and quality of the product throughout its shelf life:

- fermentation is one of the first and important technological stages. It lays the foundation for the correct course of further operations, and the main tool in this stage is the starter culture, which affects the speed of fermentation, the taste of sour-milk cheese, the physicochemical characteristics of the finished product and the continuation of the process in general;
- curdling and its course has specific technological indicators throughout the process, which are a sign of correctly carried out previous actions and will allow the conduct of subsequent ones applied in the further part of the technological process of making sour-milk cheese;
- curd cutting is one of the most important stages that determines the shape and size of the curd grain, the yield of the finished product, and the correctness and timing of subsequent processes;
- curd processing and boiling also affects size of the grain, the speed of boiling, the quality of the cheese and its characteristics (if improperly processed, it can result in overdried, dry grain; if insufficiently processed, it can result in grain with a high moisture content or 'boiled' grain, from which moisture cannot be released due to the disruption of the boiling process).

Strict adherence to a set of preparatory and technological operations, the implementation of the HACCP system enable BIAGR LLC to produce high-quality coarse-grain sour-milk cheese (Soloshenko *et al.*, 2019). Before measuring the quality indicators of the research object, its packaging and labelling were evaluated. Sour-milk cheese produced by BIAGR LLC was packed in an intact, undamaged package made of polymer film. The packaging indicated the material of manufacture – 05 PP – polypropylene. This complies with article 9.7 (DSTU 4554:2006, 2007).

The labelling of sour-milk cheese with a fat content of 5% produced by BIAGR LLC contained the following information (Fig. 3):

Figure 3. *Analysis of labelling details for sour-milk cheese with 5% fat content*

Note: *mandatory requisites: 1 – product name with indication of the mass fraction of fat; 2 – name and address of the manufacturer and place of manufacture; 3 – net weight of the package unit, g; 4 – product composition in the order of ingredient preference; 5 – information data on the nutritional and energy value of 100 g of the product; 6 – expiration date "Use by" or production date and shelf life; 7 – storage conditions; 8 – standard designation; 9 – trademark; 10 – bar code; additional requisites: 11 – batch number; 12 – information about GMOs in the composition of the food product (in accordance with the current legislation); 13 – a sign indicating that the manufactured product is certified and meets Halal requirements; 14 – a sign indicating the weight of the product without packaging (net weight)*

Source: *developed by the authors*

The analysis of the labelling requisites made it possible to conclude that the sour-milk cheese produced by BIAGR LLC with a fat content of 5% meets the requirements of DSTU 4554:2006 (2007). After analysing the labelling requisites, the organoleptic quality indicators of the product were evaluated. It is known that these properties of cheese are formed in the process of its production. Cheese with a sour-milk flavour and aroma is formed during heat treatment of milk due to the presence of aromatic compounds produced by microorganisms with the participation of starter cultures. The taste and smell of sour-milk cheese are determined during its fermentation, ripening, and storage. The intensity of the aroma depends on the composition and number of bacteria in the starter cultures, technological parameters, and storage conditions. Lactic acid and volatile fatty acids, in particular acetic acid, are responsible for the characteristic sour taste of cheese. Diacetyl and acetaldehyde create a specific aroma of fermented milk products, while alcohol and carbon dioxide give them a refreshing taste. Various flavour nuances of cheese arise due to variations in the content of acetaldehyde and ethanol, as well as the ratio of volatile fatty acids.

The organoleptic characteristics of sour-milk cheese produced by BIAGR LLC are presented in Table 1.

Table 1. *Organoleptic characteristics of sour-milk cheese with a fat content of 5%*

Indicator name	Characteristics		Compliance with the requirements DSTU 4554:2006
	according to DSTU 4554:2006	of a sample	
Consistency and appearance	Soft, creamy, or crumbly. Slight grittiness and slight whey separation are allowed	Soft, without whey separation	meets the requirements
Taste and smell	Characteristic fermented milk smell and taste, without extraneous odour and favour	Fermented milk smell and taste, without extraneous odour and favour	meets the requirements
Colour	White or with a creamy tint, uniform throughout the entire mass	White, uniform throughout the entire mass	meets the requirements

Source: *developed by the authors*

During the research of the organoleptic quality indicators of sour-milk cheese with a fat content of 5% produced by BIAGR LLC, namely consistency, appearance, taste and smell, colour, it was found that it meets the requirements of DSTU 4554:2006 (2007) in terms of these indicators.

According to M.T. Khatun *et al.* (2019), the appearance of sour-milk cheese should be uniform, smooth; its consistency should be not too hard, not too soft and pasty. In addition, the "ideal" sour-milk cheese should have the main taste similar to fresh, pure sour milk or cream. We also agree with this judgment, as evidenced by the research results presented in Table 2.

Similarly, scientists V.P. Lyasota *et al.* (2020), studying the mandatory (according to the national standard) organoleptic quality indicators of sour-milk cheese samples with a fat content of 5% – sample No. 2 (produced by PJSC "Kremenchuk Dairy Plant"), concluded that the consistency was medium-grained, with slight grittiness; the colour was white, uniform throughout the mass; the smell was pleasant, without extraneous odour; the taste was slightly sour, without extraneous favour, which met the requirements of the standard. That is, the organoleptic indicators determined in the work correlate with the conducted research and the obtained indicators.

The national standard DSTU 4554:2006 (2007) regulates the nomenclature of physicochemical quality indicators of the of sour-milk cheese, which serves as a source of information and allows to assess its quality level. Thus, the results of physicochemical indicators of the quality of sour-milk cheese produced by BIAGR LLC are shown in Table 2.

***Table 2**. Results of physicochemical quality indicators of the of sour-milk cheese with fat content of 5%*

Indicator name	Characteristics		Compliance with the requirements DSTU 4554:2006
	according to DSTU 4554:2006	of a sample	
Mass fraction of fat, %	More than 2 to 18	5.0	meets the requirements
Mass fraction of protein, %,	Not less than 14	14.6	meets the requirements
Mass fraction of moisture, %	65-80	68.0	meets the requirements
Titratable acidity, T	In the range of 170 to 250	176	meets the requirements
Phosphatase	Not allowed	absent	meets the requirements

***Source:** developed by the authors*

One of the quality indicators of sour-milk cheese is the activity of alkaline phosphatase, which demonstrates the quality and efficiency of heat treatment of dairy products, which suppresses the development of pathogenic microflora. Enterprises monitor the activity of alkaline phosphatase in dairy products, which determines compliance with the requirements of national and international standards.

The obtained results of the research of the physicochemical indicators of sour-milk cheese with a fat content of 5% produced by BIAGR LLC are close to the values reported in the work by V.P. Lyasota *et al.* (2020). A sample of sour-milk cheese No. 2 with a fat content of 5% has the following physicochemical quality indicators: a mass fraction of fat was 5.0 ± 0.27%, protein – 17.5 ± 0.72%, moisture – 69.0 ± 2.32%, titratable acidity was 171.0 ± 3.41°T, phosphatase was absent. Therefore, the physicochemical quality indicators of both manufacturers meet the requirements of the national standard DSTU 4554:2006 (2007).

The microbiological condition of fermented dairy products is an important aspect of their safety. The indicators regulated by current regulatory documents were studied on appropriate media. To determine the number of lactic acid bacteria, according to DSTU ISO 15214:2007 (2009), MRS (Man, Rogosa and Shappe) medium was used, and the obtained results indicate compliance with the standards for mesophilic lactic acid bacteria (DSTU 4554:2006, 2007). The formed colonies were stained by Gram method and subjected to microscopic analysis. On the obtained microslide (Fig. 4), oval-shaped cocci, individual, 0.5x0.5μm in size, and occasional diplococci with dimensions of 0.9x1.2μm were found, which is a typical picture for lactic lactococci (Fig. 5).

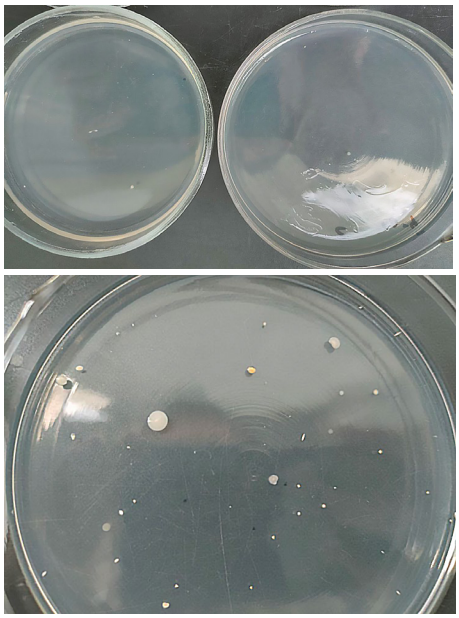
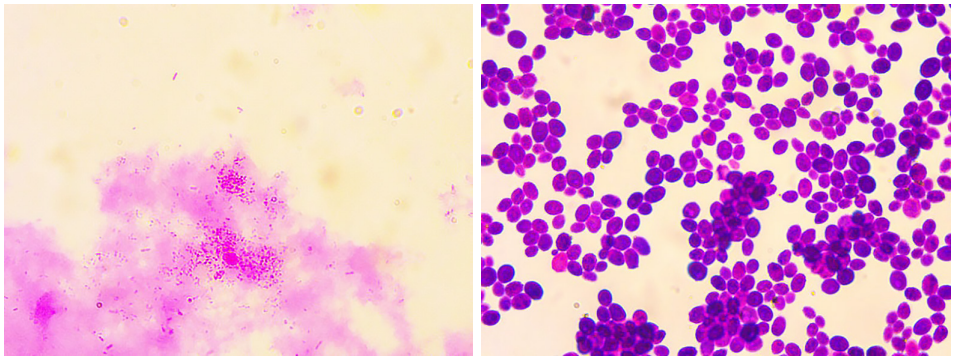


***Figure 4.** Photographic image of colonies of lactic acid bacteria and yeast found in samples of sour-milk cheese with a fat content of 5%*

***Source:** photo by the authors*



1 2

Figure 5. *Photographic image of colonies of lactic acid bacteria (1) and yeast cells (2) (Gram staining x100) found in samples of sour-milk cheese with a fat content of 5%*

Source: *photo by the authors*

The results of the studies of microbiological indicators of the quality of sour-milk cheese with a fat content of 5% produced by BIAGR LLC are presented in Table 3.

Table 3. *Results of microbiological indicators of the quality of sour-milk cheese with fat content of 5%*

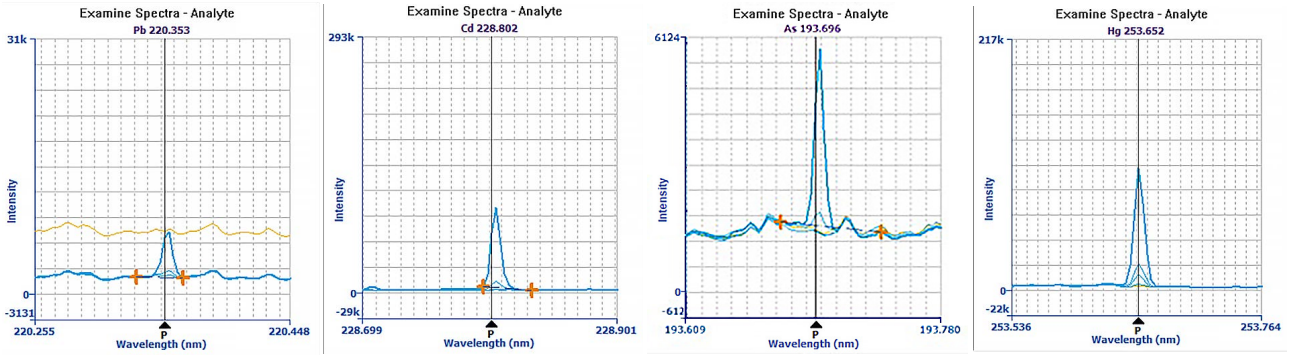
Indicator name	Characteristics		Compliance with the requirements DSTU 4554:2006
	according to DSTU 4554:2006	of a sample	
The number of lactic acid bacteria, CFU per 1 g of product	Not less than 1×10^6	2×10^6	meets the requirements
Escherichia coli bacteria	Not allowed	Not detected	meets the requirements
The number of mould fungi, CFU per 1 g of product	No more than 50	Less than 1×10^1	meets the requirements
The amount of yeast, CFU per 1 g of product	No more than 100	1×10^1	meets the requirements
Pathogenic microorganisms, including *Salmonella*, in 25 g of product	Not allowed	Not detected	meets the requirements
Staphylococcus aureus, in 0.01 g of product	Not allowed	Not detected	meets the requirements
Listeria monocytogenes	Not allowed	Not detected	meets the requirements

Source: *developed by the authors*

Additionally, besides compliance with the national standard, the obtained research results demonstrate similarity with those of sample No. 2 of sour-milk cheese presented in the work by V.P. Lyasota *et al.* (2020), in which the presence of lactic acid bacteria was $(0.49 \pm 19.2)\times10^5$ CFU/g, and coliform bacteria of the Escherichia coli group, mould fungi, yeast, and pathogenic microorganisms, including *Salmonella* and *Staphylococcus aureus*, were not detected. Similar results were obtained during our study, as evidenced by the data presented in Table 3. Therefore, the samples of sour-milk cheese from both manufacturers met the requirements of the national standard.

Thus, as a result of conducting studies of microbiological quality indicators of sour-milk cheese with a fat content of 5%, it was established that the microbiological safety of this food product meets the requirements of DSTU 4554:2006 (2007). This indicates a high level of production culture and the effectiveness of the implemented HACCP system.

The next stage of research and assessment of the safety level of sour-milk cheese produced by BIAGR LLC was the detection of toxic elements in the samples. The specialists of the Research and Testing Centre for Food Products have developed validated methods for the determination of toxic elements, namely for cadmium, arsenic, mercury – Regional Research and Technical Centre of Standardization, Metrology and Certification (2022c); lead – Regional Research and Technical Centre of Standardization, Metrology and Certification (2022d) using Avio 200 ICP-OES (Fig. 6). The conducted study of toxic elements in sour-milk cheese samples makes it possible to determine their level and establish their compliance with the mandatory requirements of the national standard (Table 4).



1 *2* *3* *4*

Figure 6. *Results of the study of toxic elements in a sample of sour-milk cheese with a fat content of 5%*
Note: *1 – lead; 2 – cadmium; 3 – arsenic; 4 – mercury*
Source: *developed by the authors*

Table 4. *Results of the study of toxic elements in a sample of sour-milk cheese with a fat content of 5%, mg/kg*

Indicator name	Levels of toxic elements		Compliance with the requirements DSTU 4554:2006
	maximum permissible according to DSTU 4554:2006	in a sample	
Lead	0.3	Less than 0.001*	meets the requirements
Cadmium	0.2	Less than 0.0001*	meets the requirements
Arsenic	0.2	Less than 0.001*	meets the requirements
Mercury	0.02	Less than 0.001*	meets the requirements

Note: ** method sensitivity limit*
Source: *developed by the authors*

Arsenic is recognised as one of the most hazardous elements, and its accumulation can result in a number of illnesses and other health impacts (Bjørklund *et al.*, 2020). Comparison of the obtained results regarding arsenic concentration for sour-milk cheese presented in the work of N.V. Chuyen *et al.* (2022), led to the conclusion that the measured data comply with the regulatory documents and have approximately the same levels: less than 0.001 mg/kg for the sample of sour-milk cheese with a fat content of 5% produced by BIAGR LLC and 0.002 mg/kg for the sample studied by N.V. Chuyen *et al.* (2022).

According to I.G. Yaroshovych *et al.* (2020), mercury is a hazard class 1 substance, and its vapours are particularly harmful. As for the results of determining the mercury content in the samples, it is also several times lower than the normative value of the national standard. Similar levels (0.51 ± 0.07 mg/kg) were obtained in the study of the Polish researcher U. Pankiewicz (2012). Thus, the analysis of the results showed that the level of toxic elements in the sample of sour-milk cheese produced by BIAGR LLC with a fat content of 5% exceeds the norm established by the requirements of DSTU 4554:2006 (2007).

According to I.M. Trakhtenberg *et al.* (2015), lead is one of the most dangerous environmental pollutants and belongs to toxins with a polytropic mechanism of action. It has a toxic effect on all organs and systems of the human body. Based on I.I. Kolosova *et al.* (2020), cadmium is characterised by a high migration rate and biochemical activity. It has a polytropic toxic effect and the ability to accumulate in various organs and tissues. Additionally, in the study by I. Suhani *et al.* (2021), it is noted that over time, cadmium accumulates and its concentration in the human body increases. In the study by M. Radzymińska & S.S. Smoczyński (2006), it is indicated that in all dairy products, including sour-milk cheese that comes from the pasture-fed cows, the average metal content ranged from 0.009 to 0.011 mg/kg for lead and from 0.001 to 0.004 for of cadmium.

Thus, summarising the results of the laboratory studies, it should be noted that the content of toxic elements in the samples of sour-milk cheese with a fat content of 5% produced by BIAGR LLC is much lower than the maximum permissible concentrations and meets the requirements of regulatory documents. Therefore, this food product is of high quality and safe for consumption.

Conclusions

A wide range of research methods was used in this study, which made it possible to assess the level of quality and safety of the research object. Conscious consumer choice begins with visual perception, preferences, and appearance of food products. Therefore, the evaluation of packaging material and the quality of labelling details is one of the factors shaping consumers' perception of the product. During the evaluation of the packaging, its compliance with the national standard was confirmed. According to the requirements of the national regulatory document, the research

object was found to comply with organoleptic indicators such as consistency (soft), appearance (no whey separation), taste and smell (fermented milk smell and taste, without extraneous odour and favour), colour (uniform white throughout the entire mass). During the study of physicochemical quality indicators, it was found that the mass fraction of fat is 5.0%; the mass fraction of protein is 14.6%; the mass fraction of moisture is 68.0%; titratable acidity was 176°T; phosphatase was absent. Thus, all mandatory physical and chemical quality indicators meet the requirements of the national standard.

In modern conditions, the mandatory indicators of the quality and safety of fermented milk products include their microbiological condition and the content of toxic elements. During the research, it was found that the number of lactic acid bacteria in 1 g of product is 2×10^6 CFU; the number of mould fungi and yeast in 1 g of product is the same – 1×10^1 CFU. Escherichia coli bacteria, pathogenic microorganisms, including *Salmonella* (in 25 g of product), *Staphylococcus aureus* (in 0.01 g of product) and *Listeria monocytogenes* were not detected. Regarding toxic elements, namely lead, cadmium, arsenic and mercury, in the sample of sour-milk cheese with a fat content of 5%, it was found that their content does not exceed their maximum permissible concentrations.

Compliance with a set of preparatory and technological operations, as well as the implementation of the HACCP system, enables BIAGR LLC to produce sour-milk cheese that meets the requirements of current regulatory documents in terms of organoleptic, physicochemical, microbiological and safety indicators. The studied product quality indicators demonstrate a high level of responsibility of the enterprise regarding the quality and safety of its products, which is important in the context of the general problem of food safety in Ukraine and worldwide.

For further research, comparative testing of sour-milk cheeses with the same fat content from different manufacturers is planned. This will allow us to study consumer demand and provide necessary, reliable, accessible, and timely information to consumers regarding the quality and safety of this food product.

Conflict of interest

None.

Aknowledgements

None.

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Комплексне оцінювання якості сиру кисломолочного українського виробництва

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Анотація. Всебічне дослідження продукції харчування, а також дотримання правил та нормативів у харчовій промисловості є необхідними для забезпечення споживачів якісними та безпечними товарами. Метою статті є комплексний аналіз якості та безпеки кисломолочного сиру, включно з оцінкою органолептичних характеристик, фізико-хімічних властивостей та мікробіологічних показників. Дослідження проводилося на прикладі одного із потужних виробників сухого молока та кисломолочної продукції на ринку України ТОВ «БІАГР». Для досягнення поставленої мети були використані наступні методи: органолептичні, фізико-хімічні, мікробіологічні та вимірювання вмісту токсичних елементів (кадмій, миш'як, свинець). На початку вимірювань показників якості було оцінено його пакування та маркування, яке відповідало вимогам національного стандарту. Під час дослідження органолептичних показників якості сиру кисломолочного із вмістом жиру 5 % було з'ясовано, що його консистенція м'яка, без виділення сироватки; виражений кисломолочний смак та запах без сторонніх присмаків і запахів; колір зразка рівномірний білий. На другому етапі проведення досліджень були виміряні та оцінені обов'язкові фізико-хімічні показники якості, а саме: масова частка жиру – 5,0 %; масова частка білку – 14,6 %; масова частка вологи – 68,0 %; кислотність титрована – 176 °Т; фосфатаза – відсутня. Оскільки безпечність продуктів харчування зараз є актуальним завданням і в Україні, то під час досліджень були виміряні такі показники безпечності, як кількість молочнокислих бактерій, що становила 2×106 КУО в 1 г; бактерії групи кишкової палички не виявлено; кількість пліснявих грибів – 1×101 КУО в 1 г; кількість дріжджів, продукту – 1×101 КУО в 1 г; патогенні мікроорганізми, зокрема Salmonella, Staphylococcus aureus, Listeria monocytogenes – не виявлено. Отже, за органолептичними, фізико-хімічними показниками та показниками безпечності сир кисломолочний із вмістом жиру на рівні 5 %, який виробляється ТОВ «БІАГР» відповідає вимогам нормативної документації. Результати дослідження можуть бути використані для контролю якості молочної продукції та вдосконалення виробничих процесів

Ключові слова: органолептичні, фізико-хімічні, мікробіологічні показники; стандартизація; безпечність; Hazard Analysis and Critical Control Points

COMMODITY BULLETIN
Journal homepage: https://c-bulletin.com.ua/en
DOI: 10.62763/ef/1.2024.55

Article's History: Received: 01.11.2023 Revised: 02.02.2024 Accepted: 26.04.2024

Vol. 17, No. 1, 2024, 55-64

UDC 641.561[664.149:635.62]

Technology development and study of properties of craft marshmallows with raspberry puree

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Abstract. The development of recipes with natural raw materials enriched with bioactive substances is an urgent task for providing the population with a complete and balanced diet. The aim of the study is to develop recipes of craft marshmallows for therapeutic, prophylactic and health-improving purposes. The research was conducted by means of the expert method, sensory analysis, and statistical methods of processing experimental data. Standard and generally accepted methods were used to determine physical and chemical parameters. To achieve this goal, it is proposed to replace part of the apple puree in the recipe with raspberry because of the raspberries' antibacterial and immunomodulatory properties. Models of marshmallow composition with different proportions of apple and raspberry puree, protein, sugar, glucose syrup and agar-agar were developed. The sensory analysis was carried out and the organoleptic characteristics of model marshmallow compositions (taste, odour, colour, consistency, structure, and surface condition) were determined. A sensory profilogram for model marshmallow compositions was created and the model composition with the best organoleptic characteristics was determined on the basis of the expert evaluation results. The content of pectin substances and L-ascorbic acid in the studied samples was determined. The physical and chemical parameters for the model marshmallow compositions were determined. It was found that due to the increase of raspberry puree content in the marshmallow recipe the moisture content of the marshmallow will increase from 21.3% ± 0.3% in MC1 with 30% raspberry puree content to 22.1% ± 0.3% in MC3 with 40% raspberry puree content. The density, active and titratable acidity of the marshmallow will decrease with the increase of raspberry puree amount in it. The expediency of using vitamin and pectin-containing raw materials (such as raspberry puree) for therapeutic, prophylactic and health-improving purposes in the marshmallow production technology has been experimentally proved. The marshmallow recipes with different proportions of apple and raspberry puree, possessing therapeutic, preventive and health-improving purposes and expanding the range of sugary confectionery products have been developed. The proposed marshmallows contain natural ingredients and are characterised by high organoleptic characteristics. Marshmallows on the developed recipes can be produced on confectionery production line of various capacities and in restaurant establishments

Keywords: pectin; L-ascorbic acid; moisture content; recipe; organoleptic evaluation; nutritional value

Suggested Citation:
Panasyuk, S., & Shemet, V. (2024). Technology development and study of properties of craft marshmallows with raspberry puree. *Commodity Bulletin*, 17(1), 55-64. doi: 10.62763/ef/1.2024.55.

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Introduction

The development of functional food is an important phenomenon in the global food market. The task of developing marshmallow recipes with a high content of vitamins, dietary fiber and high organoleptic properties, remains relevant. This is due to the growing interest of consumers to maintain and improve their health through a healthy diet. In many countries much attention is paid to the development of functional food, which uses bioactive substances in traditional products and helps to improve human health (Liufu & Martirosyan, 2020).

Among the large number of confectionery products available on the Ukrainian market, sugary products, including marshmallows, are popular treats. Many manufacturers offer a wide range of marshmallows with different flavours, fillings, and glazes. I.M. Polishchuk (2020) noted that due to the use of natural raw materials in the marshmallow recipe, marshmallows can be classified as a healthy confectionery product. Fruit and berries, in particular raspberries, contain a large amount of bioactive substances, including organic and fatty acids, sugars and polysaccharides.

Many scientists and manufacturers have been trying to address the problem of development of a marshmallow recipe enriched with functional ingredients as well as to study its properties. Y. Pronina *et al.* (2024) suggest adding cranberries, Hypericum, blueberries, and sea buckthorn leaves to the marshmallow to contribute to its functional purpose and increase its nutritional value. The authors M. Artamonova *et al.* (2023) recommend to use of vegetable raw materials (coconut sugar, blueberry powder) for production of functional marshmallows enriched with dietary fiber, protein, and vitamins. The paper by A. Zahorulko *et al.* (2020) is devoted to the development of marshmallow technology with addition of fruit and vegetable paste of apple, pumpkin and beetroot; study of structural and mechanical properties and organoleptic analysis of marshmallows made according to this recipe. It is also proposed to replace part of the apple puree with a fruit and vegetable paste made from apple, beet, pumpkin, cranberries and hawthorn, using the methods described by M. Bondar *et al.* (2021) and V. Mykhailov *et al.* (2021). To produce marshmallows and pastilles recommended for people with diabetes, obesity, and other endocrine diseases, it is suggested to use stevia and sorbitol instead of sugar, and to improve the structure of marshmallows, such authors as I. Tsykhanovska *et al.* (2019) propose to include the food additive "Magnefood" to the marshmallow composition. G.V. Korkach *et al.* (2020) state that if a synbiotic complex of lactulose and microencapsulated bifidobacteria are added to the marshmallow recipe, it will acquire medicinal properties. To obtain a stable foamy structure of marshmallows with a synbiotic, it is recommended to add dry egg white. The nutritional value of marshmallows can be increased by adding pumpkin puree. O.P. Priss & V.F. Zhukova (2020) propose to add a natural gelling ingredient – pectin to ensure high technological parameters of such marshmallows. Pectins also provide pastilles with therapeutic and prophylactic properties. They are the basis for numerous medicines and dietary supplements. By their chemical nature, pectins are high-molecular compounds that belong to the group of heteropolysaccharides. Polygalacturonic acid derivatives provide a basis for these compounds. The molecular chain of pectin substances consists of D-galacturonic acid residues, which has a pyranose configuration and is connected by a 1.4-L-glycosidic bond. Pectin substances include insoluble protopectin, soluble pectin polysaccharides and their associated galactans, arabinans, and arabinogalactans (Teterev *et al.*, 2020). B. Yudhistira *et al.* (2018) proposed to add spinach and tomato puree to the marshmallow recipe to create a product for iron deficiency anemia prevention. Thus, the use of berry and vegetable purees in the marshmallow recipe for increasing its nutritional value is promising.

The purpose of the study was to create recipes for craft marshmallows with raspberry puree designed to improve health and prevent diseases as well as to determine organoleptic, physical and chemical characteristics of this product.

Materials and methods

The research was conducted in 2023 at Lutsk National Technical University for model samples of craft marshmallows made according to the recipe indicated in Table 1. Model compositions (MC) of craft marshmallows were created with different proportions of apple and raspberry puree. Part of the apple puree was replaced with raspberry to give the marshmallows therapeutic, prophylactic and health-improving properties. Raspberries have a pleasant taste and smell and are characterised by antibacterial and immunomodulatory properties (Polishchuk, 2020; Ponder & Hallmann, 2020). The marshmallow recipe uses agar-agar as a gelling agent, which is a natural product of plant origin with no odour or off-flavours. In addition, agar-agar contains a large amount of iodine and iron, and is characterised by antibacterial properties that contribute to the long-term storage of finished products. The study was conducted by means of physical, chemical and organoleptic methods in accordance with regulatory documents DSTU 6441-2003 Confectionery pastille products (2003), DSTU 4683:2006 Confectionery products. Methods for determination of organoleptic quality indicators, dimensions, net weight and components (2006). The organoleptic characteristics of marshmallows with raspberry puree were determined by sensory testing methods (Lawless & Heymann, 2010). Research samples made according to the recipe specified in Table 1 are shown in Figure 1. Evaluation was carried out at the 5-point scale (Table 2).

Table 1. *Model compositions of craft marshmallows with raspberry puree*

Raw materials	Mass fraction of solids, %	Raw material consumption per 1 t of marshmallow			
		MC1	MC2	MC3	MC4
For syrup					
Granulated sugar	99.85	260.0	260.0	260.0	260.0
Glucose syrup	72.0	140.0	140.0	140.0	140.0
Agar	85.0	15.7	15.7	15.7	15.7
Water	–	162.2	163.4	165	159.4
For marshmallow mass					
Granulated sugar	99.85	360.0	360.0	360.0	360.0
Apple puree	14.0	265.6	246.5	228.0	380.0
Raspberry puree	10.0	114.4	133.5	152.0	–
Egg white	12.0	70.0	70.0	70.0	70.0
Total		1387.9	1389.1	1390.7	1385.1
Output		1000	1000	1000	1000

Source: *developed by the authors*

a *b* *c* *d*

Figure 1. *Model compositions of marshmallows with raspberry puree*

Note: *a – MC1, b – MC2; c – MC3, d – MC4*

Source: *developed by the authors*

Table 2. *Marshmallow grading scale*

Parameter	Number of points				
	1 point	2 points	3 points	4 points	5 points
Taste and smell	The taste is too sour, with an aftertaste not typical of raspberries. Unpleasant, pungent odour	The taste is sour, with an aftertaste not typical of raspberries. Unpleasant odour	The taste is sour, with an indistinct aftertaste. The smell is inexpressive	The taste is sweet, with sourness, with a raspberry flavour. The smell is pleasant, with light berry and fruit aroma	The taste is sweet, with slight sourness and pleasant raspberry flavour. The smell is pleasant, with berry and fruit aroma
Colour	Very uneven, dirty pink, not peculiar to the natural colour of raspberries	Uneven, dirty pink, not peculiar to the natural colour of raspberries	Slightly uneven, from dirty pink to pink	Slightly uneven, from deep pink to light pink	Even, from deep pink to light pink
Consistency	Solid, inhomogeneous, with a significant amount of raspberry seeds, does not break	Semi-solid, inhomogeneous, with a significant amount of raspberry seeds, does not break easily	Semi-solid, slightly inhomogeneous, contains raspberry seeds, does not break easily	Soft, slightly inhomogeneous, contains raspberry seeds, breaks quite easily	Soft, homogenous, small amounts of raspberry seeds occur, breaks easily
Structure	Porous, with uneven pores, inelastic, unstable	Porous, with uneven pores, insufficiently elastic, unstable	Fine-porous, with uneven pores, elastic, insufficiently stable	Fine-porous, with even pores, elastic, stable	Fine-porous, with even pores, elastic, very stable
Surface	Uneven, deformed, roughly hardened, covered with drops of syrup and sugar crystals	Uneven, with partial rough hardening, drops of syrup are released, sugar crystals are present	Slightly uneven, with partial rough hardening, syrup may be released	Peculiar to marshmallows, with slight hardening on the side edges, without syrup release	Even, peculiar to marshmallows, without hardening and syrup release

Source: *developed by the authors*

A group of 7 experts was involved in the in-person expert evaluation. They quantified the marshmallow quality indicators by a set of its properties. The moisture content of the marshmallow model compositions was determined according to the method described in How to determine moisture content in food (2024). The methods described by V.V. Yevlash *et al.* (2017) were used to determine the content of pectin substances

and L-ascorbic acid. The active and titratable acidity of marshmallows was determined according to the generally accepted methods described by C. Mutlu *et al.* (2018). The study was conducted under the ethical standards (The Declaration of Helsinki, 2013).

Results and discussion

The results of the expert evaluation of marshmallow model compositions with raspberry puree are presented in Table 3. According to the experts, all marshmallow model compositions are form-stable, have good elasticity and uniform fine-porous structure. The colour of marshmallows changes with the increase of raspberry puree in its content. All model compositions are characterised by a pleasant taste with a slight sourness, which becomes more noticeable in the model composition with 40% raspberry puree. In the control sample (MC4), a pleasant taste of apple puree is perceptible. The taste of raspberry puree prevails in model compositions MC1, MC2 and MC3. This taste becomes richer with an increase of raspberry puree in the content, whereas the taste of applesauce is not felt. The surface of marshmallows in all model compositions has a clear pattern, corresponds to the shape of the nozzle, without signs of rough hardening and syrup release after proofing. According to experts, the model composition MC2, which contains 35% raspberry puree, got the highest number of points. The sensory profilogram of the marshmallow model compositions with raspberry puree is shown in Figure 2.

Table 3. *Organoleptic characteristics of marshmallows with raspberry puree*

Parameter	Characteristics of parameter			
	MC1	MC2	MC3	MC4
Taste and smell	Sweet taste, with slight sourness typical for raspberries. Pleasant smell, with a light raspberry aroma	Sweet taste, with greater raspberry flavour. Pleasant smell, with a raspberry aroma	Sweet taste, with sourness and a tangible good raspberry flavour. Pleasant smell, with a distinct raspberry aroma	Sweet taste, with a slight flavour of apple puree. Pleasant smell, with a light fruit aroma
Colour	Light pink	Pink	Bright pink	Creamy white with a greenish tint
Consistency	Soft, with a small amount of raspberry seeds; breaks easily	Soft, with a small amount of raspberry seeds; breaks easily	Soft, with presence of raspberry seeds; breaks easily	Soft, homogeneous; breaks easily
Structure	Fine-porous, elastic, uniform	Fine-porous, elastic, uniform	Fine-porous, elastic, uniform	Fine-porous, elastic, uniform
Surface	Peculiar to marshmallows, without rough hardening and syrup release	Peculiar to marshmallows, without rough hardening and syrup release	Peculiar to marshmallows, without rough hardening and syrup release	Peculiar to marshmallows, without rough hardening and syrup release

Source: *developed by the authors*

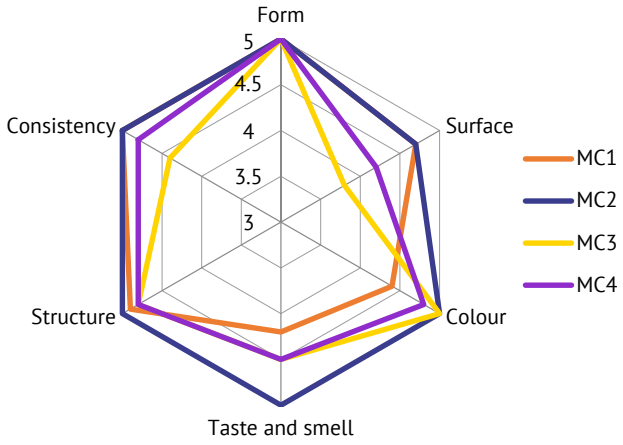

Figure 2. *Sensory profilogram of marshmallow model compositions*

Source: *developed by the authors*

A positive characteristic of marshmallow products is that its calorie content is lower than that of other confectionery products and its high pectin content is achieved due to use of fruit raw materials. The pectin content of marshmallows is one of the most important quality parameters of this confectionery product. The

structure of marshmallows depends on the pectin content, which also preserves the flavour and natural colour of the finished product. Pectin substances are essential and irreplaceable components in making food products for therapeutic, prophylactic and health-improving purposes. They have the ability to eliminate radionuclides, pesticides, heavy metals and other xenobiotics, which can cause serious diseases, from the human body.

Vitamin C (ascorbic acid) is a water-soluble vitamin that promotes cell metabolism, wound healing. It strengthens blood vessels, and increases the body's resistance to infectious diseases. It is a reducing agent (antioxidant) and a coenzyme of certain metabolic processes. Only one isomer of ascorbic acid, L-ascorbic acid, which is called vitamin C, has biological activity. Vitamin C is not synthesised or accumulated in the human body; it is supplied only from the outside, mainly from plant-based foods or herbal remedies (Shulga *et al.*, 2018). The quantification of vitamin C (L-ascorbic acid) in food is based on its chemical properties as a strong reducing agent.

The content of pectin substances and L-ascorbic acid in craft marshmallows was determined; Table 4 shows the content of pectin substances and ascorbic acid in apples, raspberries, and craft marshmallows which contain 35% raspberry puree.

Table 4. *Content of pectin substances and vitamin C in 100 g of product*

Apple	Pectin content, %	9.0 - 1.9
	Vitamin C content, mg	10.0 - 26.7
Raspberry	Pectin content, %	7.9 - 3.3
	Vitamin C content, mg	33.7 - 40.5
Marshmallows	Pectin content, %	1.04 ± 0.01
	Vitamin C content, mg	18.6 ± 0.02

Source: *developed by the authors based on E. Lemmens et al. (2020); A. Bashta et al. (2021); G. Simakhina et al. (2021)*

The results show that the total content of pectin substances in the obtained craft marshmallows is 1.04%. In addition, soluble pectin, which is characterised by high biological activity, only accounts for 31% of this content. The loss of vitamin C in finished products in ratio to its content in fruit and berry raw materials is 38.4%. Such a significant percentage of losses can be explained by destruction of vitamin C during heat treatment and the oxidation of vitamin C under the influence of air oxygen and oxidising enzymes in the process of whipping marshmallows. As a result, part of vitamin C is converted to dehydroascorbic acid.

The study of the physical and chemical parameters of the developed marshmallow model compositions was carried out. The results are presented in Table 5.

Table 5. *Physical and chemical properties of marshmallows*

Parameter	**Indicator value**			
	MC1	**MC2**	**MC3**	**MC4**
Moisture content, %	21.3 ± 0.3	21.8 ± 0.3	22.1 ± 0.3	20.08 ± 0.3
Active acidity	4.3 ± 0.03	3.7 ± 0.03	3.6 ± 0.03	4.6 ± 0.03
Titratable acidity, degree	6.6 ± 0.1	5.9 ± 0.1	5.6 ± 0.1	6.8 ± 0.1
Density, kg/m^3	721 ± 2	716 ± 2	698 ± 2	745 ± 2

Source: *developed by the authors*

The study found that with an increase in the content of raspberry puree in the marshmallow recipe, its moisture content increases: MC1, containing 30% raspberry puree, has a moisture content of 21.3% ± 0.3%. MC3, containing 40% raspberry puree, has a moisture content of 22.1% ± 0.3%. The moisture content of the control sample (MC4), which contains only apple puree, is 20.08% ±0.3%. The active and titratable acidity of the marshmallow model composition which contains 40% of raspberry puree in the recipe will have lower values (3.6 ± 0.03 and 5.6 ± 0.1, respectively) compared to the active and titratable acidity of the control sample MC4 (4.6 ± 0.03 and 6.8 ± 0.1, respectively). The density of the model marshmallow compositions will also vary: for MC3 containing 40% raspberry puree, the density is 698 ± 2 kg/m^3. For the control sample MC4, which contains only apple puree, it is 745 ± 2 kg/m^3 (Table 4).

The flow chart of production of craft marshmallows with raspberry puree is shown in Figure 3.

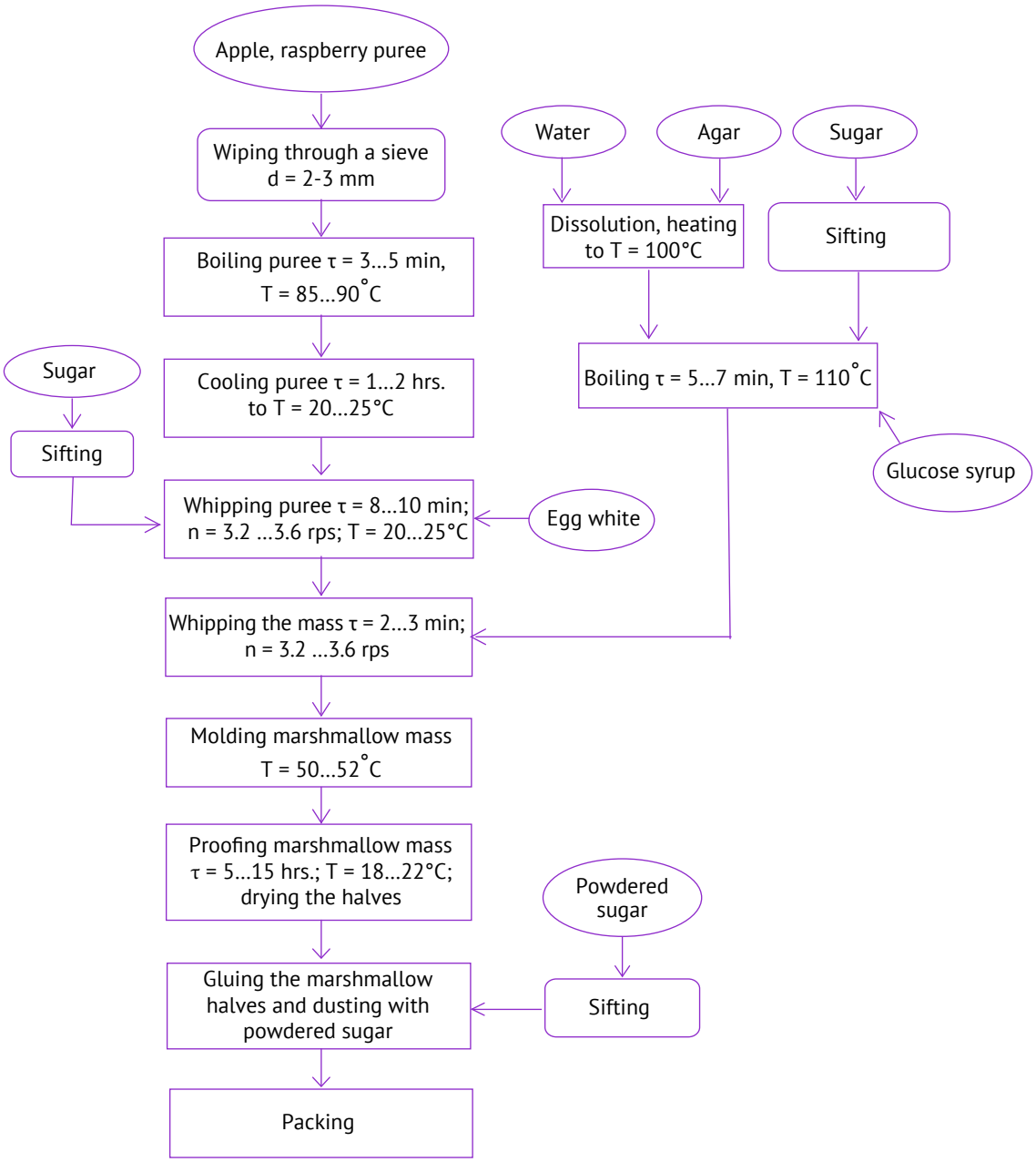

Figure 3. *Flow chart of production of craft marshmallows with raspberry puree*
Source: *developed by the authors*

The main technological operations in the production of craft marshmallows with raspberry puree are: preparation of sugar-agar syrup, boiling raspberry puree, whipping with egg white, whipping the marshmallow mass to create a fine-pore elastic structure, and proofing the formed marshmallow mass for structure formation. These stages of marshmallow production determine its quality indicators.

The study of craft marshmallows with raspberry puree results in defining its organoleptic, physical and chemical properties as well as pectin and vitamin C content. The analysis of the other authors' works devoted to the study of the properties of pastille products and, in particular, marshmallows, allowed to find out that a 5-point scale is used for the organoleptic evaluation of finished products. When comparing the model compositions of the marshmallows, the expert evaluation found that in terms of organoleptic characteristics the best one is the craft marshmallow, in which 35% of apple puree was replaced with raspberry.

The results of the study prove that the use of fruit and berry purees in the marshmallow recipe increases its nutritional value and gives it a functional purpose. In particular, scientists have noted that it is possible to obtain pastille products with original quality properties if to replace 75% of apple puree with a paste

of apple, pumpkin, beet, cranberry, and hawthorn (Bondar *et al.*, 2021). The colour characteristics, structural and mechanical as well as physicochemical properties of marshmallow masses with different concentrations of vegetable and berry paste are determined in the work. If to compare physical and chemical properties of marshmallows with raspberry puree and marshmallows with vegetable and berry paste, it is obvious that their moisture values do not differ significantly, but the density of marshmallows with raspberry puree is higher. The values of total acidity for marshmallows with vegetable and berry paste are higher than for marshmallows with raspberry puree, which can be explained by the high content of organic acids in raspberry puree.

The organoleptic, physical and chemical, structural and mechanical properties of marshmallows using blended fruit and vegetable paste from apple, pumpkin, and beetroot were studied (Zahorulko *et al.*, 2020). The content of pectin substances, ascorbic acid, and carotene in marshmallows was determined. Conducted comparison of the indicators for marshmallows with raspberry puree and marshmallows with blended fruit and vegetable paste proved that the content of pectin substances in marshmallows with raspberry puree is much lower, since raspberries contain much less pectin substances than pumpkins and beets.

O.P. Priss & V.F. Zhukova (2020) propose to introduce pumpkin puree and add pectin into the marshmallow recipe. The moisture content, density, and acidity of marshmallows with pumpkin puree were determined. When comparing the obtained values of the same indicators for marshmallows with raspberry puree, it was determined that moisture content and acidity are quite close in their values. The content of vitamin C in marshmallows with raspberry puree is significantly higher than in marshmallows with pumpkin puree.

The introduction of the food additive "Magnefood" into the recipe of marshmallows with apple puree and agar increases its moisture content and reduces its density and total acidity (Tsykhanovska *et al.*, 2019). The density of marshmallows with the food additive "Magnefood" is affected by the temperature and duration of whipping of the marshmallow mass. The comparison of the physical and chemical parameters of marshmallows with the food additive "Magnefood" and marshmallows with raspberry puree, proves that marshmallows with the food additive "Magnefood" have lower moisture content, and their density does not differ significantly from the density of marshmallows with raspberry puree, but with a decrease in the content of raspberry puree, the density difference increases.

Plant raw materials in the form of dry powders, in particular blueberry powder, are also used for increasing the nutritional value of marshmallows. For this purpose it is also possible to replace granulated sugar with coconut sugar (Artamonova *et al.*, 2023). The value of the moisture content of marshmallows with raspberry puree obtained in the study does not differ significantly from the value of the moisture content of marshmallows with blueberry powder and corresponds to the standard values. The content of pectin substances in marshmallows with raspberry puree is higher than in marshmallows with blueberry powder.

The physical and chemical as well as organoleptic characteristics of iron-enriched marshmallows with spinach and tomatoes were determined and their chemical composition was investigated (Yudhistira *et al.*, 2018). Spinach and tomato marshmallows also contain dietary fiber, which increases their nutritional value. The moisture content of marshmallows with spinach and tomatoes is lower than that of marshmallows with raspberry puree. The vitamin C content in marshmallows with raspberry puree is higher, but may decrease with increasing whipping temperature.

To make marshmallows medicinal, it was proposed to introduce synbiotic complexes into the recipe of pastilles (Korkach *et al.*, 2020). Egg white, which determines the structural and mechanical properties of the marshmallow mass and affects the quality of the finished marshmallow, was added as a foaming agent. The effect of temperature and intensity of whipping of the marshmallow mass on its density was studied and the optimal temperature for making marshmallows with a synbiotic complex was established. The obtained values of the density of marshmallows with the synbiotic complex are significantly lower compared to the density of marshmallows with raspberry puree.

There is a group of sugary products recommended for consumption by people with diabetes. In the recipe of such products, granulated sugar is replaced with natural or artificial sweeteners. The technology for the production of marshmallows with stevia and elamine as a source of iodine has been proposed (Radchenko *et al.*, 2016). The organoleptic evaluation of marshmallows was carried out on a 5-point scale. The developed evaluation scale reflects all the criteria that serve as comparative characteristics for marshmallow model compositions.

Sugary products can be enriched with biologically active ingredients by adding fruit, vegetable and berry purees to their composition. In particular, such authors as G.V. Khomych *et al.* (2022) proposed to introduce henomeles puree, which contains organic acids, phenolic substances, carotene, and pectin, into the recipe and reduce the agar content in marshmallows. The results of studies of the effect of henomeles puree on the foaming ability and the formation of structural and mechanical properties of marshmallows are presented. The content of L-ascorbic acid in marshmallows and pastille products with henomeles puree increases by 2-3 times compared to the model composition with apple puree, while in marshmallows with raspberry puree the content of L-ascorbic acid will increase by 1.5…1.8 times.

Conclusion

The research resulted in the development of a flow chart for the production of craft marshmallows with natural raw materials: apple and raspberry puree. The obtained marshmallows are enriched with vitamins and bioactive substances that a person needs for a complete and healthy diet. The recipe does not contain preservatives and artificial colours, and due to the antibacterial and immunomodulatory properties of raspberries, the finished product will have a therapeutic, prophylactic and health-improving purpose. The marshmallow recipe uses agar-agar as a gelling agent. Agar-agar is a natural product of plant origin with no odour or off-flavours and contains a large amount of iodine and iron. It also has antibacterial properties, due to which the finished product can be stored for a long time.

According to the results of expert evaluation of marshmallow model compositions, the best organoleptic characteristics are obtained for craft marshmallows, the recipe of which contains 35% raspberry puree and 65% apple puree. In this recipe the determined content of pectin substances is 1.04 ± 0.01% per 100 g of product, and L-ascorbic acid is 18.6 ± 0.01 mg per 100 g of product.

When determining the physical and chemical parameters of craft marshmallows, it was found that moisture content of the marshmallow increases with the increase of the puree content in it, while the values of density, active and titratable acidity decrease. The increase in moisture content ranges from 21.3 ± 0.3% in MC1 with 30% raspberry puree to 22.1 ± 0.3% in MC3 with 40% raspberry puree. The density decreases from 721 ± 2 kg/m^3 in MC1 with 30% raspberry puree to 698 ± 2 kg/m^3 in MC3 with 40% raspberry puree. The active acidity decreases from 4.3 ± 0.03% in MC1 with 30% raspberry puree to 3.6 ± 0.03% in MC3 with 40% raspberry puree, and the titratable acidity decreases from 6.6 ± 0.1% in MC1 with 30% raspberry puree to 5.6 ± 0.1% in MC3 with 40% raspberry puree.

Research on the use of cranberry, sea buckthorn, blackberry, and strawberry puree in the recipe of craft marshmallows for a functional purpose is promising.

Conflict of interest

None.

Acknowledgements

None.

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Розробка технології та дослідження властивостей крафтового зефіру з додаванням малинового пюре

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Анотація. Розроблення рецептур харчових продуктів з використанням натуральної сировини, збагачених біоактивними речовинами є актуальним завданням для забезпечення населення повноцінним і збалансованим харчуванням. Метою дослідження є розроблення рецептур крафтового зефіру лікувально-профілактичного та оздоровчого призначення. Дослідження проводились з використанням експертного методу, сенсорного аналізу, статистичних методів оброблення експериментальних даних. Для визначення фізико-хімічних показників використовували стандартні та загальноприйняті методики. Для досягнення мети запропоновано у рецептурі частину яблучного пюре замінити малиновим, оскільки малина має антибактеріальні та імуномодулювальні властивості. Розроблені модельні композиції зефіру, що містять різні співвідношення яблучного та малинового пюре, білок, цукор, глюкозний сироп та агар-агар. Проведено сенсорний аналіз та визначено органолептичні показники модельних композицій зефіру (смак, запах, колір, консистенцію, структуру та стан поверхні). Побудовано сенсорну профілограму модельних композицій зефіру та за результатами експертної оцінки визначено модельну композицію з найкращими органолептичними показниками. Визначено вміст пектинових речовин та L-аскорбінової кислоти у досліджуваних зразках. Визначено фізико-хімічні показники модельних композицій зефіру і встановлено, що із зростанням вмісту малинового пюре у рецептурі зефіру його вологість буде зростати від 21,3 % ± 0,3 % у МК1 із 30 %-им вмістом малинового пюре до 22,1 % ± 0,3 % у МК3 із 40 %-им вмістом малинового пюре. Із збільшенням кількості малинового пюре у складі зефіру його густина, активна та титрована кислотність будуть зменшуватись. Експериментально підтверджено доцільність використання вітамінної та пектиновмісної сировини, такої як малинове пюре, у технології виготовлення зефіру для надання йому лікувально-профілактичного та оздоровчого призначення. Розроблені рецептури зефіру з різним співвідношенням яблучного і малинового пюре, який має лікувально-профілактичне та оздоровче призначення, і сприятиме розширенню асортименту цукристих кондитерських виробів. Запропонований зефір містить натуральні компоненти і характеризується високими органолептичними показниками. Зефір за розробленими рецептурами можуть виготовляти у кондитерських цехах різної продуктивності та закладах ресторанного господарства

Ключові слова: пектин; L-аскорбінова кислота; вологість; рецептура; органолептична оцінка; харчова цінність

COMMODITY BULLETIN
Journal homepage: https://c-bulletin.com.ua/en
DOI: 10.62763/ef/1.2024.65

Article's History: Received: 10.12.2023 Revised: 03.03.2024 Accepted: 26.04.2024

Vol. 17, No. 1, 2024, 65-75

UDC 620.2:347.77

Systems of goods geographical indications: EU and Ukraine experience

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Abstract. Goods with geographical indication are an important component of the world economy, they have an impact on social and cultural development, help to preserve natural and cultural resources of the regions, therefore their investigation is relevant. The purpose of the study is to compare the systems of goods with geographical indications in the EU and Ukraine, to determine the dynamics of formation and advantages of this system functioning in Ukraine. An analysis of the literature on geographical indications in various fields is carried out; the regulatory framework that regulates geographical indications in specific countries and regions; the effectiveness of legal mechanisms for geographical indications protection, economic consequences of using geographical indication for regional markets is examined. It was proved that geographical indication introduction has advantages: it allows to determine the place of commodity production, to ensure its quality and uniqueness; contributes to the development and support of local economies, traditional industries; protects and supports traditional methods of production, recipes and other aspects of cultural heritage related to a certain region; provides consumers with an additional level of trust in the product. These aspects contribute to the development of international trade, create conditions for fair competition, promote innovation and protect the interests of producers and consumers. Studies show that producers with geographical indications can experience a positive impact on their markets due to the increased value of their goods. It is noted that geographical indication introduction can contribute to preserving and supporting traditional methods of production and cultural heritage. Analysis of registration practice and protection of geographical indications in different countries allows to identify shortcomings and opportunities for improving legislation and processes. Research indicates that consumers find the products with geographical indications more attractive and trust them because of associations with a specific region. Studying the international aspect of geographical indication allows you to understand how the use of this tool affects international trade and economic relations. The research results contribute to the development of recommendations for policies, improvement of the

Suggested Citation:
Peredriy, O., Pakholiuk, O., & Golodyuk, G. (2024). Systems of goods geographical indications: EU and Ukraine experience. *Commodity Bulletin*, 17(1), 65-75. doi: 10.62763/ef/1.2024.65.

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practice of geographical indications registration and protection, as well as to the expansion of understanding the importance of this tool for the development of various industries and regions

Keywords: goods of protected origin; the country of origin; food; sustainable development; traditional production; marking

Introduction

Goods with a protected denomination or goods with geographical indication (GI) constitute a special group of goods in international trade. The main feature of these products is a unique combination of natural and human factors, which, strengthening each other, contribute to creating a product that is unique in terms of quality and taste characteristics. Natural factors, such as climatic conditions, insolation, the amount of sunlight throughout the year, ampeological characteristics of soils, special varieties of plants and animal species are reinforced by factors of cultural development: traditions, population mentality, specific skills, traditional technological equipment passed from generation to generation. Thanks to such a combination, it is possible not only to supply high-quality traditional goods to the commodity markets, but also to preserve the authenticity of certain population groups, their cultural traditions and crafts. The protection of goods with geographical indications has a purely economic significance – it contributes to sustainable development, increases the level of income and production efficiency in remote regions, promotes the development of ethno- and gastrotourism. The system of geographical indications in Ukraine is just beginning to function, the use of geographical indications and appropriate goods marking is unfamiliar to both producers and consumers. Therefore, complex commodity studies, which take into account trade and economic aspects of using geographical indications, are quite relevant both for scientists and Ukrainian producers of goods.

This issue has been extensively researched by European sociologists, marketers and commodity market researchers. The vast majority of works are devoted to economic aspects of using geographical indications, their influence on the commodity markets functioning. In particular, C. Li *et al.* (2023) investigated the actual impact of using geographical indications on the development of agricultural regions, in particular, proved the contradiction of the statement about the rapid and undeniable increase in the production of a certain product after assigning it a GI. F.S. Meirelles *et al.* (2023) studied the economic consequences and transaction costs of using geographical indications. N. Saavedra-Rivano (2012) analysed the role of geographical indications in international trade, determining the positive impact on the preservation of traditional technologies for cultivating raw materials and producing the finished product. Considerable attention of scientists was paid to the consideration of conflicting normative and legislative aspects of using GIs in different countries, in connection with which there is an urgent issue of standards harmonisation in the field of marking goods with protected geographical denomination (Baer-Nawrocka, 2023). D.A. Niranjan *et al.* (2023) researched the limitations associated with using geographical indications, in particular, the influence of insufficient awareness of both product manufacturers and consumers on the prospects and feasibility of assigning GI marks to commodities.

Considerable attention is also paid to the study of consumer trust in geographical indications. A. Rabadán *et al.* (2021) and V.A. Cardoso *et al.* (2022) investigated the effect of the presence of GI marks on the products on forming consumer demand and determined the level of consumer trust in the marking of the product geographical origin. At the same time, the authors proved that the level of trust in GI is generally low and is significantly higher among consumers of Northern European countries. The researchers also determined the level of perception of GI, the willingness to pay more for goods marked with GI, among consumers of different ages, analysed in detail the purchasing behavior of consumers of food products that are certified according to geographical origin schemes (Barbu *et al.*, 2022). Some certain works are devoted to the consideration of legal aspects of using and protecting geographical indications in different countries (Zito, 2019; Baer-Nawrocka, 2023).

In Ukraine, there are few scientific works on geographical indications, mostly they relate to the European practice of using geographical indications (Dumanska, 2020). Also, a significant number of works are devoted to legal aspects. In particular, a number of authors consider a geographical indication as an object of intellectual property (Kodynets & Sidorenko, 2020). A lot of works concern the need to codify the legislative norms of Ukrainian legislation in accordance with the requirements of the EU and Cooperation Agreement between the EU and Ukraine and the prospects for the development of the legal field regarding goods with protected denominations in Ukraine (Barskyi & Dvornichenko, 2021).

There are practically no scientific studies on the real economic benefits of using geographical indications for Ukrainian producers; regarding the order of sale and customs movement of goods with a protected denomination in Ukraine. With the consistent implementation of geographical indications system in Ukraine, the need for thorough research on this topic will increase. This

study aims to compare the geographical indications systems of the EU and Ukraine, to determine ways of implementing this system in Ukraine.

Materials and methods

This study was carried out during 2023 by the scientists of Lutsk National Technical University. The period 2019-2023 was chosen for data analysis, since it was at this time that the system of geographical indications began to be actively implemented in Ukraine, and the legislation on geographical indications was changed in the EU countries in connection with risk factors of their use.

Practical aspects of using geographical indications were studied by analytical and statistical methods. Analytical methods were used considering the term "geographical indication" itself, analysing scientific publications, economic indicators regarding the implementation effectiveness of systems for controlling the geographical origin of goods, which were determined on the basis of European Commission reports (the last official European Commission report was prepared by AND International and Ecorys Brussels) (Publications Office..., 2021) and report of Food and Agriculture Organization UN (Report of FAO, 2023). Statistical methods were used in the processing official statistical data, in particular, in the analysis of quantitative indicators of geographical indications in European countries – based on the analysis of register data eAmbrosia register (2023) and State Register of Geographical Indications of Ukraine (2024). System analysis was used to verify claims regarding the positive impact of geographical indications on the commodity markets functioning, the growth of the individual regions economic development, and the prospects determination for the wider introduction of systems of goods control for origin on the territory of Ukraine. A comparative approach was used to compare the level of the product market coverage by geographical indications in European countries and in Ukraine, which made it possible to clearly determine the feasibility of faster implementation of geographical indications system in Ukraine, the need to register Ukrainian goods in the international registers of goods with protected denominations.

A diverse selection of sources became the key prerequisite for a qualitative analysis of the issue. This study was carried out on the basis of the analysis and systematisation of the European Commission normative documents and reports data (Publications Office..., 2021), Food and Agriculture Organization (Report of FAO, 2023). Research on using geographical indications in Ukraine was conducted based on official legislative and regulatory documents of Ukraine, in particular, Law of Ukraine No. 752-XIV (2023), official data of Ukrainian National Office of Intellectual Property and Innovation, State Service for Intellectual Property Protection of Ukraine. Analytical materials of the EU project "Institutional and political reform for small-scale agriculture" were also used in the work (IPRSA) (EU IPRSA, 2021). Secondary data for the research of this topic are scientific publications from open sources for 2018-2023, which contain the results of research on using geographical indications in different countries of the world. Cross-comparative and chronological search was used to select scientific sources. For the analysis, articles were selected that deal with economic (economic efficiency for manufacturers, impact on the economic development of regions, risks) and product science (consumer trust in GI marking, the influence of GI on consumer behavior, the peculiarities of trade in goods with GI, etc.) Aspects of using geographical indications.

Results and discussion

Geographical indications are an element of sustainable development in the modern world and an integral part of the international system of intellectual property agreements TRIPS (Agreement on Trade-Related Aspects of Intellectual Property Rights). The volume of goods with a geographical indication of the place of manufacture in 2020 amounted to 74.76 billion euros (Publications Office of the European Union, 2021). The absolute advantage of using GI is the product recognition, its differentiation among similar ones, and, accordingly, the provision of competitive advantages. The price of goods with GI increases twice on average: the growth index is 2.85 for wines, 2.52 for other alcohol drinks and 1.5 for food (Publications Office..., 2021).

Compliance with traditional technologies, use of high-quality raw materials ensures high quality of the final product. Accordingly, food products with GI receive wider access to sales markets, in particular, this applies to cheeses and wines. Another advantage worth mentioning is the increase in production, in particular, according to some scientists, during 2019-2022, 49% of traditional product manufacturers in the countries increased their production volumes (Report of FAO, 2022).

As of November 2023, 3841 names of goods with legal protection of geographical origin are registered in the EU. All of them are divided into three main categories: wines, food and alcohol drinks. Wines and food products make up approximately equal shares – 45 and 48%, respectively (Fig. 1) (eAmbrosia register, 2023).

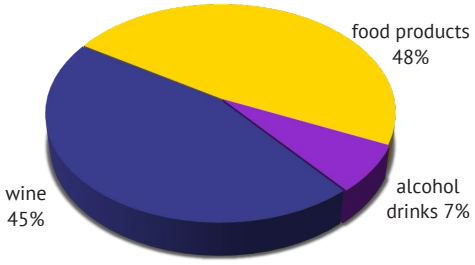

Figure 1. *Distribution of goods with a protected denomination according to categories*
Source: *developed by the authors based on the eAmbrosia register (2023)*

Analysing the distribution of GI goods by product type, it should be noted that in the category "Food products" the largest share falls on fruits and vegetables and products of their processing – 30%. The share of cheese is also significant – 15% (Fig. 2) (eAmbrosia register, 2023).

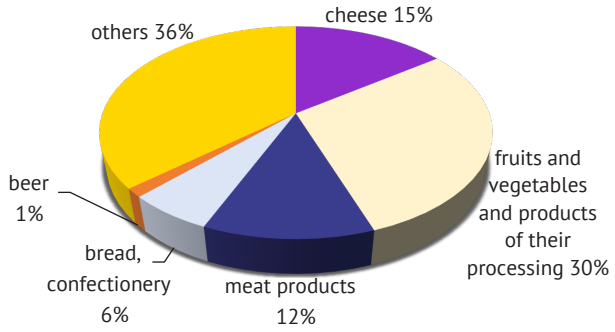

Figure 2. *Distribution of products with a protected denomination in the "Food products category"*
Source: *developed by the authors based on the eAmbrosia register (2023)*

Out of 3841 goods registered by geographical origin in the EU, 3542 goods are from EU countries, other 299 are from the other countries of the world. And it should be noted that 110 of them come from China. It is worth saying that the rather uneven distribution of GI products by the country of affiliation. 73% of all goods are accounted for 6 EU countries: Italy – 24%, France – 20%, Spain – 11%, Greece – 7%, Portugal – 6%, Germany – 5% (Fig. 3) (FAO, register of Geographical Indications, 2023).

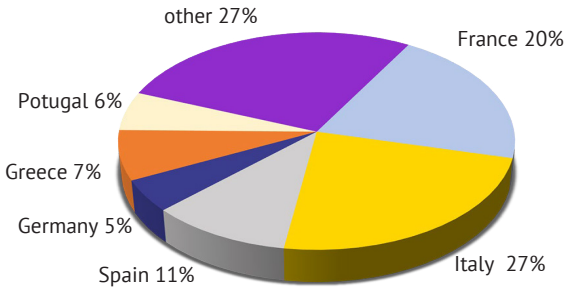

Figure 3. *Distribution of goods with a protected denomination by country of origin*
Source: *developed by the authors based on FAO register of Geographical Indications (2023)*

For example, Poland has only 40 protected denominations, Lithuania – 15. Such an uneven distribution brings a certain imbalance into international trade, giving greater competitive advantages to producers from larger countries. Therefore, in 2023, the European Commission slightly softened the conditions for GI registration, taking into account trade and economic interests of small countries.

The main geographical indications of the EU include:

- PDO – protected denomination of origin (food and wine);
- PGI – protected geographical indication (food and wine);
- GI – geographical indication (alcohol drinks) (Fig. 4) (eAmbrosia register, 2023).

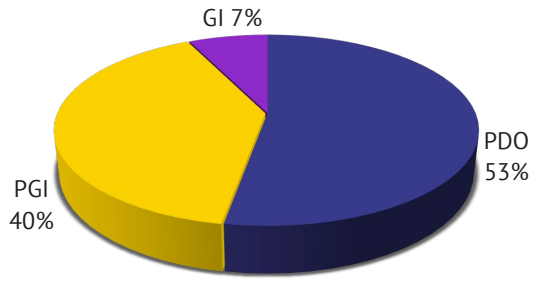

Figure 4. *Distribution of goods with protected origin according to schemes of geographical indications*
Source: *developed by the authors based on eAmbrosia register (2023)*

In addition, EU countries have developed a special marking system for products manufactured in remote regions of the EU (Treaty "On the Functioning of the European Union", 2017). These measures aim to help the most remote regions of the EU, which face particularly difficult natural conditions, such as extreme remoteness. According to Articles 349 and 355 of the Treaty "On Functioning of the European Union" (TFEU), these regions include: overseas departments of France – Guadeloupe, French Guiana, Reunion and Martinique – as well as the Azores, Madeira and the Canary Islands (Treaty "On Functioning…", 2017). To ensure greater consumer awareness of agricultural products from these regions, a special logo was created as an optional term of quality.

Also, in European countries, the term "mountain product" is widely used when marking certain types of products, which emphasises the features of a product made in a mountainous area with difficult natural conditions. The use of such a designation creates certain trade advantages for both farmers and consumers. This allows farmers to sell the product better, but also ensures that certain characteristics are clear to the consumer. The technical requirements for using this designation are following: raw materials and animal feed originate exclusively from mountainous regions; production of the final product also takes place in the mountainous area.

Beyond its borders, the EU takes many steps to protect the authenticity of products and guarantees the recognition of European product quality worldwide. The protection of GI helps to fight against counterfeit products, which threaten the reputation of authentic local and regional products and their producers earnings. In the EU countries, in which systems of geographical indications have been operating for several decades, they are constantly working on improving the regulatory

support for their functioning, developing clear and understandable mechanisms for registering goods and controlling their quality.

According to Law of Ukraine No. 752-XIV (2023), "a geographical indication defines the specific place of product origin, fully identifies it as coming from a certain geographical place and having a special quality, reputation or other characteristics due to this geographical place of origin, and at least one of the stages of its production (production (extraction) and/or processing, and/or preparation) is carried out in a defined geographical area".

Ukraine undertook to comply with European norms regarding geographical indications. According to geographical indications, the conditions of international treaties are higher than the norms of the Laws of Ukraine. In accordance with the norms of international law, the legal protection of a geographical indication is valid indefinitely, with the exception of early termination of a geographical indication registration.

Geographical indications of Ukraine, which are subject to protection in EU countries, include 5 names: Petrykiv painting, Krolevets towels, Melitopol cherry, Hutsul sheep bryndzia (cheese), Hutsul cow bryndzia (cheese) (State Register of Geographical Indications of Ukraine, 2024). In total, 55 products with protection on the territory of the EU are included in the national register of goods with protected geographical indications, and 20 products are at the stage of application consideration (State Register of..., 2024).

The project "Institutional and political reform of small-scale agriculture" (IPRSA) is successfully operating in Ukraine, which periodically conducts educational training programs for farmers, representatives of local agribusiness, employees of the Ministries of Economy and Agrarian Policy, the State Consumer Service of Ukraine. This project cooperates with the Ukrainian National Office of Intellectual Property and Innovation (UKRNOIPI) in order to establish the process of certification and control of products with geographical indication. Practically all draft laws on the functioning of the geographical indications system in Ukraine are developed with the support of IPRSA. For the effective operation of the geographical indications system, it is important to improve the ability of state bodies to work stably with GIs and introduce product certification in accordance with EU rules and practices. The Ministry of Agricultural Policy is responsible for approving specifications of agricultural products, authorising certification bodies, and approving control plans. Therefore, it is important for experts in this sector to understand the specifics of GI certification and to understand the nuances that should be taken into account during this process in order to ensure an efficient and less burdensome work for all sides involved in the process.

It is important that the Ministry of Economy understands the necessary requirements for GI registration applications for submitting an application for further certification of products in the EU, since the Ministry of Economy approves the relevant regulatory and legal actions. In its turn, UKRNOIPI validates applications for registration of GI, therefore, the skills of working correctly with such applications and understanding the requirements of the product specification for correct certification are very important for office specialists. State control is also an important part of the geographical indications system. This function is entrusted to the State Production and Consumer Service, therefore its specialists must know how to carry out control procedures in accordance with the approved GI. The unification of all these institutions and structures in one educational program made it possible to establish a unified approach to the Ukrainian system of geographical indications.

With the support and funding of the EU, the program "Geographical Indications of Ukraine" was developed in Ukraine, which was valid until 2021 (Geographical Indications of Ukraine, 2021). The main goal of this program is the development of a clear and understandable system of geographical indications of Ukrainian goods, promotion and support of Ukrainian GIs on the European market. However, it should be noted that no significant progress has been made in this direction. During the period of the program implementation, only three Ukrainian products – Hutsul cow bryndzia (cheese), Hutsul sheep bryndzia (cheese) and Melitopol cherry – received the official status of international protected geographical indications. It is worth remembering that the successful implementation of the GI program in Ukraine would contribute to the development of counrty's craft production, the development of ethno- and gastrotourism, the popularisation of the cultural heritage of Ukraine, the development of autochthonous regions of Ukraine, such as Ukrainian Bessarabia, Tavria, Volyn and others. At the beginning of 2024, not all regions of Ukraine presented traditional products of their regions for consideration. Certain products received the status of GI in the territory of Ukraine, but there are very few of them.

As a part of IPRSA project, together with the Food and Agriculture Organization of the United Nations (FAO), a program of geographical indications for Zakarpattia wines is developed – "Silver Land Wines". In 2023, grape growers and winemakers of Zakarpattia united in the Association of Grape Growers, Winemakers and Distillers of Zakarpattia with the aim of expanding the production of local wines and registering the geographical indication for their products "Silver Land Wines". For this purpose, during the year, trainings and meetings with producers and representatives of the state administration were held in various wineries within the framework of IPRSA project. In November 2023, this Association concluded a cooperation agreement with the Association of Manufacturers of Traditional Carpathian High Mountain Cheeses for the purpose of popularising the geographical indications system, developing the production of traditional products,

and promoting gastro- and ethnotourism based on geographical indications.

Similarly to some European projects ("Whiskey Road" in Scotland, "Wine Roads" of Spain and others) in Ukraine "Wine and Taste Roads" have been developed in such regions as Ukrainian Bessarabia, Zakarpattia, Kherson region. Before the start of Russia's full-scale invasion, these projects were quite successful with the support of such well-known Ukrainian manufacturers as Shabo and Kolonist. The leading Ukrainian agro-ecological recreation cluster "Frumushyka-Nova" implemented a complex offer: wine plus local traditional products. In result, "Wine and Taste Roads" was included in the programs of individual Ukrainian tour operators. During the first year of the program, the flow of tourists to the location and the sale of local products increased significantly – up to 30%, according to the manufacturer data.

Organisations-managers of geographical indications "Hutsul bryndzia", During 2022-2023, the Association of Producers of Traditional Carpathian High Mountain Cheeses and the Association of Carpathian Watags actively developed gastronomic tourism based on geographical indications in their region. Volyn, as a region with ancient and stable traditions, could also submit a number of unique products for geographical indication registration, in particular, Polish honey, Volyn mead, Porytsk cheeses. The first steps in this direction are already done. So LLC "Staryi Porytsk" developed and put into production the recipe for cheese (type of bryndzia with herbs), which is made according to the ancient recipes. The Swiss Research Institute of Organic Agriculture (FiBL), which is a partner of Volyn producer, is ready to invest in new developments of organic cheese factory. Of course, registering new geographical indications is not an easy task and requires joint efforts. So in case of registration of alcoholic drinks new name as "Volyn mead", it is necessary to unite the representatives of small and medium-sized businesses of Volyn region.

In Ukraine support for projects related to geographical indications is carried out selectively, in the form of pilot projects. Thus, in 2023 with the support of the EU and FAO a grant program to support agricultural producers in certain regions is being implemented (State agrarian register of Ukraine, 2023). This support provides grants in the form of investments for the geographical indications development. In 2023 small agricultural producers from such regions could take part:

- Lviv region (berry growing, vegetable growing, aquaculture);
- Zakarpattia region (Hutsul sheep bryndzia, Protected Denomination of Origin (PDO), Hutsul cow bryndzia, Protected Denomination of Origin (PDO), Zakarpattia honey, Protected Geographical Indication (PGI), Zakarpattia wine);
- Ivano-Frankivsk and part of Chernivtsi region (Hutsul sheep bryndzia, protected denomination of origin (PDO), Hutsul cow bryndzia, protected denomination of origin (PDO).

Funds in the amount of 10000 dollars for small farms and 25000 dollars for medium-sized enterprises and cooperatives were allocated for this program (State agrarian register of Ukraine, 2023).

The issue of geographical indications in Ukraine has the potential for further development and the support for various branches of the economy and agriculture. Here are some prospects for the development of geographical indications in Ukraine:

- protection and promotion of the regions uniqueness: GIs can help to protect and emphasize unique regional features and qualities of goods. This can become an important factor for the promotion of products in the domestic and international markets;
- increasing the competitiveness of products: protected GIs can help the products to compete in the market based on quality and origin, this can contribute to increasing the value of goods and the demand for them;
- agriculture and rural development: GIs can support the development of rural areas and contribute to the creation of new jobs in agriculture and related sectors such as tourism and gastronomy;
- attraction of foreign investments: GIs can create new opportunities for investments in regional projects and support the development of infrastructure and technological innovations in various sectors of economy;
- export growth: protected geographical indications can contribute to the promotion of Ukrainian goods on international markets and the expansion of export opportunities;
- forming consumer awareness: geographical indications can increase consumer awareness of the products quality and origin, which helps to increase consumer confidence in these products.

In accordance with the requirements of Ukraine-EU Association, Ukrainian manufacturers must completely stop using names legally protected in the EU to denominate their products by 2026. From November 1, 2022, the import of alcoholic products labeled Cognac in Ukraine was terminated, if such products do not meet the technical requirements for using this protected name. On January 24, 2022, as a result of adoption of new regulatory acts, which include the protection of GI, the name "Cognac" was included in the customs register, which is a mandatory condition for implementing the protection of GI "Cognac" on the territory of Ukraine. A transition period was established so that importers could change the labels on their products that do not comply with this GI. The transition period was extended until October 31, 2022 (inclusive), taking into account the dramatic circumstances in Ukraine (Association Agreement EU-Ukraine, 2023).

Starting from November 1, 2022, the corporation "Ukrvynprom" together with the National Interprofessional Bureau of Cognac ("BNIC") are responsible for the protection of GI "Cognac" on the territory of Ukraine and abroad, and will take the necessary measures against

products imported and presented under the name "Cognac" and/or "Коньяк", if they do not meet the technical conditions established for GI "Cognac", in accordance with Association Agreement signed between the EU and Ukraine (Association Agreement..., 2023). Earlier, until December 31, 2019, such requirements were fulfilled by Ukraine for sparkling wines Champagne.

From January 1, 2023, there would be no cheese in Ukrainian stores Parmigiano Reggiano, Roquefort and Feta of Ukrainian manufacture, however, on the shelves of all supermarkets there is a wide range of Ukrainian-made Feta cheese (Association Agreement..., 2023). Although the union of dairy enterprises of Ukraine jointly with the European project "Institutional and policy reform for small-scale agriculture" (IPRSA), the association of dairy industry proposed new names for Ukrainian producers – "Felata" and "Nabil".

In October 2023, the Cabinet of Ministers submitted to Verkhovna Rada for consideration a draft law proposing to introduce fines for violating the requirements of the legislation on the protection of GIs for food products and alcoholic beverages (Draft Law No. 10162..., 2023). The purpose of this regulatory act is to settle issues of using geographical indications and establishing responsibility for violations in the field of quality schemes and geographical indications. The project provides for administrative responsibility for such violations like non-fulfillment or untimely fulfillment of the central executive body orders, which implements state policy regarding quality requirements for agricultural products, food products and alcoholic beverages with geographical denominations. The following types of responsibilities are also provided for:

- civil responsibility: a person who illegally uses a geographical indication can be sued for damages caused to GI owners or other interested parties;
- administrative responsibility: the legislation provides for fines for the persons who violate the rights to geographical indications. The amount of fine can be determined according to the violations, and be indicated in monetary equivalent;
- criminal responsibility: for some serious violations of geographical indication rights, criminal sanctions are provided (imprisonment, confiscation and significant fines).

This problem is widely studied by foreign scientists. In particular, the issue of both positive and negative impact of GI on the development of regional production is actively considered. During the research, it was established that close cooperation between producers of a certain region is necessary for GI registration. Since the producers of GI products are mainly small regional enterprises, their cooperation will contribute to the coordination of certain stages of production (growing, processing, packaging, etc.) and product sales, the determination of the strategy for the traditional industries development, the creation of a unified quality assessment system. Scientists S. Singh & N. Bharti (2023) hold the same opinion, who claim that certification by geographical origin will contribute to the stable development of the region and social cohesion of small rural communities, will ensure the preservation of unique natural resources.

It was also proved during the research that using GI has a social aspect. The use of traditional technologies for goods production and the significant influence of the human factor and mentality on the production process contribute to preserving the cultural identity of a certain area. The expansion of traditional production contributes to the increase in the number of jobs, the development of other related industries, in particular, tourism. Such influence is widely studied by scientists. In particular, H. Pamukçu *et al.* (2023) examined the positive impact of GI products on the social and cultural and economic development of certain regions of Turkey, noted that in the regions of GI products production during post-pandemic period the development of gastrotourism is observed, the interest of the local population in their culture and traditions is growing.

It is worth noting the interest of Ukrainian scientists in researching the influence of GI products on the development of ecotourism. L. Matviichuk *et al.* (2023) in their work not only studied the development of eco- and gastrotourism in the EU countries, but also developed mechanisms for the formation of tourist routes on the basis of the Ukrainian tourism system, which will contribute to the support of the Ukrainian producer, the presentation of certain regions of Ukraine, and the activation of domestic tourism in Ukraine.

Undoubtedly, the use of GI is beneficial for consumers. Such indications on the marking are usually a guarantee of high product quality, which ensures the possibility of a correctly realised choice of the product by the consumer. If Ukrainian consumers still do not associate GI marking with quality, consumers in European countries prefer GI products when choosing products. Such results were established by Hungarian scientists Á. Török *et al.* (2022), they investigated the influence of GI marking on the choice of local products, finding that the vast majority (65%) of consumers are willing to pay a higher price for GI-labeled products, perceiving them as high-quality products.

However, the implementation of GI has a number of problems. The main one is the significant costs of registering a geographical indication, compliance with the requirements of traditional production. Strict registration rules lead to the exclusion of some products from the registers of protected GI products and the gradual refusal of manufacturers to register products according to their origin. Taking into account these problems, the question of the need to reform the system of geographical indications arises. B. Calabrese (2023) examines in detail proposals for reforming the system of geographical indications in the EU. In particular, he points to the

need to observe clear rules regarding the registration of alcoholic beverages and food products and the implementation of origin registration scheme for industrial goods, traditional crafts. The necessity of reforming the European system of geographical indications is also considered by X. Song (2024), who questions the objectivity and legality of origin certification by private rather than public organisations.

S. Joosse (2021) states that the implementation of the geographical indications system needs to provide some flexibility when following traditional technologies. Sometimes traditional technologies are quite inefficient, resource-consuming and non-ecological. Therefore, when developing new GI products, it is necessary to try to maintain a reasonable balance between sustainable traditions and innovations.

Another obstacle to using GI is the need for coordinated cooperation of different manufacturers, who often see each other as competitors. The creation of regional or branch unions of producers often leads to excessive organisational and bureaucratic costs, uneven representation of the producers interests. A. Bonanno *et al.* (2020) give thorough recommendations on ensuring the effective activity of producer unions; emphasise the necessity to coordinate actions on compliance with the traditions of product cultivation and production, cooperation in the direction of creating unified laboratory complexes for checking product quality. In order to improve the functioning the geographical indication systems, it is necessary to reduce the bureaucratic influence on the process of GI products registration. The registration process should be as transparent and clear as possible, carried out by independent, disinterested organisations.

For effective use of GI, it is necessary to ensure full access to the required information. Moreover, such information should be provided to both producers and consumers. M. Hofmeier *et al.* (2023) point out that sometimes producers, with the aim of obtaining higher profits, try to register their product as "protected by denomination" without understanding or not knowing what responsibility rests on them. Wide information about trade advantages, requirements for the quality of protected products, the level of responsibility for compliance with traditional technologies relies on the state management system. The problem of lack of information also affects consumers, who in the vast majority do not orientate themselves in GI systems. A. Goudis & D. Skuras (2021) studied the level of European consumers awareness regarding GI marking and found that from 5 to 35% of consumers understand the gradation systems of geographical indications (from 5% in Denmark to 35% in France).

It is worth noting that scientists do not consider the issue of reforming the GI system in Europe, in particular, regarding the registration of industrial goods of traditional manufactures. These issues are important for Ukraine, because there are many centers of traditional folk crafts on its territory, and authentic products have significant export potential.

Conclusions

Geographical indications are one of the modern drivers of international trade. The use of geographical indications links products to local heritage, tradition and reputation, offering a guarantee of origin and special characteristics. Consumers are often willing to pay a higher price for GI-certified products. The production of goods protected by geographical origin increases the reputation and value of local products and supports local businesses. Marketing and promotion of such products creates a positive image of the product in the minds of consumers and often contributes to the economic development of the entire region of origin. Thanks to the collective action required by the management and promotion of geographical indications, local producers have more opportunities to sell their local products abroad. This increases the international prestige of the region and stimulates the development of tourism.

The close connection between products and their geographical origin emphasise the need to preserve local natural resources, without which long-term production would be impossible. Producers of traditional products are particularly motivated to use environmentally sustainable production methods and contribute to the sustainable development of the region.

However, geographical indications have both their advantages and disadvantages, which lead to the trade barriers. The main problem is the significant costs for geographical indication registration, compliance with traditional production. Strict regulations on traditional production methods can inhibit innovation, leading to higher costs of producing a GI product. Value assignment and power asymmetry, lack of information and consumer mistrust of labeling are other barriers that are quite difficult to overcome.

However, despite the shortcomings, geographical indications have significant prospects for use in Ukraine, in particular, with a wider access of Ukrainian goods to European markets. Therefore, it is necessary to develop and implement a clear and understandable registration system of goods with geographical indications, to conduct merchandising and sociological studies on the effectiveness of such products introduction, economic studies on economic expediency.

Further research could be directed at finding ways to reduce costs associated with GI registration, especially for small producers and regions with limited resources. This may include simplification of procedures and governmental support. It is also worth considering the question of Ukrainian consumers' trust in the marking GI goods, since this issue has not been investigated before.

Conflict of interest

None.

Acknowledgements

None.

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Системи географічних зазначень товарів: досвід ЄС та України

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Анотація. Товари з географічним зазначенням є важливою складовою світової економіки, вони мають вплив на соціокультурний розвиток, сприяють збереженню природних, культурних ресурсів регіонів, тому їх вивчення є актуальним. Метою дослідження є порівняння систем товарів географічних зазначень в ЄС та Україні, визначення динаміки становлення та переваг функціонування цієї системи в Україні. Здійснено аналіз літератури про географічні зазначення у різних галузях; досліджено нормативну базу, яка регулює географічні зазначення в конкретних країнах, регіонах; ефективність правових механізмів захисту географічного зазначення; економічні наслідки застосування географічного зазначення для регіональних ринків. Встановлено, що введення географічного зазначення має переваги: дозволяє визначити місце виробництва товару, забезпечити його якість, унікальність; сприяє розвитку та підтримці місцевих економік, традиційних галузей виробництва; захищає, підтримує традиційні методи виробництва, рецептури та інші аспекти культурної спадщини, пов'язані з конкретним регіоном; надає споживачам додатковий рівень довіри до товару. Ці аспекти сприяють розвитку міжнародної торгівлі, створюють умови для чесної конкуренції, сприяючи інноваціям та захищаючи інтереси виробників та споживачів. Дослідження показують, що виробники, які мають географічне зазначення, можуть зазнавати позитивного впливу на свої ринки через підвищену цінність їх товарів. Зазначено, що введення географічного зазначення може сприяти збереженню, підтримці традиційних методів виробництва та культурної спадщини. Аналіз практики реєстрації, захисту географічного зазначення в різних країнах дозволяє виявити недоліки та можливості для поліпшення законодавства та процесів. Дослідження вказують на те, що споживачі вважають товари з географічним зазначенням більш привабливими та довіряють їм через асоціації з конкретним регіоном. Вивчення міжнародного аспекту географічного зазначення дозволяє зрозуміти, як використання цього інструменту впливає на міжнародну торгівлю та економічні відносини. Результати досліджень сприяють виробленню рекомендацій для політик, удосконаленню практики реєстрації та захисту географічного зазначення, а також розширенню розуміння важливості цього інструменту для розвитку різних галузей та регіонів

Ключові слова: товари захищеного походження; країна походження; продукти харчування; сталий розвиток; традиційне виробництво; маркування

COMMODITY BULLETIN
Journal homepage: https://c-bulletin.com.ua/en
DOI: 10.62763/ef/1.2024.76

Article's History: Received: 03.01.2024 Revised: 13.03.2024 Accepted: 26.04.2024

Vol. 17, No. 1, 2024, 76-82

UDC 633.11–026:664.641:664.013:005.936.41

Development of flour-based confectionery products with increased nutritional value based on triticale flour

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Abstract. The relevance of the research is in the potential use of triticale with increased protein and mineral content to expand the ingredient base of flour confectionery products technology. The aim of the study was to investigate the quality indicators of flour confectionery products, specifically sponge cakes, in recipes of which wheat flour was replaced with triticale flour and whole milk powder as a protein enricher. Using statistical methods to analyse experimental data, samples of each type of product with different concentrations of whole milk powder (ranging from 5 to 25%) were examined. It was concluded that the developed sponge cake recipes provide a degree of satisfaction for the average daily intake of iron – 29.21%, calcium – 95%, potassium – 40%, magnesium – 50%, phosphorus – 100%, and more; B-group vitamins – 18-80%. Compared to the control sample, the biological value is increased to 71%; the energy value is reduced by 426 kJ. The absence of egg melange in the developed product recipes allows for a 97% reduction in cholesterol content, categorising these products as dietary. The best samples and optimal dosages of whole milk powder were determined: 15% by the weight of flour during sponge cake production. The functional purpose of triticale flour was theoretically and practically confirmed, yielding new results on the dependence of dough structure formation process on technological production parameters and recipe components. A recipe for sponge cakes of increased nutritional and biological value based on triticale flour has been developed, involving the addition of enrichers such as whole milk powder and the exclusion of egg melange from the recipe. The obtained results can be utilised in the confectionery industry to create new products that meet modern trends in nutrition and cater to consumers who value higher nutritional content and healthy food composition

Keywords: sponge cakes; winter triticale; quality; functional product; expert analysis

Introduction

Flour confectionery products (FCPs) are among the most popular items, as they are purchased by nearly the entire population of Ukraine, the majority consume them on a regular basis, often at least once a week. Due to their high demand among the population, FCPs are perspective targets for enrichment with functional ingredients. In the quest to expand the ingredient base in the technology of flour confectionery products, one of the perspective crops is triticale, known for its increased content of complete protein, making the

Suggested Citation:
Taraimovych, I., & Lobanova, S. (2024). Development of flour-based confectionery products with increased nutritional value based on triticale flour. *Commodity Bulletin*, 17(1), 76-82. doi: 10.62763/ef/1.2024.76.

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product more nutritious, as well as its rich mineral content, including essential elements like iron, magnesium, and zinc, crucial for consumers' health, and its high resistance to fungal diseases.

Studies by S.A. Bazhay-Zhezherun & L.V. Bereza-Kindzerska (2020) and V. Liubych *et al.* (2021) in the food industry are aimed at substituting wheat flour with new alternatives from resilient sources to combat a range of illnesses in the population. Celiac disease, wheat allergy, and gluten sensitivity are among the most common diseases associated with gluten content in wheat. Literature analysis regarding the protein value and amino acid composition of flour products has revealed significant deficiencies in three crucial essential amino acids – lysine, threonine, and methionine – in wheat flour products. According to S.A. Bazhay-Zhezherun *et al.* (2022), alongside the imbalance of essential amino acids in flour products, there is a sharp disproportion in their ratio with non-essential amino acids. Thus, scientific research aimed at finding suitable alternatives by introducing new ingredients is relevant and meets consumers' needs.

Of particular interest is the application of triticale flour instead of wheat flour in FCP technology. Firstly, triticale differs by having a higher content of the essential amino acid lysine per gram of protein, a high content of riboflavin, thiamine, certain macro- and microelements, and secondly, it possesses better technological properties for these types of products, as it contains less weak gluten (Fraś *et al.*, 2021).

Research on triticale grain and its application in processing and food industries has been ongoing in Ukraine and abroad for a long time. However, the use of triticale flour specifically in FCP production has been poorly studied. Despite positive experiences with triticale research as a component of animal feed, flour for bakery products, and its wide application, this crop has not gained traction. Additionally, the most perspective and optimal triticale varieties in terms of technological process management for flour production have not been fully investigated, nor their milling and baking properties (Aprodu *et al.*, 2019; Aragüez *et al.*, 2020).

One of the main factors restraining the growth of triticale grain production volumes of new varieties in Ukraine is the lack of clear recommendations for the final use of its processing products. The advantages of triticale grain as a biologically valuable raw material for the food industry are underestimated. Existing triticale flour production technologies do not fully exploit the potential of the n due to the scarcity and inconsistency of recommendations regarding the organisation and management of its processing technology (Hospodarenko *et al.*, 2019).

The market for flour confectionery products (FCPs) in Ukraine is expanding with each passing year. This development is not only characterised by an increase in the diversity of product offerings but also by an active expansion of assortments, particularly in the case of sponge cakes. Manufacturers are increasingly introducing a rich variety of flour confectionery products to the market. This trend reflects the growing interest of modern consumers in product variety and their desire to explore new tastes and combinations. Such an approach by manufacturers stimulates demand for flour confectionery products and contributes to the overall competitiveness of the Ukrainian market. The aim of this article was to analyse, develop, and scientifically substantiate the technologies for enriched flour confectionery products by refining the technological process of producing sponge cakes from triticale flour and enrichers.

Materials and methods

The object of study in this article was the process of manufacturing high-nutritional-value sponge cakes based on triticale flour with the addition of non-fat dry milk as a protein enricher. The methodological basis of the research, conducted at Lutsk National Technical University during 2022-2023, involved a comprehensive approach to solving tasks related to the development of technology for flour confectionery products based on triticale flour and enrichers to obtain products of increased nutritional value, modern physicochemical methods of raw material, semi-finished product, and product analysis, and mathematical processing of experimental data.

The quality assessment of triticale flour was conducted based on organoleptic and physicochemical parameters (Table 1).

Table 1. *Triticale flour quality indicators*

Indicator	Value of indicators
Organoleptic	
Colour	White with yellowish tint
Taste	Peculiar to triticale flour, without foreign taste
Crispiness	Is not detected
Physical and Chemical	
Moisture, %	13.9
Mass fraction of crude, %	16.4
Falling number, "FN", s	321
Metal and magnetic impurities, mg per 1 kg of flour	Absent
Infection by pests	is not found

Source: *developed by the authors based on the sources of A. Fraś et al. (2018), V. Liubych et al. (2022)*

Scheme for the production of sponge cakes is presented in Figure 1.

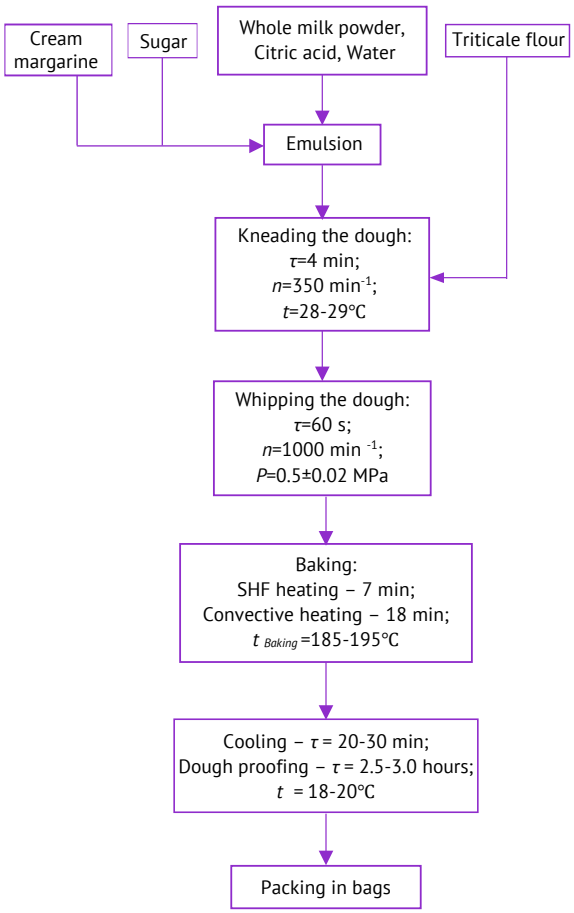

Figure 1. *Structural scheme for the production of sponge cakes from triticale flour*
Source: *developed by the authors*

To prepare the experimental samples of sponge cakes, mixing was carried out with triticale flour and a solution containing reconstituted whole milk powder, citric acid, and water, resulting in a dough with a moisture content of 40% for 2 minutes. Then, sugar was added, and the dough was further mixed for 1 minute. Subsequently, cream margarine was added, and mixing of the dough continued for another 1 minute. The total mixing time amounted to 4 minutes (Table 2).

Table 2. *Sponge cake recipe from triticale flour and whole milk powder*

Name of raw material	Consumption of raw material
Triticale flour, kg	370.0
Sugar, kg	330.0
Cream margarine, kg	150.0
Whole milk powder, kg	150.0
Citric acid, kg	2.0
Flavouring agent-vanillin, kg	0.3
Water, kg	According to calculations
Product output	1000.0

Source: *developed by the authors*

After the mixing process, the dough is unloaded, and dough pieces weighing 300-350 g are formed from it. Then the dough in the molds is heated to 100°C using microwave heating for 7 minutes and baked at a temperature of 185-195°C using convective heating for 20 minutes. After baking, the finished sponge cakes are cooled to a temperature of 30-35°C on a conveyor directly from the oven. This method of cooling prevents product deformation. In the first 3 minutes, the sponge cake cools without forced air circulation, and in the next 3 minutes, with forced air circulation at a speed of 3 m/s. After this, the sponge cake is packaged.

To obtain recommendations regarding the dosage of whole milk powder in this technology, the effect of different dosages of non-fat dry milk on the quality indicators of the dough and finished sponge cakes made from triticale flour was studied. The research included studying the effect of various concentrations of whole milk powder on the texture of the dough, crispiness, structure, and taste of the finished sponge cakes. Various ratios between triticale flour and whole milk powder were used, as well as control samples with different dosages. Based on the research results, optimal dosages of whole milk powder will be recommended to achieve the best quality indicators of the dough and sponge cakes. This approach will improve the production process and ensure stable product quality. During the research, whole milk powder (WMP) was added in dosages ranging from 5 to 25%, and quality indicators of the dough and finished sponge cakes were determined.

Results and discussion

To develop a competitive technology for producing sponge cakes with increased nutritional and biological value, it is necessary to search for new inexpensive raw material sources – enrichers and to improve the processes of dough preparation. The selection of raw materials and enrichers is based on their positive impact on the human body.

WMP is a source of animal proteins and contains all the necessary minerals and vitamins essential for human life, present in an ideally balanced, easily absorbable form. Cream margarine has the best emulsifying ability and is suitable for use in sponge cake recipes. Citric acid acts as an acidity regulator, a preservative for food products, and improves metabolism, which can positively affect weight loss. The justification for the choice of raw materials and enrichers used in sponge cake production confirms their potential for obtaining new products enriched with essential nutrients.

Upon analysing the chemical composition of the raw materials and enrichers, it should be noted that the selection of this type of raw material is expedient for the development of sponge cake technology, as it reduces sugar content and increases nutritional and biological value. The biologically active substances present in the aforementioned raw materials have a favourable effect on human body processes. Considering the presence of

a protein fraction in dry milk, it acts as an emulsifier and accelerates the foaming process. The data from the conducted research are presented in Table 3.

Table 3. *The effect of the introduction of milk powder on the quality of dough from triticale flour*

Name of indicator	Value of indicators in the samples with the introduction of milk powder, %				
	5	10	15	20	25
Bulk weight, g/cm^3	0.65	0.59	0.53	0.56	0.54
Titrated acidity, degrees	1.73	1.72	1.75	1.82	1.80

Source: *developed by the authors*

Adding milk powder in the amount of 5-25% has been found to reduce the volume mass of the dough due to the lactose in milk, which inhibits the foaming process but stabilises the foam. It has been determined that milk powder acts as an adsorbent, binding water and contributing to increased dough viscosity. Experimental samples of biscuits with this enrichment agent differed by having a smooth surface, absence of ruptures and cracks, with uniformly thin porosity. This can be explained by the increase in dough viscosity and the decrease in pressure inside the bubbles. Studies have shown that the application of WMP improves the organoleptic and physicochemical quality indicators of products (Table 4).

Table 4. *The effect of the introduction of whole milk powder on the quality indicators of sponge cake from triticale flour*

Name of indicator	Value of indicators in the samples with the introduction of whole milk powder, %				
	5	10	15	20	25
Organoleptic					
Shape	Corresponds to the form in which baking was carried out				
Surface	Smooth, not burnt				
Colour	Brown				
Crumb condition					
Baked condition	Baked				
Porosity	Fine homogeneous				
Taste and smell	Weakly expressed, peculiar to the given kind of product		Strongly expressed, peculiar to the given kind of product		
Physical and Chemical indicators					
Moisture, %	24	27	29	30	32
Porosity, %	58	74	62	78	82
Specific volume, cm^3/100 g	178	184	188	180	186

Source: *developed by the authors*

Following the conducted research, the optimal dosage of WMP at 15% has been established, leading to an improvement in biscuit quality across all indicators, based on which a recipe for triticale flour biscuits has been developed. In their work, author F. Zhu (2018) summarises the latest achievements in the nutritional composition and diverse utilisation of triticale in food products. The author also identifies that the chemical composition of triticale flour is highly diverse, indicating the potential of triticale as an alternative to whole grain flour in food and beverage production. Schemes for processing triticale grain into high-quality baking flour have been developed and analysed by authors I. Piazza *et al.* (2023) and J. Kaszuba *et al.* (2024), confirming the quality of the final product obtained in this study. Analysis of the chemical composition of grain, flour, and bread of various triticale varieties conducted by S.A. Siddiqui *et al.* (2022) demonstrates that grains of some modern triticale varieties with favourable chemical composition from a technological and nutritional perspective are suitable raw materials for flour and bread production, affirming the potential use of triticale flour in biscuit production. F. Eudes (2015) investigated triticale considering the influence of biotechnological factors crucial for agriculture, feed cultivation, food production, and industrial applications.

Flour-based confectionery products, traditional in many countries, are deficient in micronutrients and vitamins. Enhancing their nutritional and biological value can be achieved by fully or partially replacing wheat flour with triticale, rich in all necessary nutrients, as indicated by the research of S.V. Vasiliev (2018) and A.V. Sachko *et al.* (2020). According to some scientists, its application, due to the low gluten content, is possible for a limited range of confectionery products (sugar, oat, coconut, and chocolate cookies). Particularly, the study by V. Liubych *et al.* (2021) examined the quality formation of cupcakes made with triticale (baking, settling, moisture, volume, porosity), enriched with pumpkin paste. This study confirmed the feasibility of using triticale for the production of gingerbreads, cookies, muffins, and biscuits, as well as the influence of pumpkin paste on product quality. A. Fraś *et al.* (2018) developed a new healthy triticale-oat bread by replacing as much wheat flour as possible with a high-fiber triticale-oat concentrate without compromising the technological quality of the bread, resulting in a food product with high fiber content (over 6 g per 100 g) and increased levels of dietary fiber. A. Torbica *et al.* (2019) investigated the rheological properties of a mixture of whole wheat and whole grain triticale flour for pasta production and provided optimal ratios for obtaining high-quality

flour blends. Authors S. Kalnina *et al.* (2015) studied the rheological characteristics of mixed compositions of wheat and triticale flour for use in pasta production, demonstrating that an increase in whole grain flour deteriorates the rheological properties of the dough. Research by H. Woś & W. Brzeziński (2015) allowed for the identification of biologically activated triticale grain as a source of valuable nutrients and its potential use in creating functional pastry mixtures.

In the works of H. Woś & W. Brzeziński (2015), A.V. Zagrychanska & V.Ya. Golyuk (2021), various plant additives and malt flour are used as enrichments to obtain bakery products with increased nutritional and biological value from triticale flour. Products obtained using plant-based additives are of interest in terms of their chemical composition and may be considered therapeutic and prophylactic products. In this study, the following ingredients were chosen as enrichments for the development of triticale flour biscuits: triticale flour, WMP, cream margarine, and citric acid.

Therefore, the use of WMP in the recipe for triticale flour biscuits resulted in a product of functional purpose with excellent taste quality. This is because milk lactose, which inhibits the growth of harmful bacteria, promotes the maintenance of healthy gut flora and stimulates better absorption of micro- and macro-elements in its walls. The nutritional value of the product was determined based on a combination of properties. Their presence indicates the satisfaction of human physiological needs for necessary substances and energy. The main characteristic of the nutritional value of the product is its chemical composition (proteins, fats, carbohydrates, vitamins, macro- and microelements). At the same time, its consumption in commonly accepted quantities is taken into account, as well as its energy and biological value.

To determine the nutritional and biological value, as well as the degree of satisfaction of the daily human nutrient requirements, the chemical composition of the obtained triticale flour biscuits per 100 g was calculated (Table 5).

Table 5. *Degree of satisfaction of the daily human nutrient requirements*

Name of component	Daily requirement	Value of indicator in finished products per 100 g			
		Sponge cake from wheat flour	Degree of satisfaction, %	Sponge cake from triticale flour	Degree of satisfaction, %
Proteins, g	75	9.9	13.2	11.6	15.5
Fats, g	83	25.1	30.2	20.6	24.8
Carbohydrates, g	365	44.56	12.2	46.1	12.6
Dietary fiber, g	30	11.5	38.3	13.3	44.3
Minerals, mg:					
Potassium	3500	325.5	9.3	1470	42
Calcium	1000	43	4.3	1062	106.2
Magnesium	400	40.8	10.3	206	51.5
Phosphorus	1000	215	21.5	1610	161
Iron	14	4.7	33.6	3.4	24.3
Vitamins:					
E, mg	10	5.21	552.1	0.9	9
C, mg	70	–	–	–	–
B_6, mg	2.0	0.45	22.5	0.73	36.5
B_3, mg	20	0.58	2.9	3.6	18
B_2, mg	1.8	0.5	27.8	1.5	83.3
B_1, mg	1.5	0.4	26.7	0.65	43.3
Amino acids:					
Valine	2500	880	35.2	1822.5	72.9
Isoleucine	2000	690	34.5	1812	90.6
Leucine	4600	1283.4	27.9	2539.2	55.2
Lysine	4100	4679.7	11.7	1836.8	44.8
Methionine	1800	423	23.5	1054.8	58.6
Threonine	2400	508.8	21.2	1567.2	65.3
Tryptophan	800	144.8	18.1	507.2	63.4
Phenylalanine	4400	1130.8	25.7	3291.2	74.8
Biological value, %		57.55		71	
Energy value, kcal/kJ	2500/ 10475	598.8/ 2508.9	23.9	497/ 2079	19.9

Source: *developed by the authors*

Upon analysing the chemical composition of biscuits made from triticale flour, certain differences were observed compared to products made from wheat flour. As evident from the data, the content of B-group vitamins

(B1, B2, B3, and B6) increases compared to control samples, indicating an improvement in their nutritional and biological value. However, vitamin E shows a significant decrease due to the absence of egg melange in the composition. Additionally, an elevated content of mineral elements such as calcium (Ca), phosphorus (P), magnesium (Mg), and potassium (K) was noted in sponge cakes made from triticale flour with the addition of WMP. This indicates an increase in the satisfaction level of human daily nutrient requirements for minerals. Such changes in the composition of sponge cakes may affect their nutritional value and usefulness for the body.

Conclusions

Studying the technologies of using triticale flour, with its increased protein and mineral content, is relevant for expanding raw material ingredients in the production of flour-based confectionery products. The research focused on studying the quality indicators of sponge cakes made from triticale flour with the addition of whole milk powder, which acted as a protein enricher. The conducted studies indicate the feasibility of using triticale flour in the production of flour-based confectionery products, as it allows for obtaining high-quality products with increased protein value and vitamin content, particularly B-group vitamins, macro- and microelements. According to the obtained results, it has been proven that triticale flour can be used to replace higher-grade wheat flour in biscuit production. All samples made from mixtures of triticale flour with varying proportions of whole milk powder, as well as those made from 100% triticale flour, had excellent appearance. The addition of whole milk powder in amounts of 5-25% resulted in a decrease in the volume of dough, and these biscuit samples had a smooth surface and uniform porosity. Using triticale flour instead of wheat flour provides sponge cakes with high sensory characteristics, higher nutritional and biological value due to increased vitamin, macro- and microelement content, protein, and essential amino acids. Protein biological value analysis revealed that sponge cakes made from triticale flour have two times higher scores for threonine and valine, and four times higher scores for isoleucine, lysine, and tryptophan, providing significant consumer advantages to the resulting product.

A priority direction for further development of technological processes in the production of flour-based confectionery products is the search for technologies to produce products with increased nutritional and biological value using non-traditional types of flour and enrichers, which will expand the range of functional food products in general.

Conflict of interest

None.

Acknowledgements

None.

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Розроблення борошняних кондитерських виробів підвищеної харчової цінності на основі борошна тритикале

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Анотація. Актуальність дослідження полягає у можливості використання тритикале з підвищеним вмістом білка та мінеральних речовин, для розширення інгредієнтів сировинної бази технології борошняних кондитерських виробів. Метою роботи було дослідження показників якості борошняних кондитерських виробів, зокрема бісквітів, в рецептуру яких було внесено шляхом заміни борошно тритикале та сухе незбиране молоко в ролі білкового збагачувача. За допомогою методів статистичної обробки експериментальних даних було проведено аналіз зразка кожного виду виробу з різною концентрацією сухого незбираного молока (дозування від 5 до 25 %). Зроблено висновок, що розроблені рецептури бісквітів забезпечують ступінь задоволення середньодобової норми споживання заліза – 29,21 %, кальцію – 95 %, калію – 40 %, магнію – 50 %, фосфору – 100 % і більше; вітамінів групи В – 18-80 %. У порівнянні з контрольним зразком біологічна цінність підвищується до 71 %; енергетична цінність знижується на 426 кДж. Відсутність яєчного меланжу в рецептурах виробів, що розробляються, дає можливість знизити частку холестеролу на 97 %, і віднести ці вироби до групи дієтичних продуктів. Було визначено найкращі зразки та оптимальні дозування сухого незбираного молока: 15 % до маси борошна під час виробництва бісквітів. Теоретично та практично підтверджено функціональну спрямованість борошна тритикале, отримано нові результати залежності процесу структуроутворення тіста від технологічних параметрів виробництва та рецептурних компонентів. Розроблено рецептуру бісквітів підвищеної харчової та біологічної цінності, на основі борошна тритикале, що передбачає внесення збагачувачів, зокрема незбираного сухого молока та виключення з рецептури яєчного меланжу. Отримані результати можуть бути використані в кондитерській промисловості для створення нових продуктів, які відповідають сучасним тенденціям у харчуванні та споживачам, що цінують вищу харчову цінність та здоровий харчовий склад

Ключові слова: бісквіти; тритикале озиме; якість; функціональний продукт; експертний аналіз

COMMODITY BULLETIN
Journal homepage: https://c-bulletin.com.ua/en
DOI: 10.62763/ef/1.2024.83

Article's History: Received: 15.11.2024 Revised: 28.02.2024 Accepted: 26.04.2024

Vol. 17, No. 1, 2024, 83-91

UDC 691.12

Promising areas for the use of industrial hemp for the manufacture of sheet building materials

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Abstract. The relevance of the study is to identify the potential for creating innovative building materials that can improve the quality and efficiency of construction and furniture production. The purpose of the study is to analyse the market of sheet building materials, explore the possibilities of using plant materials in construction and furniture industry, and compare the properties of the latest building materials with the existing ones. The analysis of literature sources included a search and evaluation of new developments in the construction industry, as well as an analysis of statistical data on the production of architectural materials in Ukraine, using information resources and Internet search services. To evaluate the consumer properties of innovative building materials, the author used quality assessment methods using visual perception and special tools, in accordance with the established regulatory documentation. Important issues aimed at using resource-saving technologies in construction and developing the latest (environmentally-friendly) building materials are considered. The current state of the Ukrainian market of building sheet materials and the properties of industrial hemp are investigated in order to determine the most cost-effective use of hemp raw materials as an effective basis for the creation of building materials for various purposes. The suitability of the raw materials was determined and assessed, experimental samples of chipboards with different fillers were obtained, and the physical, mechanical and aesthetic characteristics of the finished products were investigated. The research will contribute to the development of the hemp processing industry, as well as enterprises that produce goods for various functional purposes from hemp, which will provide conditions for combining the agricultural sector and the construction industry, i.e. building a closed production cycle

Keywords: chipboards; wood fibre boards; density; thermal conductivity; hemp fire; hemp stem; insulation materials

Suggested Citation:

Lialina, N., Zakharchenko, P., & Bondarenko, O. (2024). Promising areas for the use of industrial hemp for the manufacture of sheet building materials. *Commodity Bulletin*, 17(1), 83-91. doi: 10.62763/ef/1.2024.83.

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Introduction

Since the beginning of 2012, the demand for wood and wood waste products from the population, construction and furniture industries has been accompanied by a significant decrease in wood resources. In addition, growing consumer demands for the quality of materials used in home furnishings are driving demand for safer products, forcing manufacturers to introduce the latest technologies to produce environmentally-friendly products.

T. Jami *et al.* (2022) noted that construction is considered one of the most dangerous sectors for the planet – it accounts for 28% of carbon dioxide emissions annually, and in general, buildings generate 40% of the total amount of harmful substances in the course of their existence. That is why considerable attention has been paid to the search for and use of environmentally-friendly building materials since the 1990s and as of 2024. There are two main areas that can reduce the negative impact on the environment and help preserve wood resources. These studies are aimed at optimising existing technologies and developing new resource-saving technologies for the production of innovative building materials. Therefore, research into the possibilities of using industrial hemp as an alternative raw material for the production of building materials is quite important and relevant.

The study by E.M. Tudor *et al.* (2020) focuses on the development of materials that can meet consumer requirements for heat, noise and other types of insulation and can also be considered environmentally-friendly. Hemp-based composite materials are an important alternative for the construction sector. These materials are considered environmentally-friendly, they contribute to the energy efficiency of buildings, absorb carbon dioxide and reduce pollutant emissions during the production process, while generating limited waste (Liu *et al.*, 2023).

Among all industrial crops, hemp attracts special attention due to its agro-technological and technical properties, as it is one of the most stable and fastest-growing agricultural plants. R. Grigorov *et al.* (2022) argue that it can be harvested twice a year, so it is twice as effective in reducing the greenhouse effect. During its growth, industrial hemp absorbs 8 to 15 tonnes of CO_2 per hectare of crop. In comparison, forests typically absorb between 2 and 6 tonnes of CO_2 per hectare per year, depending on the number of years of growth, climate region and tree type.

The search for resource-saving building technologies has become an important area of innovation in the construction sector. Natural building materials, such as wood, industrial hemp and clay, have proven their quality and durability in buildings that meet modern requirements for a healthy indoor environment (Barbhuiya & Das, 2022).

Modern research by scientists confirms that hemp is an excellent filler in composite materials for thermal insulation and the manufacture of chipboards. The source UBC students build near-zero carbon hempcrete building on vancouver campus (2023) confirms that the use of hemp aggregate for concrete mixtures began in France in the 1980s to replace adobe (mixed clay, sand and straw) for wall cladding. The introduction of the latest construction technologies in Europe through the use of plant materials has expanded the possibilities of using industrial hemp.

Studies conducted by P. Bouloc *et al.* (2023) show that almost the entire hemp stem can be used to produce a variety of building materials. Hemp fibre is an alternative substitute for synthetic fibres for the manufacture of insulation materials, and hemp is used to produce lightweight concrete and plastering solutions. Insulation materials, which are widely used in construction, improve the energy efficiency of a building and provide comfortable indoor conditions.

In the works of S.M.Q. Bokhari *et al.* (2021), J. Liao *et al.* (2022) noted that hemp has quite good acoustic and insulating properties, but the issue of maintaining these properties, as well as chemical resistance and compatibility with various adhesives during the production process, is crucial. In addition, the mechanical properties of hemp raw materials, such as particle size, density, thickness and shape, depend on the morphological structure of the stem. Therefore, these material parameters are important characteristics that are taken into account in the production of construction products and determine their performance properties.

The purpose of the article was to study the existing technologies for the manufacture of facing, insulation and composite materials based on plant-based raw materials, analyse the market for harvesting wood raw materials and producing chipboards in Ukraine, and determine the suitability of hemp raw materials for the production of sheet building materials.

Materials and methods

The study to assess the quality of raw materials to obtain experimental samples of chipboards and their physical and mechanical properties was conducted in the laboratory at the Kyiv National University of Construction and Architecture during 2019-2023. Different types of raw materials were used to make the samples: straw (unprocessed stem) and hemp bark, as well as wood chips. The raw materials were prepared by grinding, sorting into fractions, and drying to a moisture content of 6-8%. The suitability of the raw materials can be determined by their properties (homogeneity and moisture content) using organoleptic methods and instrumental evaluation. Uniformity was determined by visual and touch assessment using DSTU ISO 6658:2005. Sensory testing. Methodology. General guidelines (2006), DSTU 4922:2008. Timber and sawn timber products. Methods for determining moisture content (2009).

In order to substantiate the feasibility and possibility of replacing wood with plant-based raw materials, namely industrial hemp, a comparative analysis of the mechanical properties of prototype samples of boards made on the basis of wood chips, hemp stalk and bark was carried out. The prototypes of wood chip and hemp boards were manufactured using the hot pressing technology, the essence of which is to keep the prepared samples at high temperatures (120°C-180°C) under a pressure of 3.5-5 MPa and subsequent holding in chambers for 8-1 hours to reduce shrinkage and level the moisture level. In Germany, almost 95% of all chipboards are produced using this method and it is called "flat pressing" (Baraboi *et al*., 2019).

To make the 200x200 mm specimens, 285 g of chopped hemp bark, stem or wood shavings were used, pre-dried to a moisture content of no more than 8%. The prepared raw materials were mixed with the adhesive solution, after which the samples were moulded and compacted using a hand press and finally baked in a hot press.

The research included a search and analysis of relevant scientific sources on innovations in the construction sector. Statistical data on the production of sheet materials in Ukraine were researched using various information resources and Internet search services. To study the consumer properties of innovative building materials, such as thickness, density, bending strength, water absorption and aesthetic indicators (surface condition and colour), organoleptic and instrumental evaluation methods were used, using the regulatory documentation DSTU EN 309-2003. Particleboard. Definition and classification (EN 309:1992, IDT) (2005), DSTU EN 311:2003. Particleboards. Surface strength of particleboards. Test methods (2005), DSTU B EN 12087:2016. Thermal insulation products for construction purposes. Determination of water absorption during prolonged immersion (EN 12087:2013, IDT) (2016), DSTU EN 312:2018. Particleboard. Technical requirements (EN 312:2010, IDT) (2018).

The research complied with all the standards set out in the Convention on Biological Diversity (1992) and the Convention on International Trade in Endangered Species of Wild Fauna and Flora (1979).

Results and discussion

Economic growth, changes in consumer values, a greater awareness of social welfare and environmental issues, and evolving tastes are the main factors driving demand for woodworking and construction products. Awareness of environmental issues and consumer expectations regarding the quality and safety of goods are becoming more pronounced, prompting the development of specific requirements for the construction and furniture market.

An important factor driving the revision of technologies and the use of raw materials is the growing role of efficient use of renewable resources and waste. Increasing resource productivity and reducing waste are two key strategies for businesses to manage limited resources in the current and future.

The production of sheet wood materials in the world is constantly growing. This production is characterised by large volumes and a high position in the wood products markets. In the group of European countries, the largest share of wood panel production is accounted for by particleboard, with levels ranging from 83.3% in the UK to 57% in Italy (Kirilovs *et al*., 2012; Mirski *et al*., 2017; Hemp blocks for naturally efficient masonry, 2021). Particleboard is the most widely used material in furniture production and construction. The first production of this material began in Bremen (Germany) in 1941 (Nishimura, 2015). The main advantages of chipboard include ease of processing, cost-effectiveness, reliability and high practicality. According to the classification of the State Statistics Service of Ukraine, particleboard construction materials are used for partitioning and are classified under the code "Wood chipboards, unprocessed" (State Statistics Service of Ukraine, 2024).

Modern production technologies ensure high quality and safety of products. Particleboard is made by hot pressing wood chips, which are obtained from industrial wood of various species and waste from woodworking enterprises. During this process, bonding, water-repellent, antiseptic and other substances are added to give the board its special strength and durability.

Among the chipboard producers in Ukraine, there are Ukrainian companies that produce their own product and companies that work on behalf of well-known global brands such as Egger, Swisspan, Kronospan, whose products are supplied to most countries. The quality of board materials produced on high-tech lines (mainly Finnish and German automated conveyor systems) meets stringent European standards in terms of size, technical characteristics, performance, environmental and sanitary and hygienic indicators. The markey analysis and dynamics of chipboard production in Ukraine have undergone significant changes to both internal factors (raw materials, technology, availability of modern equipment) and external factors (COVID-19 and military situation in Ukraine). The dynamics of wood-based production in Ukraine is shown in Figure 1.

As can be seen from the data presented, since 2018, Ukraine has been experiencing a decline in the production of wood-based panels, which is due to the saturation of the market with imported goods and a decrease in the volume of wood harvesting. Thus, according to the State Statistics Service of Ukraine (2024), the volume of wood harvesting for various functional purposes has been gradually decreasing since 2018 (Table 1).

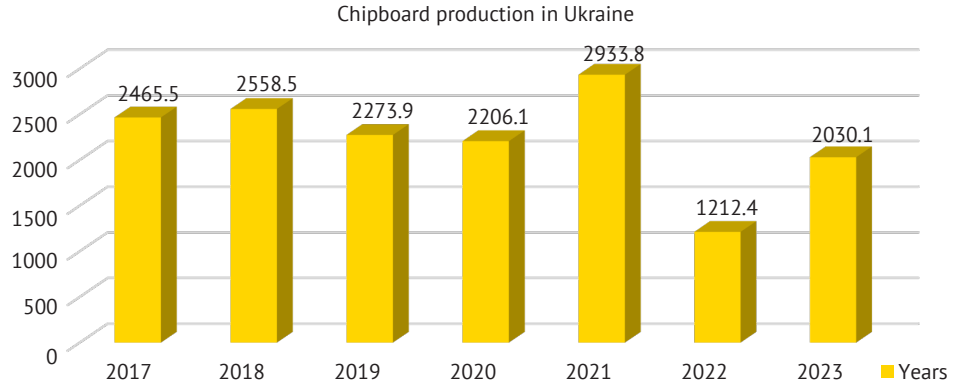

Figure 1. *Dynamics of chipboard production in Ukraine in 2017-2023, thousand m³*
Source: *developed by the authors based on data from the State Statistics Service of Ukraine (2024)*

Table 1. *Timber harvesting volumes in 2016-2023, thousand m³*

Years	2016	2017	2018	2019	2020	2021	2022	2023
The volume of workpiece	22612.8	21923.0	22529.7	20869.6	17826.2	17649.4	15934.3	12396.3

Source: *developed by the authors based on data from the State Statistics Service of Ukraine (2024)*

The data presented in Table 1 confirms the fact that the amount of own wood raw materials in Ukraine is significantly decreasing, while the demand for wood-based products is not decreasing. Therefore, an important issue is the search for alternative local raw materials that can be successfully used for the production of furniture and construction products.

The martial law and hostilities in the south and east of Ukraine have resulted in the suspension or destruction of many construction, processing and furniture companies. A large number of housing units have been destroyed, especially in the frontline areas, and various types of sheet construction materials, such as chipboard, fibreboard and OSB, are most often used to rebuild damaged housing. In order to solve the issue of providing the population with the necessary building materials and preserving our own wood, it is necessary to use plant-based raw materials that are not inferior in their properties to the wood used to make chipboard.

The properties of hemp allow it to be effectively used for the production of sound, vapour and heat insulation materials, which helps to create a special indoor microclimate, suppresses pathogens, fungi and bacteria, while its low cost and the possibility of complete recycling without harming the environment provide additional benefits to new building materials. Industrial hemp is a bast-fibre crop that has high strength and flexibility, which is a very important criterion for use in the production of various types of construction and furniture products. Therefore, the study was aimed at determining the suitability of plant-based raw materials for the manufacture of sheet building materials (SBM) and further evaluation of their consumer properties.

According to the results of the study of the quality of the input raw materials (wood chips, chopped hemp stem and bark), it was found that the presented samples differed significantly in terms of homogeneity, which is explained by the peculiarities of the morphological structure of wood and hemp, as well as the fractional composition. Thus, wood shavings and hemp pellets did not visually differ in homogeneity, although there was a difference in the surface condition of the crushed particles: the pellets, unlike the shavings, had a smoother surface. The raw material, which consisted of chopped hemp stem, was heterogeneous due to the high content of the fibrous part of the stem. The moisture content of the raw material samples was almost the same. The results of the raw material suitability assessment are presented in Table 2.

Table 2. *Raw material quality indicators*

Indicators	Types of input raw materials		
	wood chips	cannabis bonfire	chopped hemp stalk
Homogeneity	chopped wood particles – 25-30 mm thick, 10-50 mm long, golden to brown in colour	all the firewood particles are almost the same size: thickness – 15-20 mm, length – 20-25 mm, colour – light yellow with grey tint	the mixture is heterogeneous, contains wood and fibrous particles that vary in length and thickness, the colour is light yellow with a green tint
Moisture content, %	12	15	15

Source: *developed by the authors*

The results of the quality assessment of the prepared raw materials show (Table 2) that the hemp bark and stem do not differ significantly in fractional composition from wood chips, the differences in colour are not significant, and the humidity will be brought to the normalised level (6-8%) by further drying, which confirms the possibility of using hemp raw materials for the production of particleboards.

The technical characteristics of chipboard depend on the properties of the chips and impurities used in its manufacture, as well as on the thickness and dimensions of the board (Baraboi *et al.*, 2019). The main ones are:

- density;
- strength;
- rigidity;
- water absorption;
- fire resistance;
- environmental friendliness;
- size.

The results of the analysis of the mechanical properties of the experimental samples of slabs obtained from three types of raw materials by hot pressing are presented in Table 3.

Table 3. *Mechanical properties of the prototypes of wood chipboard and hemp chipboard*

No.	Indicators	Chipboard	Hemp chipboard obtained from a fire	Hemp chipboard made from the stem
1	Thickness, mm	15.0	15.0	15.0
2	Density, kg/m^3	670.2	658.6	598.3
3	Bending strength, MPa	6.2	7.1	7.5
4	Water absorption, %	120	135	395
5	Aesthetic indicators, points	5	5	3.5

Source: *developed by the authors*

The results of the studies of the mechanical properties of the experimental samples show that the hemp chipboard made from bark has better bending strength (7.1 MPa) and lower density (658.6 kg/m^3) compared to wood chipboard and bark chipboard, but is better than both samples in terms of strength (7.5 MPa). This is due to the presence of fibrous impurities in the raw material mixture.

The water absorption (after full immersion for 28 days) of the boards differs significantly. For example, the best value is achieved by the chipboard – 120%, which is 15% better than that of the board made from bark (135%), which is explained by the more porous structure of bark and the lower density of the board. As for the sample obtained from the hemp stem, a rather high percentage of water absorption (395%) is observed due to the heterogeneous structure of the prepared mixture and the presence of the fibrous part of the stem.

The aesthetic characteristics of the samples, namely the surface condition (smoothness, roughness, structure) and colour, which were assessed by visual inspection, have the same score for chipboard and bark board. The stem board received a lower score due to its heterogeneous structure and atypical colour (yellow with a greenish tint), but this feature can be corrected in the process of further processing of the board (painting, applying a protective film, etc.).

Theoretical and experimental studies aimed at assessing the suitability of various hemp raw materials for the production of sheet building materials and determining their consumer properties confirm the possibility of using industrial hemp. This paper presents the results of producing plates using only one method – the hot pressing method. Studies conducted by H. Kallakas *et al.* (2018), in which different raw material compositions (hemp trust, hemp bark, and a mixture of wood chips and bark) are used to produce particleboards, proved the possibility of producing different sheet materials – wood chip and fibreboard – by dry and wet pressing, as well as by applying a special type of paper to the surface to improve strength and aesthetics. The authors note that the best bending strength (7 MPa) is achieved by boards made from hemp bark, followed by boards made from wood chips (6.26 MPa). Wood-fibre boards made from hemp resin are significantly inferior in terms of flexural strength, which is 0.31-1 MPa. The water absorption of the board samples also differed. It is noted that the water absorption of wood-based panels from hemp bark is 18% higher than that of wood chips. Wood-fibre boards from hemp residue obtained by dry pressing did not pass the test for water absorption at all – as a result, they dissolved.

B. Abu-Jdayil *et al.* (2022) argue that due to the rapid growth of hemp and the accumulation of large biomass, the possibilities of using this plant are endless. In their work, the authors examined various ways to use composite panels made of hemp bark for insulation and sealing of buildings. The results of the study showed that energy consumption for heating the house decreased by 42%, and the airtightness of the room insulated with hemp panels increased by almost 70%, with heat loss overnight in winter being less than 1°C compared to 9ºC when using typical insulation materials.

B. Martínez *et al.* (2023) studied the influence of various factors on the formation of acoustic and thermal insulation properties of hemp-based materials. The authors note that reducing the particle size of the stem helps to improve the acoustic properties of finished

building products, the optimal particle length is 4-6 mm, and their density of 0.3 g/cm^3 improves thermal insulation performance.

In the production of particleboards and other sheet building materials, phenol-formaldehyde resins are used as an adhesive mixture, which were recognised as carcinogenic by the World Health Organisation in 2004 (World Health Organisation, 2010). Therefore, many manufacturers are facing the issue of replacing them with environmentally-friendly and human-friendly components in the production of chipboard. P. Alao *et al.* (2020) in their work manufactured particleboards from hemp bark using different adhesives: urea-formaldehyde, formaldehyde-free, acrylic and soybean resin on a biological basis. The samples were obtained by hot pressing and their properties were investigated. The results of the study show that hemp boards based on soy resin have the best strength and water absorption characteristics, which can be an alternative to hazardous formaldehyde aggregates.

A.T.M.F. Ahmed *et al.* (2022) note the wide potential of industrial hemp in various industries. The authors paid special attention to the study of methods for the production of composite materials as substitutes for plastic or polystyrene foam. The paper describes several methods of producing and processing composites and compares the mechanical properties of hemp fibre with other plants. The researchers noted that the tensile strength of hemp is 1100 MPa, which exceeds that of the following plants: jute – 800 MPa, ramie – 938 MPa, sisal – 855 MPa, which confirms the possibility of using hemp raw materials in construction, automotive industry, and for roadway reinforcement. In the production of composite materials for the woodworking and construction industries, important criteria for raw materials include not only basic properties, mechanical strength, and possible applications, but also additional characteristics such as microbiological resistance and thermal conductivity (Constantine *et al.*, 2018).

S.L. Lee *et al.* (2022) investigate the chemical composition and physical and mechanical properties of various types of plant material and agricultural waste to produce particleboards. The authors point out that non-wood biomass (leaves, seeds, fruits, stems, straw, husks) should be used for the production of sheet building materials. To this end, it is necessary to study their chemical composition, namely the content of cellulose and lignin, which are valued in wood, as they contribute to the strength and durability of finished products. The results of the study showed that the cellulose and lignin content of different plant species differs and is as follows: pine wood – 49.5% and 27.5%, wheat straw – 39.3% and 20.7%, hemp raw materials – 67.5% and 8.0%, respectively. Experimental samples of chipboard based on the presented types of raw materials did not differ significantly in terms of strength and density, but water absorption was higher in those boards with a lower lignin content.

As noted by S. Sair *et al.* (2018), the physical and mechanical properties of hemp-based insulation materials, namely thermal conductivity, flexural strength and water absorption, vary depending on the percentage of hemp fibre. In their research, the scientists produced polyurethane insulation materials by adding different amounts of fibres from 5 to 30%. When assessing thermal conductivity, it was noted that with an increase in the content of hemp fibres, the thermal conductivity of products increases. This is due to an increase in the density of the sample and the morphological characteristics of the raw material. Water absorption also increased with the percentage of hemp impurities. An inverse proportional relationship was observed in the bending strength study: with an increase in fibre content, the strength of the boards increased.

C. Lühr *et al.* (2018) studied the effect of hemp variety, growing conditions and primary processing on the quality of the resulting particleboards. The authors used varieties that differed significantly in their properties: the content of fibrous and woody parts, the amount of cellulose and lignin, as well as different methods of grinding raw materials. As a result, it is noted that the density of the boards depends on the particle size and the number of grinding stages. Thus, the studies conducted confirm the possibility of using hemp bark for the production of sheet building materials. However, it is necessary to take into account the functional purpose of innovative hemp boards (for what purpose and under what conditions such material will be used) for further development of manufacturing technology and adhesive solution components.

Conclusions

The research has confirmed that hemp-based chipboards are a suitable substitute for wood-based chipboards. In addition, the production method of hemp-based panels has a significant impact on their mechanical and technical characteristics. An analysis of the Ukrainian particleboard market and wood harvesting volumes confirms a gradual decline in chipboard production and wood harvesting.

Thus, in 2023, chipboard production in Ukraine decreased by 18% compared to 2017, while timber harvesting almost halved. Given the high demand for sheet construction materials and the need to preserve forests, it is proposed to use a rapidly renewable raw material, industrial hemp.

The study assessed the mechanical and esthetic properties of the experimental samples, which confirmed the feasibility of replacing wood raw materials with hemp in the manufacture of wooden boards. The results obtained in determining the suitability of hemp for the production of sheet materials showed that the bark has a good homogeneous structure and does not contain fibrous impurities, which is important when

mixed with adhesives. The strength of a board made from hemp bark is 7.1 MPa, which is 13% better than that of wood chipboard, and the water absorption is 15% higher. The board made from chopped stalks has the best bending strength of 7.5 MPa, but is significantly inferior in terms of water absorption, which is explained by its lower density (598.3 kg/m^3) and the presence of fibre.

Further research will focus on optimising hemp processing to produce the highest quality and most efficient building materials. New technologies and methods for the production of sheet building materials using industrial hemp will be developed, which can increase their productivity and reduce costs. The environmental performance of the production and use of such materials will be studied in detail to ensure their sustainability and compliance with environmental standards.

Conflict of interest

None.

Acknowledgements

None.

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Перспективні напрямки використання технічних конопель для виготовлення листових будівельних матеріалів

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Анотація. Актуальність дослідження полягає у виявленні потенціалу створення інноваційних будівельних матеріалів, які можуть покращити якість та ефективність будівництва та меблевого виробництва. Метою роботи є аналіз ринку листових будівельних матеріалів, дослідження можливостей використання рослинної сировини у будівництві та меблевій промисловості, а також порівняння властивостей новітніх будівельних матеріалів із вже наявними. Під час аналізу літературних джерел проходив пошук та оцінка нових розробок у галузі будівництва, а також було проаналізовано статистичні дані щодо виробництва архітектурних матеріалів в Україні, з використанням інформаційних ресурсів та сервісів пошуку в мережі Інтернет. Для оцінювання споживчих властивостей інноваційних будівельних матеріалів було використано методи оцінки якості за допомогою зорового сприйняття та спеціальних інструментів, згідно з встановленою нормативною документацією. Розглянуто важливі питання, які спрямовані на використання ресурсозберігаючих технологій в будівництві та розробку новітніх (екологічних) будівельних матеріалів. Досліджено сучасний стан ринку будівельних листових матеріалів України та властивості технічних конопель з метою визначення максимально рентабельного напрямку використання конопляної сировини в ролі ефективної основи для створення будівельних матеріалів різного призначення. Визначено і обґрунтовано проведено оцінювання придатності сировини, одержано експериментальні зразки деревостружкових плит з різними наповнювачами, а також досліджено фізико-механічні на естетичні характеристики готових виробів. Проведені дослідження будуть сприяти розвитку коноплепереробної галузі, а також підприємств, які виготовляють товари різного функціонального призначення з конопель, що забезпечить умови для об'єднання аграрної сфери та будівельної галузі, тобто побудову замкненого циклу виробництва

Ключові слова: деревостружкові плити; деревоволокнисті плити; щільність; теплопровідність; конопляна костра; конопляне стебло; ізоляційні матеріали

COMMODITY BULLETIN
Journal homepage: https://c-bulletin.com.ua/en
DOI: 10.62763/ef/1.2024.92

Article's History: Received: 01.12.2024 Revised: 23.02.2024 Accepted: 26.04.2024

Vol. 17, No. 1, 2024, 92-104

UDC 620.2: 338.439

Security requirements for personal computers

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Abstract. The relevance of the study lies in guaranteeing the safety of personal computers for consumers (users) and complying with the requirements of technical regulations in this part. The purpose of the study was to determine and analyse the factors of personal computer assortment formation under the conditions of the uncertainty of economic and social features of modern times, with a focus on aspects of safety and environmental responsibility of computer equipment, as a priority mechanism for consumers. Emphasis is placed on cyber security, the importance of protecting a personal computer from cyber attacks. Methods of systematic analysis of statistical databases were used in the study. The high rates of development of Ukraine in the field of computerisation of many areas of industry and economy during the years 1993-2023 were noted. It has been proven that as of the year 2024 there is one personal computer, a tablet, a laptop or a netbook in every household. Changes in the economy, politics, technological aspects and other external factors that can affect the personal computer market are shown. The ability of companies to adapt to changes and requirements is noted as a key source of their success. The ergonomic, anthropological, psychophysiological requirements for screen devices that guarantee the safety of consumers (users) are given. The conditions of compliance of personal computers with the requirements of technological regulations in terms of ecodesign, aimed at improving the environmental safety component in accordance with consumer requirements, are defined. It is shown that the modern market of personal computers has several key trends in the formation of assortment policy which includes: flexible configurations and individualisation; increased attention to the gaming segment; development of artificial intelligence technologies; increasing the amount of memory and speed; environmental responsibility; development of wireless technologies; high mobility; focus on high-performance workstations. It has been determined that compliance with environmental safety requirements is important for business, because companies that pay attention to environmentally responsible may have a competitive advantage. It is shown that the most common are the standards and certification systems for personal computers, which are a series of certification standards that determine the requirements for the environmental and ergonomic quality of computer equipment, in particular, monitors. The practical significance of the results lies in increasing of the competitiveness of personal computers, taking into account the safety recommendations for consumers (users) of the relevant equipment to strengthen the role of environmental aspects and cyber security requirements

Keywords: computer engineering; regulations; security; cyber security; consumer; environmental responsibility

Introduction

The relevance of the chosen research topic lies in the fact that Ukraine, being in a state of war from February 24, 2022, is confidently gaining a leading position in the IT-services markee, taking a leading position among other countries in terms of access to the Internet. The market of IT-goods and services being a segment of the economy is rapidly developing in accordance with the strategic course of the Ministry of Digital Information of Ukraine. According to the Ukrainian Institute of the Future (2018), digitalisation is the main mechanism for

Suggested Citation:
Yemchenko, I. (2024). Security requirements for personal computers. *Commodity Bulletin*, 17(1), 92-104. doi: 10.62763/ef/1.2024.92.

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achieving Ukraine's strategic goal of increasing GDP eightfold (up to USD 1 trillion) by 2030. The priority programs determined by the Government of Ukraine (Official website of the Government Portal, 2024) are the digitisation of all basic public services for citizens and businesses. Therefore, it is impossible to achieve success without having the tools to implement the strategy: equipment, technologies, personnel. Events during the period of 2019-2023 (COVID-19, distance education and work, a full-scale invasion of the aggressor country into Ukraine) gave the computer equipment market new challenges related to the need to solve new tasks (Decree of the President of Ukraine No. 64, 2022). The importance of a clear system of requirements for the personal computers (PC) safety and its compliance by manufacturers with the provision of a guarantee for users make the chosen topic of research important and indicates its feasibility in the future.

With the development of computer technologies, user requirements for the personal computers safety are changing, so it is relevant to identify and analyse these changes. During 2020-2021, a revival of trade of this type of product was observed in connection with the need of remote work. Years 2022 and the first half of 2023 were marked by a decrease in sales, and at the end of 2023 an increase was observed, what indicates the balancing of supply and demand.

The authors L.O. Chernyshova & L.V. Novikova (2021) in their work researched information and communication technologies regarding methods of data collection, processing and transmission in order to obtain the latest data on the state of the object, process, phenomenon in order to create qualitatively new information. According to H. Cabezas (2022), a professor at the Research Institute of Applied Earth Sciences of the University of Miskolc in Hungary, the amount of electronic waste (computers, monitors, computer peripherals) in the United States counts 205 million units of computer products every year. The amount of e-waste is growing rapidly in India and China due to the high demand for computers. An increasing number of Ukrainian consumers have access to the Internet and they use personal computer in their professional activities, which requires compliance with consumer safety and cyber security requirements for computer systems.

According to O. Dovgan (2023), the global market for cyber security, as a component of the development of the ecosystem, is aimed at protecting personal computers (PCs), networks and databases from criminals and will reach 484.97 billion US dollars by 2030. In her work the author also emphasises that the issue of information security is extremely relevant in difficult conditions of uncertainty, economic crisis during military operations. In the works of I. Makarchuk & I. Fedulova (2023), issues of cyber security of computer devices, methods of protection against unauthorised disclosure of confidential information of consumers are considered. In the article of the authors R. Odarchenko *et al.* (2023) the connection between the development of communication networks and the implementation of internationally accepted 5G standards is shown. It is shown that the transition to the 5G network requires compliance with cyber hygiene to prevent cyber threats. S. Fedushko (2023) points out the possibility of cyberattacks to cause damage to both PC consumers, companies, and the state, and considers the importance to develop new methods of protecting the information database and training users. According to the author, cyber security and cyber hygiene are critically important components of ensuring the security of computer systems. The priority is the issue of consumer (user) safety which is regulated by regulatory and legal documents. Research in this area will allow to find out the consequences of the impact of electronic devices on the health of consumers (PC users) and the environment and determine factors to minimise this impact.

In many countries of the world, working at a computer belongs to the category of dangerous activity due to the influence of various factors on the health of the consumer (user), therefore it is important to determine the methods of informing consumers about the personal computer safety requirements, which affect conscious choice during geopolitical, economic and social instability.

In the conditions of military operations in Ukraine, it is relevant not only to comply with the requirements of safety standards and energy efficiency of PCs and other electronic devices, but also to ensure the fulfillment of other tasks related to energy supply and energy saving (Decree of the President of Ukraine No. 722, 2019). According to occupational health researchers O.E. Kruzhilko *et al.* (2021), users of computer equipment may be exposed to various hazards: electrical, energy, fire, thermal, chemical, mechanical, radiation. For electronic devices, one of the best safety systems, recognised at the world level, is considered to meet the requirements of European directives, which declare the absence of a negative impact on the health of the consumer and on the environment. And therefore do not cause a threat to the user's life, economic development, trade relations and the reputation of the state on the international arena (Directive 2014/30/EU, 2014).

The purpose of the article was to determine the specifics of changes in the personal computer market in terms of increasing consumer attention to the environmental requirements of certifications in accordance with safety requirements. The task was also set to show the importance of informing consumers (users) about the safety of products for changes in the formation of companies strategy of selling personal computers.

Materials and methods

The object of the study was the system of compliance with PC security regulations, which was developed and

implemented by the countries of the European Union, its goals and competitive advantages for both enterprises and consumers (users), possible threats due to non-compliance with security requirements for the human user. Security requirements for PC users are covered in Technical Regulations and EU directives (Council Directive 90/270/EEC, 1990; Directive 2009/125/EU of the European Parliament and of the Council..., 2009; Directive 2014/30/EU of the European Parliament and of the Council..., 2014). The importance of cyber security under the conditions of a hybrid war has been studied. The requirements for convincing compliance with the environmental responsibility of manufacturers and the formation of an assortment policy of trade enterprises were also studied.

The theoretical and methodological basis of the study was the change and growth of the importance of consumers in the formation of modern requirements for the safety of computer equipment. Scientific publications from 2019 to 2024 in professional journals were monitored while conducting this research. Articles for analysis were selected in the following areas: commodity science; practice of modern materials science and commodity science; entrepreneurship and trade; safety of goods and products; ecology and technology of environmental protection; environmental engineering; medical sciences and public health. The search for scientific publications was carried out based on such keywords as "personal computer", "computer equipment market", "electronic devices", "monitor consumer safety", "security systems", "technical parameters of security", "safety", "electronic waste", "computer technology", "cyber security", "cyber hygiene", etc. Data from the information sites of the State Statistics Service of Ukraine (State Statistics Service of Ukraine. Statistical Collection, n.d.), the Government Portal (Official website of the Government Portal, 2024) were also used. While working on the article, the content of the Laws of Ukraine was analysed: "On the Main Principles (Strategy) of the State Environmental Policy of Ukraine for the Period until 2030" (Law of Ukraine No. 2697-VIII, 2019), "On the Public Health System" (Law of Ukraine No. 2573-IX, 2022), "On General Safety of Non-Food Products" (Law of Ukraine No. 2736-VI, 2010), "On Electronic Communications" (Law of Ukraine No. 1089-IX, 2022); Decrees of the President of Ukraine "On the Goals of Sustainable Development of Ukraine for the Period up to 2030 (Decree of the President of Ukraine No. 722, 2019), Resolutions of the Cabinet of Ministers of Ukraine: "On Approval of the List of Types of Products for which State Market Surveillance Bodies Carry Out State Market Surveillance" (Resolution of the Cabinet of Ministers of Ukraine No. 1069, 2016), "On Approval of the Technical Regulation on the Establishment of a System for Determining Requirements for Ecodesign of Energy-Consuming Products" (Resolution of the Cabinet of Ministers of Ukraine No. 804, 2018), "On Approval Technical Regulations on Ecodesign Requirements for Computers and Computer Servers" (Resolution of the Cabinet of Ministers of Ukraine No. 737, 2019). The European legal framework for safety requirements was analysed (Council Directive 90/270/EEC, 1990; Council Directive 89/391/EEC, 2008). The content and requirements of these documents were examined using the method of analytical analysis.

While conducting an research for the article, both general scientific and special methods were used: economic and statistical: a method of comparative analysis to determine the level of consumer access to the Internet in Ukraine and other countries of the world, an analytical comparison of various aspects of the computer market situation and generalisation of official data of foreign marketing structures, the State Statistics Service of Ukraine, system analysis of statistical and informational databases. The observation method was used to study the consequences of non-compliance with safety requirements when working with PCs of consumers of different gender and age. Methods of logical analysis and generalisation of scientific literature were used to make conclusions. The abstract-logical method was used to understand the relationship between such parameters as the degree of PC provision of consumers, the degree of accessibility to the Internet, the indicator of screen time and the possibility of potential dangers for the health of users. This method is also used to identify patterns and formulate assumptions regarding the impact of user safety on achieving the goals of the strategy of environmental policy of sustainable development. Methods of analysis and synthesis were used to generalise problematic issues and determine development trends in the outlined field. The method of forecasting was used to determine the prospects for the development of the PC market with the maximum possible indicators of safety and environmental responsibility of both manufacturers and consumers of electronic devices regarding the management of computer device wastes. With the help of this method, a conclusion was made about the expediency of further research in this field. Analytical method was used to determine the topic for further research.

Results and discussion

The modern market of computer equipment is quite saturated, dynamic and import-dependent. In the era of information technologies, such indicator of activity as efficiency, which can be achieved thanks to the use of a personal computer, is gaining more and more importance. PC belongs to high-tech products, the component base of which has individual technical characteristics and purpose, and this fact determines the choice of the consumer depending on his needs (Technical characteristics and purpose of the main components

of a personal computer, 2024). Many jobs, as of 2024, require the use of computers the business could not function without.

Operational assessment of the development of information and communication technologies is the basis of a balanced policy at the regional level for managing sustainable development and is a determining criterion for progress in a digital, economic and social society (Korepanov, 2018). The development of computer technologies is related to cyber security. An increase in cyber attacks is recorded in all countries of the world, mostly in the fields of education, health care, scientific research, government and military structures. According to O. Dovgan (2023), the number of encrypted attacks increased by 22% in 2022, which caused a significant increase in cyber threats in Asia (287%), Europe (119%) and Latin America (2851%).

According to statistics from the Official website of CERT-U (2024), in the period from 23:00 January 21, 2024 to 10:30 January 22, 2024, malicious files were downloaded more than 3000 times, and they successfully "infected" several dozen computer devices. A computer functioning in an affected state for about a week can have from 80 to 120 or more malicious (infected) files, not counting those that will be created on removable storage media that will be connected to electronic devices during this period.

Requirements for the safety of consumers (users) of personal computer equipment with screen devices were developed according to the European Council Directive 90/270/EEC dated 05/29/1990 (Council Directive 90/270/EEC, 1990). The minimum requirements for safety and health were taken into account by technical coordination with the provisions of the fifth framework Directive in the interpretation of Article 16, part 1 of the European Community Directive 89/391/EEC (Directive 2014/30/EU of the European Parliament and of the Council, 2014). The authors L.V. Pelyk & Y.A. Peleh (2018) investigated the requirements for the safety of non-food products, which are planned by the manufacturer during the design, production, and use of the product by the consumer during the service life, and which form the regulatory and legal framework.

Safety in Ukraine is regulated by state medical and sanitary rules (sanitary regulations), which are mandatory for the implementation of measures and requirements necessary to ensure state medical and sanitary standards, non-compliance with which poses a threat to the health and life of consumers, as it is specified in the Law of Ukraine No. 2573-IX (2022). The importance of guaranteeing product safety is emphasised by the integration of European and Ukrainian requirements in terms of consumer health protection. All dangerous factors available among PC consumers, must comply with scientifically based safety standards, hygienic and ergonomic requirements, approved by the resolution of the Chief State Sanitary Doctor of Ukraine dated December 10, 1998 No. 7 (State Sanitary Rules and Regulations for Working with Visual Display Terminals of Electronic Computing Machines 3.3.2.007-98, 1998). This regulatory document defines the permissible parameters of electromagnetic non-ionising radiation and electrostatic field. Problems of determining the safety requirements of consumers when using goods of a technically complex group and regulating standards in order to provide them with the necessary information and favourable working conditions are discussed in works of such scientists as L. Andriievska *et al.* (2021), Y. Mineshita *et al.* (2021), D.O. Badea *et al.* (2022).

To assess the level of compliance of computers with environmental requirements, the operational characteristics of those available on the international market, and reference indicators established by the legislation of other countries are taken into account (Directive 2009/125/EU, 2009). Computers belong to the list of products (Resolution of the Cabinet of Ministers of Ukraine No. 1069, 2016), on which the State Production and Consumer Service carries out state market supervision in accordance with the current legislation (Law of Ukraine No. 2736-VI, No. 2735-VI, 2010). According to the requirements of the Technical Regulation (Resolution of the Cabinet of Ministers of Ukraine No. 737, 2019), manufacturers of stationary computers, monoblocks and laptops must provide information about their safety in technical documentation and post it on websites. The assessment of compliance of computers with the requirements of the Technical Regulations is carried out in accordance with the internal control procedure.

Changes in the economy, politics, technology and other external factors affect the personal computer market, and companies' quick adaptation to change is an instrument resulting in their success. It is important to develop a marketing product policy for such high-tech products as PCs. The author K.L. Lukach (2018) notes that the PC market is developing along with the development of the computer technology market, and the prospects of their development are connected with the improvement of the state of modern international trade. The main task of commodity policy, as noted by the authors E.V. Lisenyi & Yu.I. Dyachenko (2021), is the creation of a product that has competitive advantages and simultaneously gives maximum satisfaction to consumer and market needs and the company's profit. The number of users with access to the Internet worldwide is constantly increasing (Fig. 1). According to Digital 2023 research October global statistics report (2023) as of October 2023, the number of Internet users in the world was 5.3 billion, which was 65.7% of the total population. And as of January 2024, according to Global Digital 2024 (2024), the total number of users worldwide is 5.35 billion, or 66.2% of the world's population.

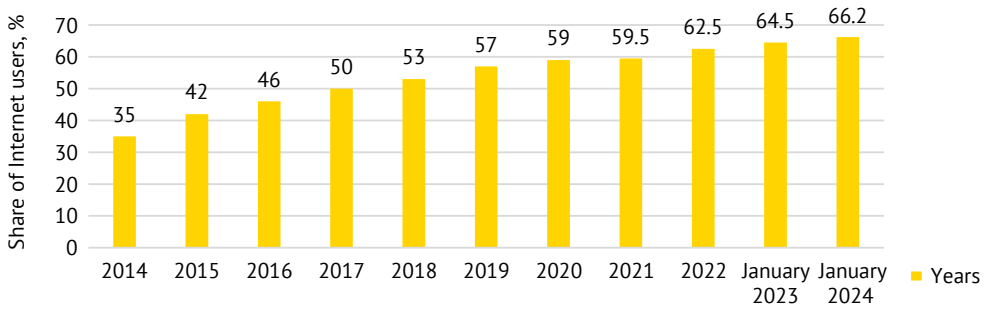

Figure 1. *Share of users worldwide with access to the Internet for the period from 2014 to January 2024*
Source: *developed by the author based on the Official website of Statista (2024)*

According to the mentioned data, within one year, from January 2023 to January 2024, the number of Internet users increased by 1.7%, and in 10 years (from 2014 to 2024), it has almost doubled. Laptops account for 57% of the time spent by consumers (Internet users) on a PC. It is established that the use of PCs and laptops has increased, similarly, the rate of access to the Internet network has increased by 3.9% relative to 2022 (State Statistics Service of Ukraine. Statistical Collection 2022, n.d.).

Analysing the standard of living in Ukraine during the years 1993-2023, despite the deep economic crisis of the past years, the coronavirus pandemic, military actions in Ukraine, and the low standard of living of the average citizen, it is worth noting Ukraine's achievements in the field of computer technologies and their implementation in various household segments (Table 1).

Data in Table 1 shows that as of 2020, each household already had one personal computer, tablet, laptop, or netbook. But there are households that have a personal computer for each family member. The indicator of access of personal computer users to the "Internet" network of the global electronic communication system, which operates according to international Internet protocols (Law of Ukraine No. 1089-IX, 2022), is important. Authors I.O. Pyshnograiev & I.O. Tkachenko (2022) believe that access to the Internet is one of the many indicators of human life, which are used for modelling the level of sustainable development. Statistics have shown a fairly significant difference in access to the Internet between users living in urban and rural areas (Solop, 2022). Data as of 2022 regarding the access of Ukrainian households to the Internet in 2021 are shown in Table 2.

Table 1. *Number of PCs per 100 households*

Years	2000	2005	2010	2014	2016	2018	2020
Personal computers, tablets, laptops, netbooks, pcs	1	9	31	63	80	90	98

Source: *developed by the author based on Statistical Yearbook of Ukraine for 2021 (2022)*

Table 2. *Data on the share of households in Ukraine with access to the Internet at home (as a percentage of the total number)*

No.	All households	Those who live	
1		in cities	in the countryside
2	82.7	87.4	72.8

Source: *developed by the author based on the State Statistics Service of Ukraine Statistical Collection 2022 (n.d.)*

The data in Table 2 indicate the insufficient level of access to the electronic communication network, especially in rural areas. The same opinion is shared by the authors I. Makarchuk & I. Fedulova (2023), who defined a high, but still insufficient, level of household access to the Internet. These authors believe that for the further development of the digital economy, at least 95% of the population should have access to the Internet at home. Despite a slight slowdown in access in 2022 (only 2%), 2023 trends indicated that by the end of 2023, almost 2/3 of the world's population had no Internet connection (Computer review, 2022). This is confirmed by the data presented by the analytical company in the annual report (Global Digital 2023, 2024).

According to the analytical report (Digital 2024: Ukraine, 2024), there were 29.64 million Internet users in Ukraine in January 2024, and the Internet access rate at the beginning of 2024 was 79.2% of the total population. From January 2023 to January 2024, the number of Internet users in Ukraine increased by 1.1 million (+3.7%).

The United Nations (UN), recognising access to the Internet as a "fundamental human right", declared universal connection of the population to the Internet as its goal by 2030. According to the chief analyst of Data Reportal and CEO of Kepios Simon Kemp (Digital 2023. October global statistics report, 2023), as of October 2023, the level of Internet access is below 20% in 9 countries of the world and less than 50% of the

population uses the Internet in 61 countries of the world. 2.85 billion of the world's population out of 8.06 billion, as of October 2023, remain without access to the Internet. However, among the countries of the European Union, the largest share of Internet users is in Northern European countries (Fig. 2).

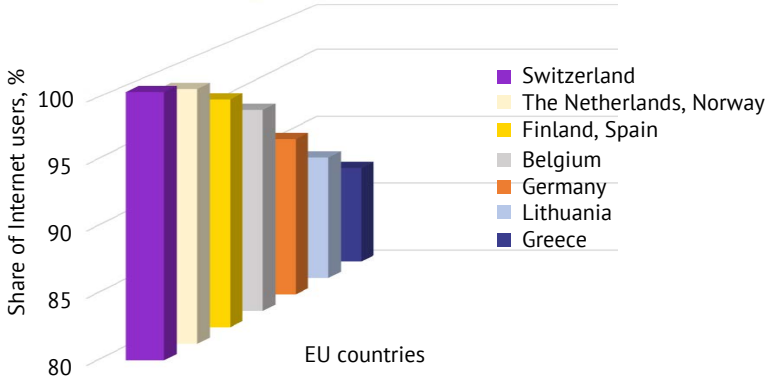

Figure 2. *Share of Internet users in EU countries*
Source: *developed by the author based on the Official website of Eurostat Statistics Explained (2023)*

According to the Official website of Eurostat Statistics Explained (2023), the first places in terms of access to the Internet in 2023 belongs to Switzerland (100%), the Netherlands (99.2%), Luxembourg and Norway (99%), and the average the indicator for the European Union was 91.5%. World analysts claim that despite Ukraine lagging behind developed countries in terms of the number of computerised professional processes, in terms of the introduction of computer technologies, Ukraine belongs to the countries with high rates of computerisation, which is confirmed by the data in Table 3.

Table 3. *Differentiation of households by the level of access to the Internet by computer users of different gender and age (data as of 2022)*

No.	Persons in households	Households with people of certain age (in %)					
1		all households	children up to 18 years	18 years and older	from 18 to 35 years	from 36 to 59 years	59 years and older
2	Women	82.7	99.0	83.8	99.2	95.5	65.8
3	Men			87.9	99.2	93.8	69.3

Source: *developed by the author based on Global Digital 2023 (2024)*

According to the data of statistical observations (Statistical Yearbook of Ukraine, 2022), in 2019-2021, the retail turnover of enterprises retailing computers, peripheral equipment, and software grew dynamically and amounted (in millions UAH): in 2019 – 7530.5; 2020 – 9903.7; 2021 – 13527.2. At the same time, there was a decline in sales of personal computers due to the growing popularity of portable devices such as tablets and smartphones. Thus, according to the research data of L. Andriievska *et al.* (2021), the smartphone market was actively developing. However, there are certain segments of the market that remain stable or even grow in terms of sales, such as gaming computers and personal computers for professional use. The gaming segment remains one of the most dynamic in development.

The Ukrainian market still remains quite profitable for well-known computer systems manufacturers despite the fluctuations associated with the pandemic and the war. According to the analytical research company International Data Corporation (2023), the personal computer market saw its most significant decline in 2023, caused by the result of the COVID-19 pandemic, which affected the growth of demand for PCs and other computing tools for remote work and distant learning in 2021-2022. The company's analysts believe that the market and the supply of personal computers in 2024 will grow by 3.7%, to 261.4 million units compared to the previous year. This level will exceed the indicators of 2018, but will be lower than the similar indicator in 2019, when the pandemic had not yet affected the personal computer market (Table 4).

Table 4. *Volumes of supply of personal computers and netbooks on the world market*

Years	2018	2019	2020	2021	2022	2023	2024*	2027*
million units	259.6	266.1	302.6	341.04	285.1	248.5	261.4	287.9

Note: **calculated based on forecasts of the analytical company International Data Corporation*
Source: *developed by the author based on International Data Corporation (2023)*

In the modern market of personal computers, several key trends in the formation of assortment policy are observed, namely: flexible configurations and individualisation; increased demand for gaming devices; development of artificial intelligence and wireless technologies; increasing the amount of memory and speed; environmental responsibility; high mobility; focus on high-performance workstations. All this prompts the release of new products and components, such as high-performance graphics cards, processors and other components aimed at gamers.

High-speed SSD storage, new processor architectures, improved screens and other technological innovations affect the formation of competitive advantages of users and the competitiveness of companies. But the most important consumer advantage for the user when purchasing a personal computer is safety indicators. The goals of sustainable development of Ukraine for the period up to 2030 identified as a priority vector the safety of life and health of consumers, which is impossible without access to safe and high-quality industrial goods (Decree of the President of Ukraine No. 722, 2019).

Authors D.V. Diachkov *et al.* (2020) consider the increase of the competitive position of companies and ensuring competitive advantages with the help of assortment to be one of the important goals of the product policy of enterprises. The transition to resource-saving technologies in the field of computer technologies, the full implementation of environmental impact assessment is provided for by Law 2697-VIII, which adopted the Strategy of the State Environmental Policy of Ukraine for the period until 2030 (Law of Ukraine No. 2697-VIII, 2019) in 2019. Consumers and companies are increasingly paying attention to the environmental aspects of their products and compliance with safety standards. As noted by the authors V.D. Khurdey *et al.* (2021) the purchasing behavior of consumers regarding the priority in the crisis is changing towards product safety. This is a key issue for business, as companies that pay attention to environmental responsibility can have a competitive advantage. It is worth noting that the COVID-19 pandemic has had a significant impact on the PC market due to the increased demand for workstations for remote work and distant learning. Existing standards and certification programs help consumers and manufacturers in the evaluation and selection of computer monitors that meet ergonomics, safety and environmental indicators. According to the authors V. Vishnevsky *et al.* (2021), environmental requirements for computer monitors are becoming increasingly important in the world, in conditions of growing attention to sustainable development and environmental responsibility.

Standards and certification programs establish requirements for ergonomics, energy efficiency, use of environmentally-friendly materials and reduction of environmental impact. Safety certification for computer monitors may include indicators of electromagnetic compatibility, safety in compliance with electrotechnical standards, migration of harmful substances and other important parameters. The most frequently used standards and certification systems are listed in Table 5.

Table 5. *Security standards and computer equipment certification systems*

Conditional abbreviation	Full name, developer	Purpose and characteristics
CE (Conformité Européenne)	European certificate of conformity, European Union	Testifies to compliance with all European safety standards and other requirements, is a mandatory condition for the sale of radio-electronic products in EU countries
FCC	Federal Communications Commission	Determines compliance with electromagnetic compatibility and other aspects related to the electronics quality and safety
ISO 9241	International Organization for Standardization	Defines workplace ergonomics requirements for work with display screen equipmen
ISO 13406	International Organization for Standardization	Sets the classification of defects on LCD screens
Certification ENERGY STAR		Establishes requirements for energy efficiency of electronic products
EPEAT Certification	Electronic Product Environmental Assessment Tool	It takes into account such aspects as energy efficiency, material use, recycling and other parameters
RoHS Directive	Restriction of Hazardous Substances	Limits the use of certain hazardous substances (lead, mercury, cadmium and others) in the production of electronics, monitors in particular
TÜV Certification System	Technischer Überwachungsverein, Germany	Tests and certification to ensure the safety and quality of electronic products, monitors in particular
MPR II	National Department of Sweden (SWEDAC–Swedish National Board for Measurement and Testing)	Establishes requirements for electromagnetic radiation levels at a distance of 50 cm from the monitor, permissible level of electromagnetic field intensity: • in the frequency range from 5 Hz to 2 kHz – 25 V/m; • in the frequency range from 2 to 400 kHz – 2.5 V/m.
TCO'92	The Swedish Confederation of Professional Employees, Sweden	Regulates even lower radiation levels at a distance of 30 cm from the PC monitor. Contains requirements for the efficiency of energy consumption of monitors, as well as electrical and fire safety

Table 5. Continued

Conditional abbreviation	Full name, developer	Purpose and characteristics
TCO'95	The Swedish Confederation of Professional Employees, Sweden	Contains requirements for extended range of PC parameters, ergonomic and environmental properties, radiation, power consumption, monitor screen generation, image brightness and keyboard requirements
TCO'99	The Swedish Confederation of Professional Employees, Sweden	Contains stricter requirements for radiation level. Permissible level of electromagnetic field strength: • in the frequency range from 5 Hz to 2 kHz – 10 V/m; • in the frequency range from 2 to 400 kHz – 1 V/m, ergonomic, environmental indicators, energy consumption of monitors, system units, keyboards
TCO'03 TCO'06	The Swedish Confederation of Professional Employees, Sweden	Contains strict requirements for environmental indicators
Certified Certification Standard	Sweden	Defines requirements for environmental and ergonomic quality of computer equipment, monitors in particular
The DfE Approach	Design for Environment	It includes the development of products with the aim of minimising the impact on the environment at all stages of their life cycle: production, use and withdrawal from circulation
UL	Underwriters Laboratories	Certification of safety and other properties of electrical and electronic products

Source: *developed by the author based on Computer review (2022)*

Individual organisations develop recommendations to ensure the safety of electronic equipment and computer systems. For example, the International Electrotechnical Commission (IEC) and the European Committee for Electrotechnical Standardization (CENELEC) develop safety standards for personal computers and other electronic devices. In addition, countries can define their own national standards and requirements for the security of electronic devices, including personal computers. For example, in the EU, products must meet the requirements of the Electromagnetic Compatibility Directive (Directive 2014/30/EU, 2014) and the Low Voltage Directive (Directive 2014/35/EU – Low Voltage Directive, 2014).

Compliance with electromagnetic compatibility is important in order to prevent negative effects on other electronic devices and to ensure the normal functioning of the computer monitor. Despite the statements of consumers regarding the possible negative impact of electromagnetic radiation (thermal, non-thermal and specific types) on health, scientific studies do not yet provide clear confirmation of a large risk. The arguments of scientists are reduced to the fact that the existing standards for electromagnetic compatibility establish permissible levels of radiation for electronic devices in order to protect users. A large amount of scientific research has been aimed at studying the thermal effect on the temperature of tissues as a result of exposure to an electromagnetic field. Generally, electronic devices, particularly computers, do not generate enough energy to have a significant thermal effect. Some studies are looking into possible non-thermal effects, but so far scientists have not reached a consensus on the existence of a major risk to the health of users. Specific effects are the subject of studies examining the possible effects of electromagnetic radiation on specific aspects of health, namely sleep, cardiovascular and nervous system functioning, fertility, etc. (Badea *et al.*, 2022).

A significant argument regarding the potential danger is the use of PC monitors, that was the reason to approve the user safety and health requirements when working with screen devices (Order of the Ministry of Social Policy of Ukraine No. 207, 2018). Most digital devices, including PCs, emit blue light when in use. Artificial light displays contain high energy light with a high frequency spectrum. Research results conducted in Japan by Y. Mineshita *et al.* (2021), proved the negative impact of blue light from computer screens on the circadian cycle, sleep duration, energy metabolism, and academic performance of primary school students. This is due to the nature of the short waves, which are perceived as blue, in the visible light spectrum, and which have a significant effect on the phase delay of the circadian rhythm (Wahl *et al.*, 2019). According to the results of experiments conducted by L. Tähkämö *et al.* (2019) it was established that disruption of the circadian rhythm and decrease in sleep quality of users of digital technological devices, computer monitors in particular, occurs as a result of melotonin suppression.

Although the average user spent 21 minutes less on the Internet in 2022 compared to 2021, this indicator increased by 4 minutes in 2023. The data in Table 6 prove that the time prescribed by sanitary and hygienic standards was exceeded.

Table 6. *Duration of time spent by consumers on the Internet per day*

Years	2019	2020	2021	2022	2023
Duration, hours	6.38	6.54	6.58	6.37	6.41

Source: *developed by the author based on Official website of the State Statistics Service of Ukraine. Statistical Information (2024)*

According to the data of the global overview report (Digital 2022: Global overview report, 2022), the largest time spent (in hours) on connected technologies per day is observed among users of: South Africa (10.46); Philippines, Colombia, Brazil (9.25); China (5.15); Japan (4.5). A significant decrease in the duration of Internet use in 2023 by 56 minutes of PC consumers in Japan can be explained by the tradition of taking care of their health, culture, and the majority of the country's population are middle-aged people, which is confirmed by the data of the digital report (Digital 2023. October global statistics report, 2023). Figure 3 shows a direct relationship between the age of consumers (users) and the length of time spent using the Internet.

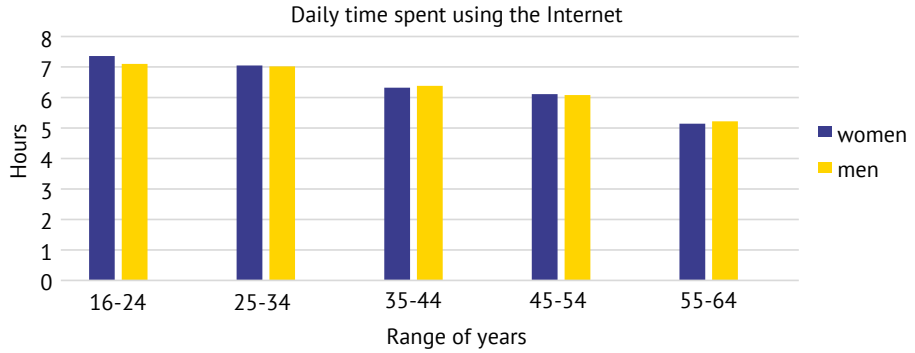

Figure 3. *The amount of time spend by consumers using the Internet*
Source: *developed by the author based on Digital 2023. October global statshot report (2023)*

In general, the average time spent on the Internet is characterised by a tendency to decrease when the consumer age increases. Due to the increasingly widespread use of the Internet, the duration of time spent by primary school students at the computer monitor is growing annually. The effect of radiation is especially dangerous, blue light in particular, on consumers – students of primary school and teenagers, who spend in front of computer screens extra time.

Ukraine, having 4% of GDP in the field of information technologies, is confidently advancing in the market of IT-services. During 2013-2023, a lot of information appears regarding the study of solid waste, which includes electronic waste, both consumers (users) and producers themselves are responsible for. Scientists M.V. Ruda *et al.* (2021), I.Yu. Yegorov *et al.* (2022), M.-H. Le *et al.* (2023) and many other have devoted their research works to the problems of handling and management of electronic wastes

It is important to follow the recommendations specified in the standards of international organisations in order to guarantee the safe use of electronic devices and computers. It is also related to the general impact on human health. Significant risks to the health of a person who actively uses electronic devices have not been sufficiently proven, so research in this area will be continued.

Conclusions

According to the research results, it was noted that sustainable development is impossible without taking into account the competitive advantages of commercial products. In today's digital society the determining criteria for the competitiveness of personal computers is determined by their compliance with safety requirements, regulated in view of European practices. Safety for PC users is regulated by the requirements of the European Council Directive, which defines the following principles: prevention of occupational risks, safety and health protection, elimination of accidents, employer and staff responsibilities and informing about the results of risk assessment for PC users and management. The UN has defined access to the Internet as a "fundamental human right" and declared the global connection of the world's population to the Internet by 2030. However, according to research, there is an insufficient level of accessibility to Internet services.

Studying the level of satisfaction of consumer demand for safe computer devices is important both for the possibility of the most complete satisfaction of ergonomic and environmental needs. The study of security requirements is aimed at determining the factors affecting the change in demand for PCs. It has been confirmed that most PC monitors become sources of danger, therefore they must comply with the regulations of safety standards. The given characteristics of standards and certification systems prove the change of safety requirements to implementation of stricter parameters.

Consumers and companies are paying increasingly more attention to compliance with the requirements of personal computer safety regulations, environmental and ergonomic ones in particular. Due to the fierce competition in the world of computer technology and devices, opinions about safety differ among manufacturers, medical professionals and consumers. To stay in trend manufacturing companies and are placing greater emphasis on the ecological parameters of their products. The production of energy-efficient and easily

recyclable components, as well as the implementation of secondary use programs, are becoming relevant.

It has been proven that absolutely safe monitors and processors do not exist, as the consequences of exposure to hazardous factors on the consumer's body for several years, or on their descendants, are unknown. In addition, scientists are considering the issue of the negative "informational" impact of the electromagnetic field on consumers.

Considering environmental requirements, consumers can choose electronic devices with better environmental performance, and manufacturers can focus their efforts on creating sustainable, environmentally-friendly equipment. It is shown that due to the rapid development of technologies and a short service life, it causes the rapid replacement of old modifications of devices with new ones, which affects the rapid accumulation of electronic waste. It is also relevant and expedient to direct scientific research in the following works to the issue of determining the main trends of the world, in particular, European and Ukrainian policies in the field of electronic waste management and minimising harm to the environment and directly to the health of consumers.

A further research perspective is the analysis of the state of improvement and implementation of the main norms of normative legal acts aimed at improving the guarantee of consumer safety from potentially hazardous factors of PCs influence.

Conflict of interest

None.

Acknowledgements

None.

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Вимоги до безпечності персональних комп'ютерів

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Анотація. Актуальність дослідження полягає у гарантуванні безпечності персональних комп'ютерів для споживачів (користувачів) та дотримання вимог технічних регламентів в цій частині. Метою дослідження було визначення та аналіз чинників формування асортименту персональних комп'ютерів в умовах дії невизначеності економіко-соціальних особливостей сучасності із фокусуванням на аспектах безпечності та екологічної відповідальності комп'ютерної техніки, як механізму пріоритетності для споживачів. Зроблений акцент на кібербезпеці, важливості захисту персонального комп'ютера від кібератак. У дослідженні були використані методи системного аналізу статистичних баз даних. Відзначені високі темпи розвитку України у сфері комп'ютеризації багатьох ділянок господарства, економіки за 1993-2023 роки. Доведено, що у кожному господарстві, станом на 2024 рік, є по одному персональному комп'ютері, планшету, ноутбуку чи нетбуку. Показано зміни в економіці, політиці, технологічних аспектах та інших зовнішніх чинниках, які можуть впливати на ринок персональних комп'ютерів. Відзначена здатність компаній пристосовуватися до змін і вимог, як ключового джерела їхнього успіху. Наведені ергономічні, антропологічні, психофізіологічні вимоги до екранних пристроїв, що гарантують безпечність споживачів (користувачів). Визначені умови відповідності персональних комп'ютерів вимогам технологічних регламентів в частині екодизайну, спрямованих на покращення екологічної складової безпечності згідно із вимогами споживачів. Показано, що сучасний ринок персональних комп'ютерів має декілька ключових тенденцій у формуванні асортиментної політики, а саме: гнучкі конфігурації та індивідуалізація; підвищена увага до геймерського сегменту; розвиток технологій штучного інтелекту; підвищення обсягів пам'яті та швидкодії; екологічна відповідальність; розвиток бездротових технологій; висока мобільність; орієнтація на високопродуктивні робочі станції. Визначено, що для бізнесу є важливим дотримання вимог екологічної безпеки, оскільки компанії, які приділяють увагу екологічній відповідальності, можуть мати конкурентну перевагу. Показано, що найпоширенішими є стандарти та системи сертифікації персональних комп'ютерів, які є серією сертифікаційних стандартів, що визначають вимоги до екологічної та ергономічної якості комп'ютерного обладнання, зокрема моніторів. Практична значимість результатів полягає у підвищенні конкурентоспроможності персональних комп'ютерів, із урахуванням рекомендацій безпеки споживачів (користувачів) відповідної техніки щодо посилення ролі екологічних аспектів та вимог кібербезпеки

Ключові слова: комп'ютерна техніка; регламент; безпека; кібербезпека; споживач; екологічна відповідальність

COMMODITY BULLETIN
Journal homepage: https://c-bulletin.com.ua/en
DOI: 10.62763/ef/1.2024.105

Article's History: Received: 14.12.2024 Revised: 18.02.2024 Accepted: 26.04.2024

Vol. 17, No. 1, 2024, 105-115

UDC 663.86.054.1

Development of craft drinks with oat milk and fruit and berry powders

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Abstract. Consumption of plant-based milk is growing every year, especially among allergy sufferers and lactose intolerant people. The development of beverages based on it with the addition of nutrients and improved taste properties is a trend among soft drink manufacturers. The purpose of the article is to develop recipes for craft drinks with oat milk and powders from freeze-dried fruits and berries, as well as to determine their sensory and physicochemical characteristics. The research was conducted using the method of expert evaluation of the sensory characteristics of drink compositions, the calculation method for calculating the nutritional and energy value of drinks, qualimetry methods for calculating a comprehensive indicator of drink quality, methods for determining the physicochemical characteristics of drinks, the Color Detector & Catcher mobile application for determining the colour of drinks using the RGB additive colour model, and methods of statistical data processing using Mathcad 14 software. For drinks based on plant-based milk, it is proposed to use powders from freeze-dried fruits and berries as a recipe components. Freeze-dried plant powders preserve the colour, smell and taste of natural raw materials, as well as their nutrients. Model compositions of drinks with oat milk and powders made from freeze-dried mango, blueberries, strawberries, bilberries and raspberries were developed. The best drink compositions with high sensory properties (taste and smell, colour, appearance and consistency) were identified by an expert evaluation method. The density and active acidity of the developed drink compositions were investigated and their nutritional and energy values were calculated. It was found that the density of drinks increases with the increase in the content of fruit and berry powders, and the pH of drinks decreases. It has also been found that an increase in the content of freeze-dried fruit and berry powders in a drink leads to an increase in the content of protein and carbohydrates. Fruit and berry powders fortify drinks with nutrients and diversify their taste and aroma. The proposed drinks can be recommended for implementation in food industry enterprises, craft food production facilities and restaurants

Keywords: plant-based milk; drink recipe; drink properties; freeze-dried fruit; freeze-dried berries

Introduction

The consumption of plant-based milk is increasing globally, driven by its health benefits and the growing number of people with milk protein allergies and lactose intolerance, as well as consumer awareness of the environmental impact of cow's milk production. According to J. Mylan *et al.* (2018), the raw materials for plant-based milk include legumes (soybeans, peanuts, peas, lupins, cowpeas), nuts (almonds, coconut, hazelnuts, pistachios, walnuts, cashews), cereals (oats, rice, corn, spelt), pseudo-cereals (quinoa, teff, amaranth), as well as sesame, flax, hemp and sunflower seeds. Almond, soy and coconut milk are the market leaders (Craig & Fresán, 2021), but oat milk is becoming increasingly popular in this beverage category, with an average annual sales increase of 131.9%. Oat milk is low in sugar and fat, and contains calcium, potassium, phosphorus, iron, vitamins A, B_{12}, and D (Collard & McCormick, 2021). An important area for improving plant-based milk is to improve the sensory properties of these drinks and fortify them with nutrients, which will help increase demand for these products.

Suggested Citation:
Dudarev, I. (2024). Development of craft drinks with oat milk and fruit and berry powders. *Commodity Bulletin*, 17(1), 105-115. doi: 10.62763/ef/1.2024.105.

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Plant-based milk mimics the physicochemical and sensory properties of animal milk. This product should be safe, healthy, tasty and affordable for consumers (Nawaz *et al.*, 2022). The ingredients of plant-based milk are plant raw materials, water, emulsifiers and other additives (flavours, colours, preservatives, stabilisers, thickeners) that ensure the formation of the required functional properties of the final product. The main technological operations for the production of plant-based milk are soaking and wet grinding or dry grinding and extraction, separation of insoluble substances, product formation (addition of other ingredients), homogenisation, heat treatment, nutrient enrichment and packaging. F. Reyes-Jurado *et al.* (2023) found that vitamins, minerals, sweeteners, flavours, colourants, salt, oil, and stabilisers are added during product formulation. The most common stabilisers are carrageenan, rice starch, gelatin, corn dextrin, xanthan gum, guar gum and tapioca starch. Citric acid is used as an antioxidant in the drinks. To improve and diversify the taste of beverages and fortify them with nutrients, various natural raw materials, mainly of plant origin, are used (Saleba *et al.*, 2020).

A promising product on the market is a powder made from freeze-dried fruits, berries and vegetables that retains the colour, aroma and taste of fresh raw materials (Liu *et al.*, 2022). Freeze drying is the preferred method of drying foods containing compounds that are temperature-sensitive and prone to oxidation, as it takes place at low temperatures and high vacuum. Therefore, freeze-drying is the best way to dehydrate fruits, berries and vegeTables in order to maintain an optimised content of bio-compounds in the final product (Fructuoso *et al.*, 2021). Fruits and vegetables in powder form are used in the confectionery, bakery, alcoholic beverage, and other food industries to make a variety of sauces, teas, puddings, natural colours, additives, etc. Freeze-dried fruit powders fortify foods with nutrients and improve flavour and aroma properties and colour. It is important to enrich drinks based on plant-based milk with nutrients and to give these products new flavours, including fruit and berry flavours. Therefore, the aim of the study was to develop recipes for craft drinks based on oat milk and powders obtained from freeze-dried fruits and berries, and to evaluate their sensory, physicochemical characteristics.

Materials and methods

The study was conducted at Lutsk National Technical University (Lutsk, Ukraine) in 2023. The developed model compositions (MCs) of drinks (Tables 1-5) containing ultra-pasteurised oat beverage (hereinafter oat milk), powders (Fig. 1) from freeze-dried fruits and berries (mango, bilberry, strawberry, blueberry, raspberry) were studied.

Figure 1. *Freeze-dried plant powders*
Note: *a – mango (M); b – bilberry (B); c – strawberry (S); d – blueberry (Bl); e – raspberry (R)*
Source: *compiled by the author*

Table 1. *Model drink compositions with oat milk and mango powder*

Recipe component of the drink	The content of components in the model compositions of the drink with oat milk and mango powder, wt. %			
	MC1	MC2(M)	MC3(M)	MC4(M)
Oat milk	100.0	99.0	94.0	89.0
Mango powder	–	1.0	6.0	11.0
Total	100.0	100.0	100.0	100.0

Source: *compiled by the author*

Table 2. *Model drink compositions with oat milk and bilberry powder*

Recipe component of the drink	The content of components in the model compositions of the drink with oat milk and bilberry powder, wt. %			
	MC1	MC2(B)	MC3(B)	MC4(B)
Oat milk	100.0	99.0	94.0	89.0
Bilberry powder	–	1.0	6.0	11.0
Total	100.0	100.0	100.0	100.0

Source: *compiled by the author*

Table 3. *Model drink compositions with oat milk and strawberry powder*

Recipe component of the drink	The content of components in the model compositions of the drink with oat milk and strawberry powder, wt. %			
	MC1	MC2(S)	MC3(S)	MC4(S)
Oat milk	100.0	99.0	94.0	89.0
Strawberry powder	–	1.0	6.0	11.0
Total	100.0	100.0	100.0	100.0

Source: *compiled by the author*

Table 4. *Model drink compositions with oat milk and blueberry powder*

Recipe component of the drink	The content of components in the model compositions of the drink with oat milk and blueberry powder, wt. %			
	MC1	MC2(Bl)	MC3(Bl)	MC4(Bl)
Oat milk	100.0	99.0	94.0	89.0
Blueberry powder	–	1.0	6.0	11.0
Total	100.0	100.0	100.0	100.0

Source: *compiled by the author*

Table 5. *Model drink compositions with oat milk and raspberry powder*

Recipe component of the drink	The content of components in the model compositions of the drink with oat milk and raspberry powder, wt. %			
	MC1	MC2(R)	MC3(R)	MC4(R)
Oat milk	100.0	99.0	94.0	89.0
Raspberry powder	–	1.0	6.0	11.0
Total	100.0	100.0	100.0	100.0

Source: *compiled by the author*

Characteristics of the nutritional value and calorie content of the components of the drink compositions are presented in Table 6. The recipe components of the drink compositions were purchased at a local supermarket (Lutsk, Ukraine).

Table 6. *Nutrient content and calorie content of drink composition components*

Component of drink compositions	Nutrient content and calorie content of drink composition components (per 100 g of component)*			
	Protein, g	Fat, g	Carbohydrates, g	Calorie content, kcal
Oat milk	1.0	2.5	6.5	52.5
Mango powder	4.7	2.2	86.0	382.0
Bilberry powder	7.7	2.1	87.0	398.0
Strawberry powder	4.9	2.5	84.9	381.0
Blueberry powder	8.1	0.8	56.4	265.0
Raspberry powder	8.0	4.3	79.6	389.0

Note: **according to manufacturers*
Source: *developed by the author*

Manufacturers of components of drink compositions:

- oat milk (ultra-pasteurized oat beverage fortified with calcium) – produced by Lustdorf LLC, Illintsi, Vinnytsia region, Ukraine;
- freeze-dried mango, bilberry and blueberry powders – produced by Gulfrost LLC, Byshkiv, Lviv region, Ukraine;
- freeze-dried strawberry and raspberry powders – produced by Ledova LLC, Chornomorsk, Odesa region, Ukraine.

Drink compositions were prepared by mixing oat milk with powders from freeze-dried fruits and berries according to the recipe. The sensory properties (taste and smell, colour, appearance, consistency) of the drink compositions were evaluated by experts according to the methodology (Lawless & Heymann, 2010; Pudovkin, 2021) on a five-point scale. The study was conducted in accordance with the standards set out in the Declaration of Helsinki (1979). The weighting coefficients of these indicators were also calculated based on the results of the expert survey. Statistical processing of the survey results was performed using Mathcad 14 software, which was used to build sensory profiles of drink compositions. In addition to scoring the sensory properties of drink compositions, experts gave their verbal description. The colour of the drink compositions was determined using the camera of the Xiaomi Redmi Note 8 Pro smartphone (China) and the Color Detector & Catcher mobile application, using the RGB additive colour model. Oat milk (MC1) was chosen as the control variant.

The quality indicator of the of drink compositions was calculated by Equation:

$$Q = \frac{m_1 P_1}{P_{b1}} + \frac{m_2 P_2}{P_{b2}} + \frac{m_3 P_3}{P_{b3}} + \frac{m_4 P_4}{P_{b4}}, \quad (1)$$

where m_1, m_2, m_3, m_4 – weighting coefficients of drink sensory indicators, respectively, taste and smell, colour, appearance and consistency; P_1, P_2, P_3, P_4 – sensory indicators of the drink, respectively, taste and smell, colour, appearance and consistency; P_{b1}, P_{b2}, P_{b3}, P_{b4} – basic values of sensory indicators of the drink, respectively, taste and smell, colour, appearance and consistency (5 points).

The nutritional value and calorie content of model compositions of drinks was calculated by Equation:

$$P = \sum_{i=1}^{n} \frac{a_i m_{pi}}{100} \quad F = \sum_{i=1}^{n} \frac{a_i m_{fi}}{100} \quad C = \sum_{i=1}^{n} \frac{a_i m_{ci}}{100}; \quad (2)$$

$$E = 4 \cdot P + 9 \cdot F + 4 \cdot C, \quad (3)$$

where P, F, C – the content of protein, fat and carbohydrates per 100 g of soft drink, g; a_i – the content of the i-th recipe component per 100 g of soft drink, %; m_{pi}, m_{fi}, m_{ci} – the weight, respectively, of protein, fat and carbohydrates per 100 g of the i-th recipe component, g; 4, 9, 4 – the calorie content of 1 g, respectively, of protein, fat and carbohydrates (Capuano *et al.*, 2018), kcal g^{-1}; n – the number of components of the drink composition; E – the calorie content of 100 g of the soft drink, kcal.

The density of drink compositions with oat milk and freeze-dried plant powders was determined by the pycnometric method (Yohannes *et al.*, 2013). The active acidity of the developed drink compositions was determined using a pH-meter (Yohannes *et al.*, 2013). The statistical processing of the study results involved determining the arithmetic mean and standard deviation using Mathcad 14 software.

Results and discussion

The results of the expert verbal characterization of the developed model drink compositions with oat milk and freeze-dried fruit and berry powders are presented in Tables 7-11. The developed drink compositions with a weight content of fruit and berry powders of 1% have a liquid consistency and the appearance of an opaque homogeneous liquid. Drink compositions with a weight content of freeze-dried plant powders of 6% and 11% have, respectively, a liquid sour cream-like and sour cream-like consistency and an appearance of an opaque homogeneous mass.

Table 7. *Sensory characteristics of model compositions of drink with oat milk and mango powder*

Sensory characteristics	Characteristics of indicators for drink compositions			
	MC1	MC2(M)	MC3(M)	MC4(M)
Taste and smell	pleasant oat taste; oat aroma	pleasant oat taste; oat aroma	sweet-sour taste, oat-mango flavour; oat aroma	sweet-sour taste, oat-mango flavour; oat aroma
Colour	RGB (243, 239, 231)	RGB (238, 225, 200)	RGB (245, 218, 161)	RGB (236, 205, 127)
Consistency	liquid	liquid	liquid sour cream-like	sour cream-like
Appearance	opaque, homogeneous liquid	opaque, homogeneous liquid	opaque, homogeneous mass	opaque, homogeneous mass

Source: *developed by the author*

Table 8. *Sensory characteristics of model compositions of a drink with oat milk and bilberry powder*

Sensory characteristics	Characteristics of indicators for drink compositions			
	MC1	MC2(B)	MC3(B)	MC4(B)
Taste and smell	pleasant oat taste; oat aroma	pleasant oat taste; oat aroma	less sour taste, oat and bilberry flavour; oat aroma	sour taste, oat and bilberry flavour; oat aroma
Colour	RGB (243, 239, 231)	RGB (187, 149, 135)	RGB (68, 22, 22)	RGB (29, 16, 16)
Consistency	liquid	liquid	liquid sour cream-like	sour cream-like
Appearance	opaque, homogeneous liquid	opaque, homogeneous liquid	opaque, homogeneous liquid	opaque, homogeneous liquid

Source: *developed by the author*

Table 9. *Sensory characteristics of model compositions of a drink with oat milk and strawberry powder*

Sensory characteristics	Characteristics of indicators for drink compositions			
	MC1	MC2(S)	MC3(S)	MC4(S)
Taste and smell	pleasant oat taste; oat aroma	pleasant oat taste; oat aroma	sour oat and strawberry flavour; oat and strawberry aroma	sour strawberry taste; oat and strawberry aroma
Colour	RGB (243, 239, 231)	RGB (233, 211, 209)	RGB (212, 100, 100)	RGB (140, 24, 28)
Consistency	liquid	liquid	liquid sour cream-like	sour cream-like
Appearance	opaque, homogeneous liquid	opaque, homogeneous liquid	opaque, homogeneous liquid	opaque, homogeneous liquid

Source: *developed by the author*

Table 10. *Sensory characteristics of model compositions of a drink with oat milk and blueberry powder*

Sensory characteristics	Characteristics of indicators for drink compositions			
	MC1	**MC2(Bl)**	**MC3(Bl)**	**MC4(Bl)**
Taste and smell	pleasant oat taste; oat aroma	pleasant oat taste; oat aroma	sour berry flavour; light oat aroma	sour berry flavour; light oat aroma
Colour	RGB (243, 239, 231)	RGB (175, 164, 186)	RGB (94, 56, 100)	RGB (61, 39, 58)
Consistency	liquid	liquid	liquid sour cream-like	sour cream-like
Appearance	opaque, homogeneous liquid	opaque, homogeneous liquid	opaque, homogeneous liquid	opaque, homogeneous liquid

Source: *developed by the author*

Table 11. *Sensory characteristics of model compositions of a drink with oat milk and raspberry powder*

Sensory characteristics	Characteristics of indicators for drink compositions			
	MC1	**MC2(R)**	**MC3(R)**	**MC4(R)**
Taste and smell	pleasant oat taste; oat aroma	oat-raspberry taste with sourness; oat aroma	sour raspberry flavour; light oat and raspberry aroma	sour raspberry flavour; light oat and raspberry aroma
Colour	RGB (243, 239, 231)	RGB (240, 224, 224)	RGB (231, 163, 172)	RGB (203, 96, 119)
Consistency	liquid	liquid	liquid sour cream-like	sour cream-like
Appearance	opaque, homogeneous liquid	opaque, homogeneous liquid	opaque, homogeneous mass	opaque, homogeneous mass

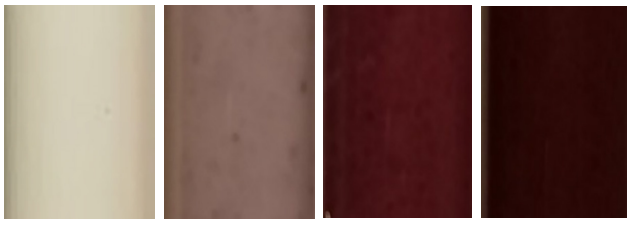
Source: *developed by the author*

Drink compositions with an increase in the content of fruit and berry powders develop a more intense taste and smell, which is typical of the raw materials used. The taste also becomes more sour, especially for compositions with berry powders. The colour of drink compositions with different fruit and berry powders is shown in Figures 2-6, and its characteristics using the additive RGB colour model are shown in Tables 7-11. The colour of the drinks depends on the colour of the raw material used (fruit or berry powder) and becomes more saturated with an increase in the content of this raw material.

MC1 *MC2(M)* *MC3(M)* *MC4(M)*

Figure 2. *Colour of the drink compositions with oat milk and mango powder*

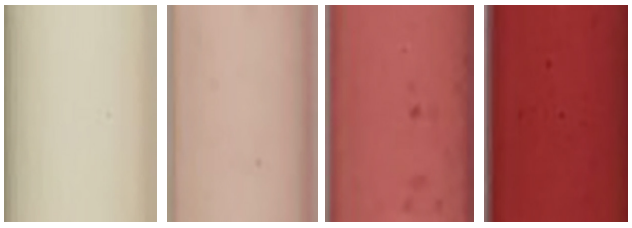
Source: *developed by the author*



MC1 *MC2(B)* *MC3(B)* *MC4(B)*

Figure 3. *Colour of the drink compositions with oat milk and bilberry powder*

Source: *developed by the author*



MC1 *MC2(S)* *MC3(S)* *MC4(S)*

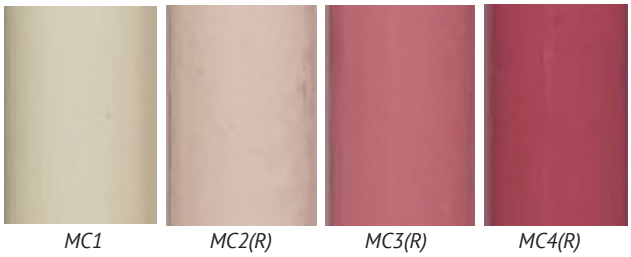
Figure 4. *Colour of the drink compositions with oat milk and strawberry powder*

Source: *developed by the author*

MC1 *MC2(Bl)* *MC3(Bl)* *MC4(Bl)*

Figure 5. *Colour of the drink compositions with oat milk and blueberry powder*

Source: *developed by the author*



MC1 *MC2(R)* *MC3(R)* *MC4(R)*

Figure 6. *Colour of the drink compositions with oat milk and raspberry powder*

Source: *developed by the author*

Sensory profilograms of drink compositions with oat milk and freeze-dried plant powders are shown in Figure 7. Among the developed drinks with mango powder (Fig. 7a), composition MC4(M) has the highest scores for taste and smell and colour. Compositions MC2(M) and MC3(M) have the highest scores for appearance and consistency.

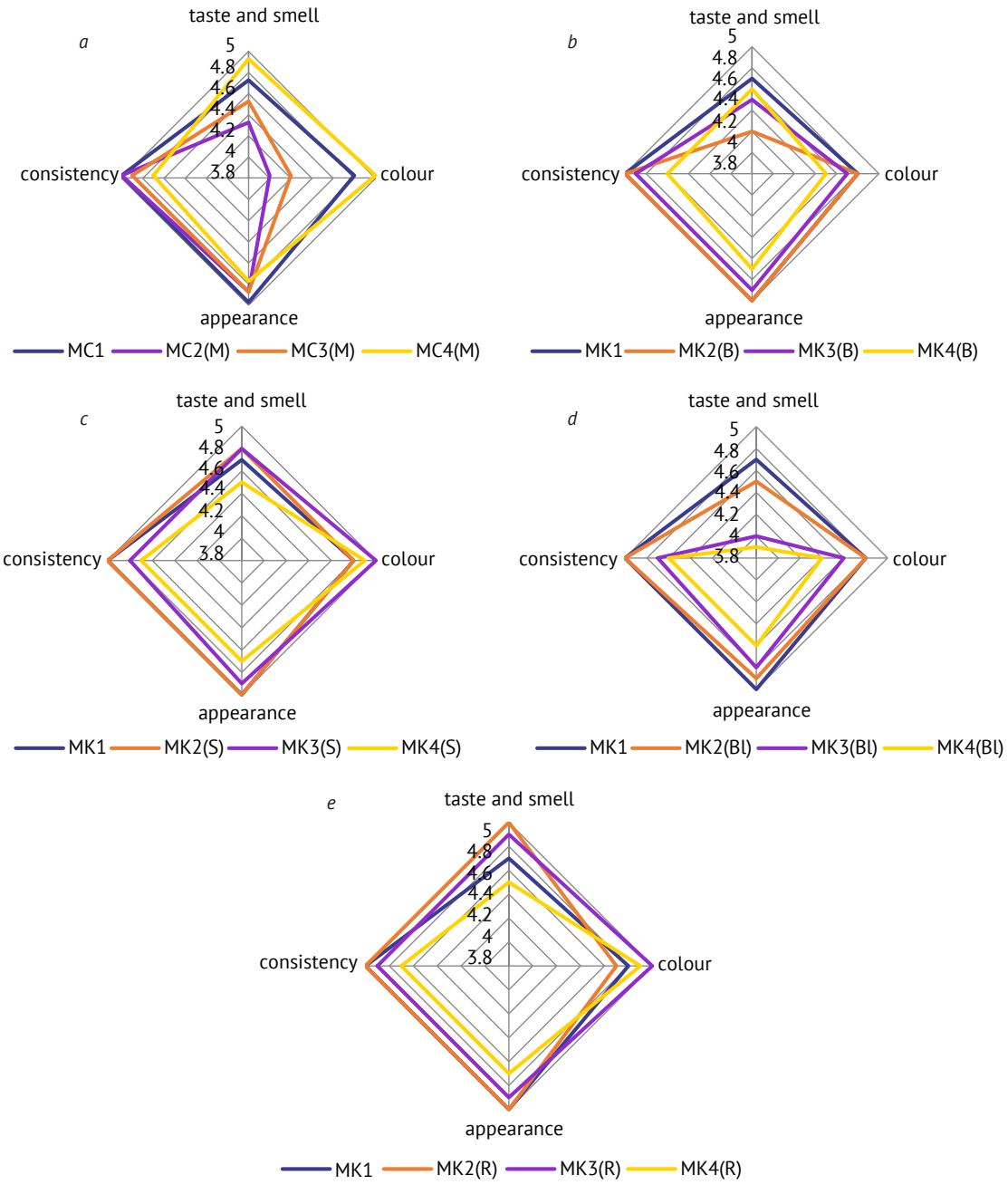


Figure 7. *Sensory profiles of drink compositions with oat milk and freeze-dried plant powders*

Note: *a – mango powder; b – bilberry powder; c – strawberry powder; d – blueberry powder; e – raspberry powder*
Source: *developed by the author*

The taste and smell of composition MC4(B) were rated by experts as the highest among drinks with bilberry powder (Fig. 7b). However, the highest scores for colour, appearance and consistency were given to composition MC2(B). Among the compositions of the drink with freeze-dried strawberry powder, the highest scores for all sensory indicators (Fig. 7c), except for colour, were obtained by composition MC2(S), and for colour – by MC3(S). The highest scores for all sensory indicators of drinks with blueberry powder were obtained by composition MC2(Bl) (Fig. 7d). Taste and smell, appearance and consistency of composition MC2(R) were rated by experts as the highest among the developed compositions with freeze-dried raspberry powder (Fig. 7d).

The highest score for the colour indicator was given to composition MC3(R).

Following an expert evaluation of the importance of sensory characteristics for drinks with oat milk and freeze-dried plant powders, sensory indicator weighting coefficients were calculated: taste and smell – $m_1 = 0.4$; colour – $m_2 = 0.2$; appearance – $m_3 = 0.15$; consistency – $m_4 = 0.25$. According to experts, the most important indicators of drink quality are taste, smell and consistency.

According to the sensory characteristics of drink compositions, the values of the quality indicator Q calculated by Equation (1) are shown in Figure 8. The highest values of the Q indicator were found in the drink compositions with oat milk and freeze-dried plant powders (Fig. 8):

- among the compositions with mango powder: MC4(M) – $Q = 0.971$;
- among the compositions with bilberry powder: MC3(B) – $Q = 0.94$;
- among the compositions with strawberry powder: MC2(S) – $Q = 0.976$;
- among the compositions with blueberry powder: MC2(Bl) – $Q = 0.949$;
- among the compositions with raspberry powder: MC2(R) – $Q = 0.988$.

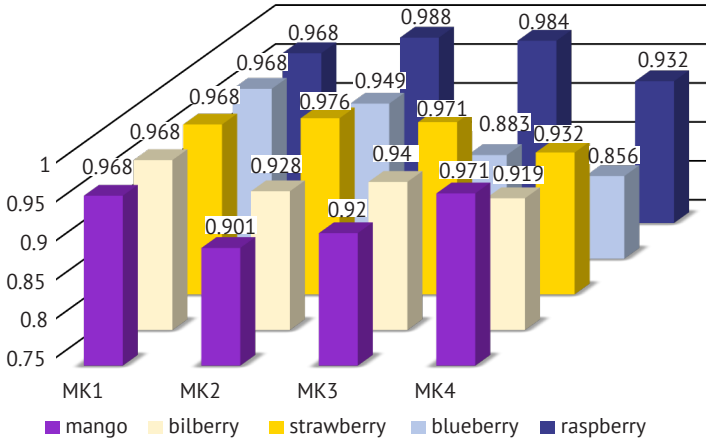


Figure 8. *Quality indicator Q for sensory characteristics of drink compositions with oat milk and freeze-dried plant powders*

Source: *developed by the author*

The results of calculating the nutritional value and calorie content of the drink compositions with oat milk and freeze-dried plant powders are presented in Table 12. Regardless of the fruit and berry powders, increasing their content in the drink results in an increase in protein and carbohydrate content compared to the control. The protein content in the drink compositions varies within the following range (per 100 g of drink): with mango or strawberry powder – 1.0-1.4 g; with bilberry powder – 1.1-1.7 g; with blueberry or raspberry powder – 1.1-1.8 g. Thus, by adding fruit and berry powders, the protein content of the drinks increases by up to 80% compared to oat milk. The content of carbohydrates in the drink compositions varies within the following ranges (per 100 g of drink): with mango powder – 7.3-15.2 g; with bilberry powder – 7.3-15.4 g; with strawberry powder – 7.3-15.1 g; with blueberry powder – 7.0-12.0 g; with raspberry powder – 7.2-14.5 g. Due to the addition of fruit and berry powders, the content of carbohydrates in the drinks increases by 7.7-136.9% compared to oat milk. There are no significant changes in the fat content of drinks with mango, bilberry and strawberry powder compared to oat milk. In drinks with blueberry powder, compared to the control variant, the fat content with an increase in the powder content within 1-11% decreases from 2.5 to 2.3%, and in drinks with raspberry – increases from 2.5 to 2.7%.

Table 12. *Nutritional value and calorie content of drink compositions with oat milk and freeze-dried plant powders*

Drink compositions	Nutritional value and calorie content of drink compositions (per 100 g of drink)			
	Protein, g	Fat, g	Carbohydrates, g	Calorie content, kcal
MC1	1.0	2.5	6.5	52.5
MC2(M)	1.0	2.5	7.3	54.0
MC3(M)	1.2	2.5	11.3	69.5
MC4(M)	1.4	2.5	15.2	85.0
MC2(B)	1.1	2.5	7.3	54.1
MC3(B)	1.4	2.5	11.3	70.4
MC4(B)	1.7	2.5	15.4	86.6
MC2(S)	1.0	2.5	7.3	54.0
MC3(S)	1.2	2.5	11.2	69.5

Table 12. Continued

Drink compositions	Nutritional value and calorie content of drink compositions (per 100 g of drink)			
	Protein, g	Fat, g	Carbohydrates, g	Calorie content, kcal
MC4(S)	1.4	2.5	15.1	84.9
MC2(Bl)	1.1	2.5	7.0	52.9
MC3(Bl)	1.4	2.4	9.5	62.9
MC4(Bl)	1.8	2.3	12.0	72.9
MC2(R)	1.1	2.5	7.2	54.1
MC3(R)	1.4	2.6	10.9	70.0
MC4(R)	1.8	2.7	14.5	85.9

Source: *developed by the author*

The calorie content of the developed drink compositions is higher than that of oat milk and ranges from 52.9-86.6 kcal 100 g^{-1}, and it increases with the increase in the content of fruit and berry powders.

The results of determining the density and active acidity of the developed drink compositions with oat milk and freeze-dried plant powders are given in Table 13. The density of oat milk is 1031.4 ± 2.3 kg m^{-3}. The density of drinks with an increase in the content of fruit and berry powders within 1-11% increases and varies within the range: for compositions with mango powder – 1033.6-1052.4 kg m^{-3}; for compositions with bilberry powder – 1033.9-1054.1 kg m^{-3}; for compositions with strawberry powder – 1033.8-1052.8 kg m^{-3}; for compositions with blueberry powder – 1032.9-1044.1 kg m^{-3}; for compositions with raspberry powder – 1033.7-1048.5 kg m^{-3}.

Table 13. *Physicochemical characteristics of drink compositions*

Composition indicators	Value of the indicators			
Compositions with mango powder	**MC1**	**MC2(M)**	**MC3(M)**	**MC4(M)**
Density, kg m^{-3}	1031.4 ± 2.3	1033.6 ± 1.8	1043.7 ± 2.5	1052.4 ± 2.8
Active acidity (pH)	7.1 ± 0.2	6.3 ± 0.1	5.0 ± 0.0	4.5 ± 0.1
Compositions with bilberry powder	**MC1**	**MC2(B)**	**MC3(B)**	**MC4(B)**
Density, kg m^{-3}	1031.4 ± 2.3	1033.9 ± 1.6	1044.5 ± 2.9	1054.1 ± 2.5
Active acidity (pH)	7.1 ± 0.2	5.6 ± 0.0	4.0 ± 0.1	3.6 ± 0.0
Compositions with strawberry powder	**MC1**	**MC2(S)**	**MC3(S)**	**MC4(S)**
Density, kg m^{-3}	1031.4 ± 2.3	1033.8 ± 2.0	1043.9 ± 2.4	1052.8 ± 2.1
Active acidity (pH)	7.1 ± 0.2	5.4 ± 0.1	4.0 ± 0.0	3.6 ± 0.0
Compositions with blueberry powder	**MC1**	**MC2(Bl)**	**MC3(Bl)**	**MC4(Bl)**
Density, kg m^{-3}	1031.4 ± 2.3	1032.9 ± 2.3	1038.4 ± 2.0	1044.1 ± 1.9
Active acidity (pH)	7.1 ± 0.2	5.2 ± 0.0	3.8 ± 0.0	3.4 ± 0.0
Compositions with raspberry powder	**MC1**	**MC2(R)**	**MC3(R)**	**MC4(R)**
Density, kg m^{-3}	1031.4 ± 2.3	1033.7 ± 2.1	1040.2± 2.5	1048.5 ± 1.4
Active acidity (pH)	7.1 ± 0.2	5.0 ± 0.1	3.5 ± 0.0	3.3 ± 0.0

Source: *developed by the author*

The active acidity (pH) of oat milk is 7.1 ± 0.2. With an increase in the content of fruit and berry powders in the drink compositions, the pH of the drinks decreases. In particular, with the content of fruit and berry powders in the range from 1% to 11%, the pH of the drink compositions fluctuates: for compositions with mango powder – from 6.3 ± 0.1 to 4.5 ± 0.1; for compositions with bilberry powder – from 5.6 ± 0.0 to 3.6 ± 0.0; for compositions with strawberry powder – from 5.4 ± 0.1 to 3.6 ± 0.0; for compositions with blueberry powder – from 5.2 ± 0.0 to 3.4 ± 0.0; for compositions with raspberry powder – from 5.0 ± 0.1 to 3.3 ± 0.0.

Many scientists have conducted similar studies. For example, D.J. McClements *et al.* (2020) examined the scientific aspects of formulating the composition, production technology and quality assurance of milk substitutes. Understanding the scientific principles of the development and production of plant-based milk products is important for increasing their usefulness and acceptance by consumers in the soft drinks market. A.R.A. Silva *et al.* (2020) found that alternatives to milk can have benefits, such as lower saturated fat and cholesterol, and supply of essential nutrients such as calcium and vitamin D. However, they can also pose challenges related to allergens and additives. From a technological point of view, the development and production of plant-based alternatives to milk requires careful selection of raw materials and processing methods to achieve the desired taste, texture and stability, making this an active area of research and development in the food industry. A. Sousa & K.A.K. Bolanz (2017) state that the composition of plant milk varies depending on

the raw material in terms of macro- and microelements, the presence of biologically active compounds and anti-nutrients. Plant-based beverages contain bioactive substances, in particular, soy-based beverages contain isoflavones and phytosterols, almond-based beverages contain α-tocopherol and arabinose, and oat-based beverages contain β-glucan (Karam *et al.*, 2016; Fructuoso *et al.*, 2021). Fortification of drinks can cause significant changes in their physicochemical properties and affect the taste of the product, as noted by A. Angelov *et al.* (2018), E. Vasquez-Orejarena *et al.* (2018). Therefore, it is important that the sensory properties of plant-based milk are acceptable to consumers, as this affects the success of the product on the market (Gorman *et al.*, 2021).

In the scientific study by C. Alsado *et al.* (2023), it was proposed to fortify oat milk with β-glucan (6.25 g L^{-1}). Soluble fibre in the form of β-glucans reduces LDL cholesterol (low-density lipoprotein), in particular, consumption of 750 ml of oat milk with a β-glucan content of 0.5 g 100 g^{-1} per day reduces LDL cholesterol (Chalupa-Krebzdak *et al.*, 2018).

In the scientific study by H. Zhou *et al.* (2021), it was proposed to fortify almond milk with calcium and vitamin D, the lack of which in the human body can cause long-term health problems. Almond milk contains 6.33 mg 100 g^{-1} of vitamin E, which is 42% of the recommended daily dose of 15 mg. Hemp milk contains α-linoleic acid 0.4 g 100 mL^{-1}, which is 25% of the recommended daily dose of 1.6 g.

At the same time, the plant raw materials used for the production of plant-based milk have disadvantages. S. Chalupa-Krebzdak *et al.* (2018) proved that, in particular, cereals and legumes contain phytic acid, which is considered an anti-nutrient due to its ability to combine with macro- and microelements (calcium, zinc, iron, magnesium and copper) to create insoluble complexes of these minerals that prevent their absorption in the intestine. Soybeans, almonds, cashews and other nuts contain oxalates, which not only interfere with calcium absorption but also act as a component in the formation of calcium stones in the kidneys. Soybeans, peanuts and other beans contain lectins that inhibit the absorption of glucose in the intestine. Soybeans, oats, peas and beans also contain saponins, which affect the digestion of proteins by creating insoluble saponin-protein complexes.

Scientists A. Drewnowski *et al.* (2021) proposed requirements (standard) for the nutrient content of plant-based beverages (per 100 g), which are positioned as an alternative to traditional milk: protein – more than 2.2 g; saturated fat – less than 0.75 g; added sugar – less than 5.3-6.25 g; sodium – less than 120 mg; calcium, vitamins A, D, B_2 and B_{12} – in a 200 g serving, more than 15% of the daily requirement; calorie content – less than 85-100 kcal.

As a result of the current study, model compositions of drinks with high sensory characteristics, including taste, smell, colour, appearance and consistency, were developed. The physicochemical properties of these drinks were also investigated and it was found that the use of powders from freeze-dried fruits and berries enriches the drinks with useful substances and makes them more diverse in taste and aroma. The results of the study indicate the potential of the proposed drinks for implementation in the food industry, craft production and restaurant business.

Conclusions

Using freeze-dried fruit and berry powders to make oat milk-based drinks is promising, because these drinks are fortified with nutrients. Freeze-dried fruit and berries, particularly in powder form, retain macro- and microelements and vitamins contained in fresh fruit and berries without significant loss. Plant powders also preserve the colour, taste and aroma of fresh fruit and berries. The use of powders in drinks helps to expand the range of non-alcoholic drinks that are plant-based alternatives to milk for vegans and consumers who are allergic to milk protein and lactose intolerant or who do not consume animal-based beverages for other ethical or environmental reasons. Among the developed and studied craft drink compositions, the following are recommended for implementation, which have the highest values of the quality indicator: composition: oat milk – 89 wt.%, mango powder – 11 wt.%; composition: oat milk – 94 wt.%, bilberry powder – 6 wt.%; composition: oat milk – 99 wt.%, strawberry powder – 1 wt.%; composition: oat milk – 99 wt.%, blueberry powder – 1 wt.%; composition: oat milk – 99 wt.%, raspberry powder – 1 wt.%.

The density of the recommended drinks with oat milk and fruit and berry powders ranges from 1032.9 to 1052.4 kg m^{-3}. The active acidity (pH) of the recommended drinks ranges from 4.0 to 5.4. The addition of fruit and berry powders to oat milk increases the content of protein and carbohydrates in the drinks. The calorie content of the proposed drinks ranges from 52.9-85.0 kcal 100 g^{-1}. The developed drinks with freeze-dried strawberry, blueberry and raspberry powder have a liquid consistency, and the drinks with freeze-dried mango and bilberry powder have a creamy consistency, which makes them similar to smoothies. The colour of the developed craft drinks corresponds to the fruit and berry raw materials used, and its intensity depends on the content of these raw materials.

Further research should be directed towards the development of drinks with different combinations of powders from freeze-dried berries, fruits and vegetables, as well as using different plant-based milk.

Conflict of interest

None.

Acknowledgements

None.

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Розроблення крафтових напоїв з «вівсяним молоком» та фруктово-ягідними порошками

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Анотація. Споживання «рослинного молока» зростає щороку, особливо серед алергіків та осіб з непереносимістю лактози. Розробка напоїв на його основі із додаванням корисних речовин та поліпшенням смакових властивостей є трендом серед виробників безалкогольних напоїв. Мета статті – розроблення рецептур крафтових напоїв з «вівсяним молоком» та порошками із сублімованих фруктів і ягід, а також визначення їх органолептичних і фізико-хімічних показників. Дослідження проводили, застосовуючи метод експертного оцінювання органолептичних показників композицій напоїв, розрахунковий метод обчислення поживної та енергетичної цінності напоїв, методи кваліметрії для обчислення комплексного показника якості напоїв, методи визначення фізико-хімічних показників напоїв, мобільний застосунок Color Detector & Catcher для визначення кольору напоїв із використанням адитивної колірної моделі RGB, методи статистичного оброблення даних із використанням комп'ютерного програмного забезпечення Mathcad 14. Для напоїв на основі «рослинного молока» запропоновано в якості рецептурного компонента використовувати порошки із сублімованих фруктів і ягід, спосіб виробництва яких дозволяє зберегти колір, аромат та смак натуральної сировини, а також її корисні речовини. Розроблені модельні композиції напоїв з «вівсяним молоком» та порошками із сублімованих манго, чорниці, полуниці, лохини та малини. Експертне оцінювання дозволило визначити кращі композиції напоїв, що мають високі органолептичні властивості (смак і запах, колір, зовнішній вигляд та консистенцію). Досліджені густина та активна кислотність розроблених композицій напоїв та обчислена їх поживна і енергетична цінність. Встановлено, що густина напоїв зі збільшенням вмісту фруктово-ягідних порошків збільшується, а показник pH напоїв – зменшується. Також встановлено, що збільшення вмісту в напої порошків із сублімованих фруктів і ягід спричиняє збільшення у ньому вмісту білків та вуглеводів. Використання фруктово-ягідної сировини в рецептурі напоїв дозволяє збагатити їх корисними речовинами та урізноманітнити смак і аромат. Запропоновані напої можуть бути рекомендовані до впровадження на підприємствах харчової промисловості, на крафтових виробництвах харчових продуктів та у закладах ресторанного господарства

Ключові слова: рослинне молоко; рецептура напою; властивості напою; сублімовані фрукти; сублімовані ягоди

COMMODITY BULLETIN
Journal homepage: https://c-bulletin.com.ua/en
DOI: 10.62763/ef/1.2024.116

Article's History: Received: 15.11.2024 Revised: 24.01.2024 Accepted: 26.04.2024

Vol. 17, No. 1, 2024, 116-124

UDC 677.1.5

Controlled diffusion of medical textile materials filled with nanomagnetic components

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Abstract. The actuality of the research is defined by the need of creation means for wound treating, the insufficient development of methods of the use of the possibilities of modern nanomaterials. The purpose is to substantiate the possibility of creating materials of a given structure to ensure controlled liquid removal using magnetic nanocomponents. The research involved methods of solving the nonlinear diffusion equation, macroexperiments on liquid sorption by materials filled with nanocomponents. The main approaches and boundary conditions for solving nonlinear equations are substantiated. The approximate analytical solution of the diffusion equation clearly highlighted the possibility of finding the basic diffusion coefficient and the inhibition coefficient, which determines the nonlinear nature of the sorption process. Two experiments register the liquid reaching the opposite surface of the healing material and the mass of the accumulated liquid at a certain time. It has been proven that the introduction of magnetic nanocomponents into the structure of medical materials affects the sorption processes. The addition of magnetic nanocomponents at the initial moment reduces the diffusion coefficients. At the same time, the content of such components increases the bacteriostatic properties of the material. The organisation of the sorption process in the conditions of a variable magnetic field significantly affects the sorption process. An increase in the magnetic field strength significantly increases the diffusion coefficient and decreases the braking coefficient. The dependence of the diffusion coefficients on the content of nanocomponents and the strength of the magnetic field is given in the article. These data make it possible to predict the diffusion properties of the material, as well as to determine the process parameters that provide the specified sorption parameters. The practical value is determined by the possibility of creating materials for the treatment of wounds with adjustable intensity of exudate removal

Keywords: fabric; wound; sorption; nanostructure; exudate removal

Suggested Citation:
Riabchykov, M., Nazarchuk, L., & Tkachuk, O. (2024). Controlled diffusion of medical textile materials filled with nanomagnetic components. *Commodity Bulletin*, 17(1), 116-124. doi: 10.62763/ef/1.2024.116.

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Introduction

The relevance of the research is determined by the contradiction between the need to create effective methods for treating wounds, the potential opportunities of nanocomponents in textile materials and the need to determine their real impact. The particular importance can be related to war in Ukraine that cause the introduction of the latest technologies related to humanitarian issues. In particular, this applies to the treatment of wounds. In some cases, wound treatment involves the use of special bandages. One of the main requirements for such means, as noted by D. Arcangeli *et al*. (2023), should be the removal of exudate from purulent wounds. Optimisation of the wound healing process is related to the possibility of regulating the sorption process. Innovative approaches to creating connections with the necessary authorities have grown significantly. The main requirements for medical textiles and the main achievements in this field are given in the study of R. Rathinamoorthy (2023). At the same time Y.-S. Ho *et al*. (2022) substantiated the main directions of further research on the improvement of wound dressings, which are related to bacteriostatic properties and regulated removal of exudate. The main requirements for fibers and materials are aimed at the intrinsic properties of fibers and textile materials, as described by Y. Qin (2023). In a significant number of studies, the provision of most properties of medical textile materials is associated with the introduction of nanotechnology and nanomaterials. S. Tripathi *et al*. (2023) note the emergence of an additional therapeutic effect in medical textile materials using nanocomponents. As sorption processes related to the structure of the material, the use of porous structures may be relevant for such a system, as shown by M. Nasir *et al*. (2023). In the study of M. Riabchykov *et al*. (2021) the possibility of creating materials with specified porosity parameters, which can be used to create materials with specified sorption parameters is showed.

Thus, the following requirements for medical materials, main achievements and unresolved issues can be noted. The main principle of wound treatment with the help of textile medical materials is the removal of exudate. For each wound, it is desirable to ensure the specified efficiency of this process. The removal process is related to diffusion processes in the material. Theoretically, the sorption process is described by nonlinear differential equations, the general methods of which do not exist. Promising nanocomponents in the composition of textile materials can provide a given structure and corresponding sorption parameters. The location of such materials in the magnetic field additionally regulates these processes. Such materials can demonstrate qualitatively new properties, provide favourable regulation of exudate sorption and, accordingly, more effective treatment. It should be determined that the use of magnetic nanocomponents to regulate sorption parameters is a promising but unexplored direction in the field of medical textiles. At the same time, the determination of normalised diffusion rates for such materials in the express mode remains an insufficiently substantiated issue.

The purpose of this work consists in the justification of the creation of materials with specified parameters of exudate sorption based on the use of nanocomponents in magnetic field conditions.

Materials and methods

The first task for conducting research is to justify the methodology for determining sorption parameters.

Sorption characteristics of the material are related to diffusion processes. This process is described by a nonlinear differential equation taking into account the complex dependence of the diffusion coefficient on the liquid content:

$$\frac{\partial U}{\partial t} = \frac{\partial}{\partial x} D \frac{\partial U}{\partial x}, \quad (1)$$

where U – the liquid content in relative units to full density.

The diffusion coefficient depends on the liquid content:

$$D = D_0(1 + \sigma \cdot U). \quad (2)$$

In such conditions, the diffusion process is determined by two parameters. The static diffusion coefficient D_0 can theoretically be determined by traditional methods. Methods for determining the saturation coefficient σ are generally unknown. The diffusion equation does not have exact analytical solutions. Approximate solutions given, for example, in the article of L. Yan *et al*. (2023) should be developed for an operational approximate solution.

To determine the diffusion coefficients, a modified semi-emeric method was used. Such method was described by S. Arabuli *et al*. (2018). It consists in the use of analytical dependencies compatible with express experiments on liquid absorption. This method requires the use of analytical solution methods, since the main diffusion constants remain unknown in the solution process. The theory of differential equations indicates that two unknown constants require the use of at least two conditions. Considering the fact that the mass growth of the textile material in the sorption process can be found under experimental conditions, at least two such experiments must be conducted.

Determination of diffusion coefficients is not the end of this work itself. In order to regulate the sorption process, nanomagnetic powder consisting of a mixture of ferric and ferric oxides is added to porous textile materials. Such a powder is synthesised as a result of the process described by M. Riabchykov *et al*. (2022).

The structural characteristics of the material obtained with the inclusion of nanocomponents were determined by microscopy methods.

Sorption processes in the material were determined by weighing methods, as a result, the main indicators and diffusion constants were found. Taking into account the real magnetic properties of the obtained material, a hypothesis was made about the influence of the magnetic field on the structure and dimensions of the cavities inside the material, which should undoubtedly affect the sorption indicators. In order to study this process, a porous material containing magnetic nanocomponents was placed inside a ring magnet with the possibility of adjusting the magnetic field tension. Sorption properties were determined for several cases of stress and content of magnetic nanocomponents.

Results and discussion

The first step of this study was the substantiation of express methods for determining diffusion coefficients. The calculation scheme for the passage of liquid through the material is shown in Figure 1.

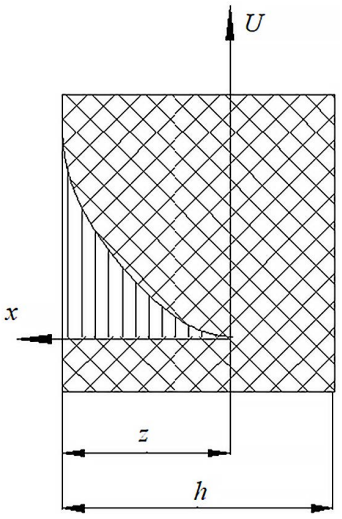


Figure 1. *Calculation scheme of the liquid sorption process*

Source: *developed by the authors on the base of L. Yan et al. (2023)*

A material of thickness *h* is subjected to the action of a liquid from one side. Wetting occurs on the left side of the material. At the same time, complete saturation of the material with liquid is observed at this point, i.e., the saturation value $U = 1$. In a certain time *t*, the liquid reaches a certain point inside the material. In the figure, this distance is denoted by *z*. The differential equation of diffusion in conditions of substituting the diffusion coefficient depending on the liquid content can be converted to the form:

$$\frac{\partial U}{\partial t} = D_0\left(\frac{\partial^2 U}{\partial x^2} + \sigma\left(\frac{\partial U}{\partial x}\right)^2 + \sigma \cdot U \cdot \frac{\partial^2 U}{\partial x^2}\right). \quad (3)$$

The equation has a pronounced non-linear appearance, as it contains terms that include derivatives raised to certain powers. There are no exact methods for solving such equations. To find an approximate equation, was estimated a possible solution taking into account the boundary conditions. For ease of approximation, the origin of the coordinates is located at the point of reaching the liquid. The *x* coordinate from this point was directed to the plane from where wetting occurs.

In this case, the boundary conditions can be written in the form:

$$\begin{aligned} U&=1,\ x=z,\\ U&=0,\ x=0. \end{aligned} \quad (4)$$

A power function meets these conditions. In a simpler form, it can be written as:

$$U = \left(\frac{x}{z}\right)^n. \quad (5)$$

In this expression, it is necessary to determine the exponent of the power function. After substituting into the differential equation, it's possible to can get an equation in which the distance traveled by the liquid is the unknown.

$$\frac{dz}{dt} = -D_0\frac{n}{z}\left[\frac{n-1}{n}\left(\frac{x}{z}\right)^{-2} + \sigma\frac{2n+1}{n}\left(\frac{x}{z}\right)^{n-2}\right]. \quad (6)$$

In the future the dimensionless coordinate will be used for convenience:

$$\vartheta = \frac{z}{h}. \quad (7)$$

Then the equation will be rewritten in the form:

$$\frac{d\vartheta}{dt} = -\frac{D_0}{h}\frac{n}{\vartheta}\left[\frac{n-1}{n}\frac{1}{\vartheta^2} + \sigma\frac{2n+1}{n}\vartheta^{n-2}\right]. \quad (8)$$

It is necessary to take into account fact that the thickness of the material for bandages is small. So, it can be possible to ensure equality at two points, $\vartheta = 0.5$, $\vartheta = 1$. This condition will provide a solution:

$$4\frac{n-1}{n} + \sigma\frac{2n+1}{n}\left(\frac{1}{2}\right)^{n-2} = \frac{n-1}{n} + \sigma\frac{2n+1}{n}. \quad (9)$$

The last equality allows to find the coefficient of nonlinearity depending on the exponent:

$$\sigma = 3\frac{n-1}{2n+2}\cdot\frac{2^{n-2}}{2^{n-2}-1}. \quad (10)$$

At the same time, the distance of liquid diffusion into the material can be determined from the equation:

$$\frac{d\vartheta}{dt} = -\frac{D_0}{h}\frac{n}{\vartheta}\left[\frac{n-1}{n} + \sigma\frac{2n+1}{n}\right]. \quad (11)$$

This equation can be solved exactly. Thus, the dependence of the liquid penetration depth on time can be written in the form:

$$\vartheta = 1 - exp\left\{-\frac{D_0}{h}[n - 1 + \sigma(2n + 1)]t\right\}. \quad (12)$$

In this equation, the degree and the diffusion coefficient remain unknown. Two results are necessary for the experimental determination of the exponent. The mass of liquid accumulated in the material can be found as an integral:

$$M = A \cdot \rho \int_0^z U(x)dx = A \cdot \rho \int_0^z \left(\frac{x}{z}\right)^n dx = \frac{A \cdot h \cdot \rho \cdot \vartheta}{n+1}. \quad (13)$$

In this equation, A determines the area of action of the sorption process:

$$\mu = \frac{M}{A \cdot h \cdot \rho}. \quad (14)$$

When the liquid reaches the opposite boundary, a wetted zone begins to appear on this boundary, which can be fixed. At the same time, the mass of the sample with accumulated liquid can be determined:

$$\mu_0 = \frac{1}{n+1}. \quad (15)$$

The obtained experimental results allow to determine the degree indicator immediately:

$$n = \frac{1-\mu}{\mu}. \quad (16)$$

The use of this indicator immediately determines the value of the braking coefficient σ according to the above expression. Integration taking into account the change in the liquid distribution zone determines the mass of the accumulated liquid after a certain time interval.

$$\mu(t) = \frac{1 - exp\left\{-\frac{D_0}{h}[n-1+\sigma(2n+1)]t\right\}}{n+1}. \quad (17)$$

Weighing the sample over a specified interval allows to determine directly the value of the static diffusion coefficient, taking into account the real spread of the liquid and the presence of the braking process in the process of liquid accumulation. Obvious transformations give an expression for this indicator in the form:

$$D_0 = \frac{h}{[n-1+\sigma(2n+1)]t} ln\big(1 - \mu(t) \cdot (n + 1)\big). \quad (18)$$

Thus, the process of determining of the diffusion coefficients includes two measurements of the mass of the accumulated liquid. The first measurement determines the mass after a certain period of time while the liquid is inside the material. The second experiment measures the mass of accumulated liquid after wetting the opposite side. This value allows to determine immediately the indicator of the degree of the function of the spread of the liquid during using the dependence shown in Figure 2.

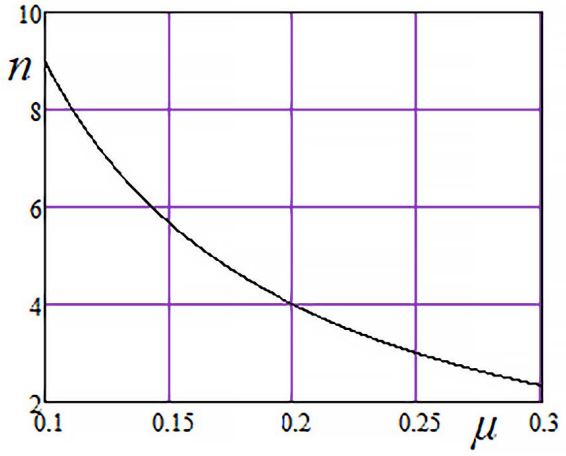


Figure 2. *Indicator of the degree of the distribution function depending on the accumulated liquid*
Source: *developed by the authors*

The inhibition coefficient associated with the nonlinear component of the differential equation determines the influence of the liquid already accumulated in the material on the sorption properties. Considering the above equations, this coefficient can be determined using the dependence shown in Figure 3.

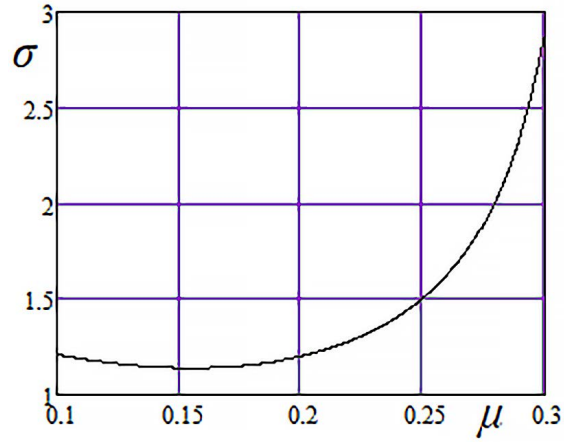


Figure 3. *Braking coefficient depending on the amount of accumulated liquid*
Source: *developed by the authors*

The static diffusion coefficient can be determined based on the liquid accumulated in the material after a certain period of time. At the same time, the dependence will have three factors that must be taken into account. These factors include the total accumulated liquid, the time that must be less than the full soaking time, and the amount of accumulated liquid up to that time. For example, these indicators were determined theoretically for a liquid content of 0.05 from full for different moments of time (Fig. 4).

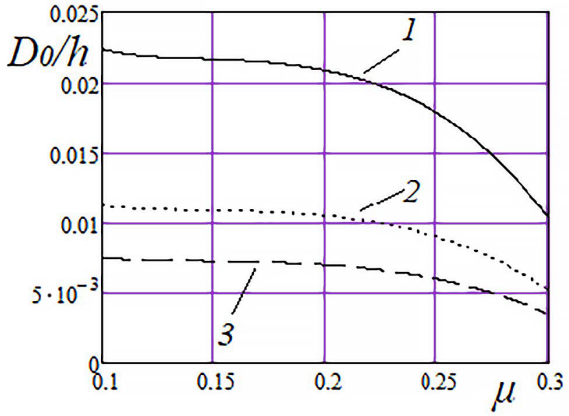
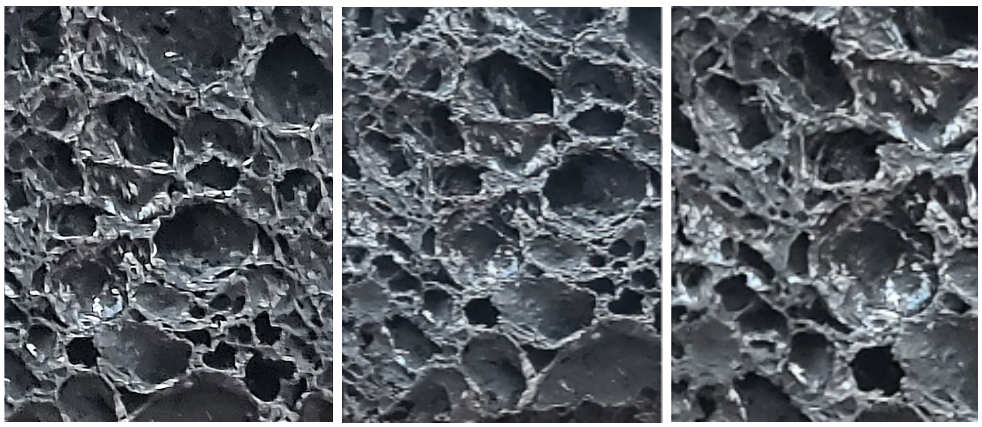


Figure 4. *Static diffusion coefficient for different moments of time*
Note: *1 – t1; 2 – t2; 3 – t3; t1<t2<t3*
Source: *developed by the authors*

Nanomagnetic technologies for filling medical materials fully justify themselves based on their bacteriostatic properties. At the same time, their content in a certain way affects the structure and size of the pores inside such materials. The addition of certain components based on oxides of divalent and trivalent iron in a certain way reduces the average pore size. The study of the microstructure of similar materials, shown in Figure 5, at first glance does not determine a significant impact.



a *b* *c*

Figure 5. *Structure of porous material saturated with iron oxide nanocomponents, nanocomponent content*
Note: *a – 0.3%; b – 0.2%; c – 0.1%*
Source: *developed by the authors*

A more detailed study of the average size of the structural components shows a decrease in the average pore size by approximately 8-12% with a reduction in size dispersion by the same amount. The decrease in average dimensions determines leads to change in the time of passage of liquid through the textile material. Conducting experimental studies shows a decrease in the static diffusion coefficient and an increase in the braking coefficient. The introduction of magnetic nanocomponents affects the sorption indicators, but does not directly determine the possibility of regulating this process.

In order to regulate the sorption process, the material saturated with magnetic nanocomponents was placed in the area of action of a ring electromagnet with controlled power. The electric voltage, supplied to the electromagnet, was adjusted using an autotransformer. As a result of this process, the strength of the magnetic field changed. On the basis of mechanical gravity tests, the ratio of electric voltage and magnetic field strength was determined. This device allows you to change the strength of the magnetic field in the range from 0 to 3 mT. At different indicators of the content of magnetic nanocomponents and the strength of the magnetic field, samples of the material to be sorbed were weighed. Water was used as a model fluid. According to the method given above, the values of the static diffusion coefficient and the braking coefficient were determined. The results of determining these paraseirs are shown in Figure 6, Figure 7.

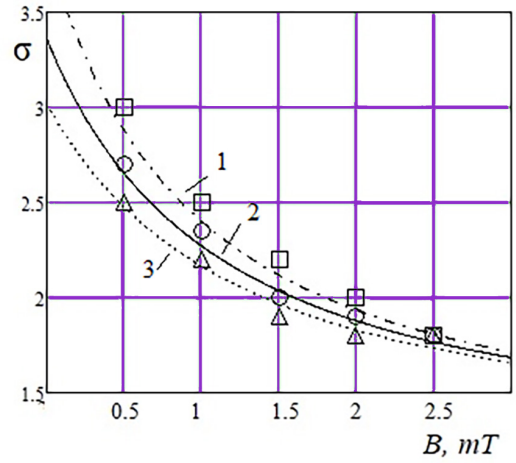


Figure 6. *Change in the braking coefficient depending on the strength of the magnetic field and the content of magnetic nanocomponents*

Note: *1 – 0.1%; 2 – 0.2%; 3 – 0.3%*
Source: *developed by the authors*

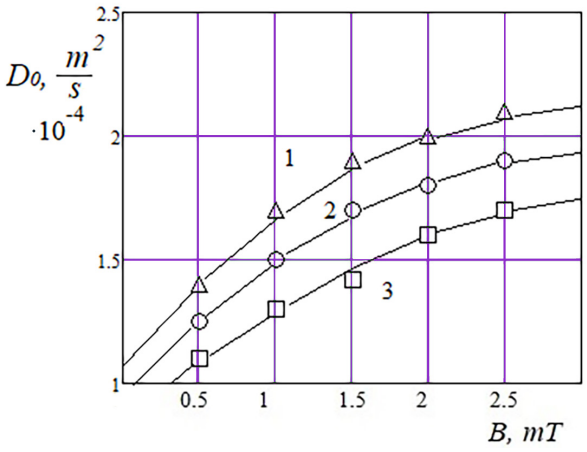


Figure 7. *Change of the static diffusion coefficient depending on the strength of the magnetic field and the content of magnetic nanocomponents*

Note: *1 – 0.1%; 2 – 0.2%; 3 – 0.3%*
Source: *developed by the authors*

The dependences demonstrate a decrease in the diffusion coefficient with an increase in the content of magnetic nanocomponents and an increase in this indicator with an increase in the magnetic field strength. The braking coefficient decreases with an increase in the content of nanocomponents and an increase in the strength of the magnetic field. The obtained results prove the possibility of real regulation of the sorption properties of textile materials in the treatment of wounds. Express methods for determining diffusion indicators have been developed.

In the process of reviewing the main achievements in the field of creation of textile medical materials, additional results obtained in this study were noted. The main requirements for wound dressings determine their effective bacteriostatic and sorption properties. Major advances in the creation of textile materials for wound care are presented in a study of P.D. Venkatraman *et al.* (2023), while the peculiarities of the use of nanotechnologies are noted. A systematic review of the development of wound dressings, as well as the various directions related to their development, are reviewed in a review by Z. Liu *et al.* (2023). In the article of Y. Wu *et al.* (2022) it was considered the main requirements of textile medical materials regarding hygroscopicity, bacterial resistance and certain activity. The results of this research make it possible to significantly expand the nomenclature of medical textiles, taking into account the possibilities of creating a given structure. In a study of N. Zhang *et al.* (2023) the importance of antibacterial properties of medical materials were proved. At the same time, P. Singh *et al.* (2023) claim that the use of nanomagnetic materials significantly increases the bacteriostatic properties of textile materials. Such properties of nanocomponents were additionally proven by R. Masood *et al.* (2015). The main properties of nanocomponents and means of their synthesis are given in the book by H. Gao *et al.* (2023a).

Magnetic nanocomponents, the bacteriostatic properties of which have been proven by previous studies, were used in this study. Thus, the use of such materials is fully justified for medical purposes. G. Chen *et al.* (2023) reported about the technology of saturation of textile materials with nanocomponents for the purpose of protection against bacteria and viruses. In a study by S. Banerjee *et al.* (2023) the facts about the possibility of controlling medicinal liquids in medical textile materials with the addition of nanocomponents are provided.

Regulation of liquid sorption was proclaimed in previous publications, but was not scientifically substantiated. The obtained results confirmed the real possibility of regulating this process. Considering the importance of removing exudate from wounds, a number of publications investigate the process of fluid movement in textile materials. L. Hou *et al.* (2023) determined the gradient of fluid movement through textile materials. M. Riabchykov *et al.* (2022) used mathematical modeling methods to determine patterns of fluid movement through textile materials. S. Stanković (2023) described the parameters of fluid transport through textile materials.

In contrast to known results, the nonlinear nature of the diffusion process and two coefficients characterising the diffusion process are taken into account. The intensity of liquid sorption inside textile materials is related to the definition of the diffusion coefficient, which is not an absolute constant, but is related to the accumulated amount of liquid in the material, as shown in particular by Z. Tan & Y. Zeng (2024). The difficulty of directly determining the values of the diffusion coefficient is noted by X. Linh Nguyen *et al.* (2022). Such researchers as H. Gao *et al.* (2023b) relate sorption

characteristics, in particular diffusion coefficients, to porosity parameters. Porosity is generally poorly regulated. In the article of R.K. Prasanth Kumar *et al.* (2024) the possibility of influencing the porosity parameters of the material filled with nanocomponents using a magnetic field was proved. The given partial solutions of the diffusion equations do not have a clear possibility of determining the nonlinear diffusion coefficients. The obtained results will make it possible to determine nonlinear diffusion coefficients based on macro experiments.

A. Mao *et al.* (2022) attempted to model the structure of the textile material to ensure the given sorption properties. Q. Chen *et al.* (2023) investigated the effects of coatings and saturating materials on wet transport performance. Means of controlling fluid movement in textile materials are defined in a study by K. Bal & B. Das (2023). This study clearly shows the prospects of using nanocomposites based on iron oxides to create a certain structure. Y. Lin *et al.* (2023) consider the possibility of controlling fluid movement in a textile material. J. Ma *et al.* (2023) note the possibility of simultaneously ensuring the movement of liquid in a given direction and preserving the bacteriostatic properties of the textile material. It was also noted in the study by M.R. El-Naggar *et al.* (2024) the influence of magnetic nanocomponents on the parameters of diffusion in the material. Additionally, the effect of nanomagnetic particles of iron oxides on sorption processes is considered in the article of C. Wang *et al.* (2024).

This article proves the real possibilities of regulating the movement of liquid in textile materials under the influence of a magnetic field under the conditions of using magnetic nanocomponents.

Conclusions

One of the main indicators of the effectiveness of the functioning of medical textile materials for the treatment of wound infections is the possibility of regulated removal of exudate. The process of liquid sorption by textile materials is strongly non-linear in nature. It is characterised by two diffusion constants that cannot be explicitly determined experimentally. The first indicator determines the static diffusion coefficient, which does not take into account the influence of the amount of saturated liquid on the sorption process. The second indicator demonstrates the process of inhibiting the saturation of the liquid with the textile material. The study provides an approximate solution to the differential equation of diffusion. This solution allows to clearly identify the desired parameters on the basis of express experiments during weighing the sample to be wetted.

The use of nanocomponents based on oxides of divalent and trivalent iron introduced into the structure of the material allows to change the sorption characteristics to a certain extent. In the process of adding nanopowder in the amount of 0.1-0.2%, the diffusion coefficient decreases by 8-12%, correspondingly, the time to remove exudate from the wound increases. Under the influence of a magnetic field, the diffusion parameters of the textile material change. At the same time, the static diffusion coefficient increases from (0.8-1.1)·$\cdot 10^{-4}$ m^2/s to (1.8-2.2)·10^{-4} m^2/s. The braking coefficient decreases from 3.3.5 to 1.7-1.8. The obtained results make it possible really regulation of the process of sorption of textile materials. This fact can significantly improve the effectiveness of treatment of wound infections. Further research involves determining the parameters of materials for real biological fluids and developing practical methods of using the developed technologies.

Conflict of interest

None.

Acknowledgements

None.

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Контрольована дифузія медичних текстильних матеріалів, наповнених наномагнітними компонентами

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Анотація. Актуальність дослідження визначається необхідністю створення засобів для лікування ран, недостатньою розробленістю методів використання можливостей сучасних наноматеріалів. Метою роботи є обґрунтування можливості створення матеріалів заданої структури для забезпечення контрольованого видалення рідини з використанням магнітних нанокомпонентів. В роботі використано методи розв'язання нелінійного рівняння дифузії, макрокліматичні експерименти з сорбції рідини матеріалами, наповненими нанокомпонентами. Обґрунтовано основні підходи та граничні умови для розв'язання нелінійних рівнянь. Наближений аналітичний розв'язок рівняння дифузії чітко висвітлив можливість знаходження основного коефіцієнта дифузії та коефіцієнта інгібування, який визначає нелінійний характер сорбційного процесу. У двох експериментах реєструється кількість рідини, що досягає протилежної поверхні лікувального матеріалу, і маса накопиченої рідини в певний момент часу. Доведено, що введення магнітних нанокомпонентів у структуру медичних матеріалів впливає на процеси сорбції. Додавання магнітних нанокомпонентів в початковий момент знижує коефіцієнти дифузії. Водночас вміст таких компонентів підвищує бактеріостатичні властивості матеріалу. Організація процесу сорбції в умовах змінного магнітного поля суттєво впливає на процес сорбції. Збільшення напруженості магнітного поля суттєво збільшує коефіцієнт дифузії та зменшує коефіцієнт гальмування. У статті наведено залежність коефіцієнтів дифузії від вмісту нанокомпонентів та напруженості магнітного поля. Ці дані дають можливість прогнозувати дифузійні властивості матеріалу, а також визначати технологічні параметри процесу, які забезпечують задані параметри сорбції. Практична цінність визначається можливістю створення матеріалів для лікування ран з регульованою інтенсивністю видалення ексудату

Ключові слова: тканина; рана; сорбція; наноструктура; видалення ексудату

COMMODITY BULLETIN
Journal homepage: https://c-bulletin.com.ua/en
DOI: 10.62763/ef/1.2024.125

Article's History: Received: 07.12.2024 Revised: 05.03.2024 Accepted: 26.04.2024

Vol. 17, No. 1, 2024, 125-133

UDC 343.98

Corrective coefficients for bargaining for forensic commodity expertise of leather and haberdashery products

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Abstract. The relevance of the work is due to the need to improve the level of ensuring the requirements for completeness, validity and objectivity of the conclusion of a forensic commodity expert by introducing corrective coefficients for bargaining. The purpose of the study is to establish the numerical values of corrective coefficients for bargaining, which must be used by forensic commodity experts when establishing the market value of leather wallets. General scientific analytical methods (grouping, tabular, theoretical generalisation, analysis and synthesis of information, abstraction, formalisation); generating random numbers; questionnaire; audio recording of the bargaining process were used in the work. It has been established that the offer of leather wallets on OLX is 1189 units at a price from 30 UAH to 7799 UAH. A sample was formed – 80 offers of leather wallets at a price from 145 UAH to 6800 UAH, of which 76.3% were not in use. It was found that 17.5% of sellers of leather wallets provide the possibility of bargaining to a potential buyer regardless of the commodity condition and the initial price of wallets offered for sale, and only 7.5% of sellers did not reduce the price announced by them due to the insignificant cost (from 150 UAH to 350 UAH) and the commodity condition "new". It turned out that after the bargaining procedure, the discount to potential buyers is ready to provide 92.2% of respondents or 88.8% of the total number of sellers; the absolute size of this discount – from 5 UAH to 350 UAH and most often is up to 50 UAH; discount percentage – from 3.0% to 29.5% and most often (48.8%) is in the range from 7.0% to 15.0%; arithmetic mean – 84.62 UAH. It is proved that it is advisable to apply a correction coefficient for bargaining in the amount of 11.2% in determining the market value of leather wallets. The practical value of the work is to determine the numerical value of the corrective coefficient for bargaining for the needs of forensic experts-commodity experts and the positive effect of the adjustment on bargaining on the degree of objectivity of the conclusions of forensic experts

Keywords: leather wallets; the process of buying and selling goods; commodity research; conclusion of the forensic expert; adjustment

Introduction

At the request of the Law of Ukraine "On Forensic Examination", the forensic expert is obliged to "conduct a full study and give a reasonable and objective written conclusion" (Law of Ukraine No. 4038-XII, 1994). Therefore, scientific studies, the results of which improve these characteristics of the forensic expert's opinion,

Suggested Citation:
Bednarchuk, M., & Zaiats, Ya. (2024). Corrective coefficients for bargaining for forensic commodity expertise of leather and haberdashery products. *Commodity Bulletin*, 17(1), 125-133. doi: 10.62763/ef/1.2024.125.

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are relevant and significant in the conditions of European integration of Ukraine. Analysis of the results and experience of forensic experts-commodity experts shows that the level of objectivity of their conclusions is influenced not only by the qualification, administrative, organisational and material support of activities, but also by the correspondence of the scientific and methodological base to the real state of the goods market. Most of the problems that these specialists solve are focused on the objective determination of the market value of property.

A.M. Tymchyshyn (2023) has studied the peculiarities and potential possibilities of applying special knowledge in the pre-trial investigation process. P.M. Baranov *et al.* (2020) substantiated the tasks of the forensic expert concerning the determination of the market value of the research object through the prism of the use of price lists and the author's algorithm. A.V. Yukhymenko & V.O. Volokov (2019) summarised the practice of forensic commodity expertise and determined the definition of the market value of property as a specific activity. O.G. Ruvin & V.V. Matveiv (2020) noted that determining the market value of movable property is an integral part of the forensic commodity examination methodology. V.V. Boiko & D.G. Pavlichenko (2019) summarised the possibilities of applying adjustment coefficients in determining the market value of research objects and stated that the current methods provide only adjustment coefficients for commodity condition and/or completeness.

In higher education institutions of Ukraine, the peculiarities of examination of goods that are tangent to forensic commodity expertise were actively studied by V.V. Indutny *et al.* (2019), M.O. Kraliuk *et al.* (2021), N.V. Lutsiv (2021). The peculiarities of behavior, intentions, opportunities and other characteristics of potential sellers and buyers related to the bargaining process were also studied by specialists in evaluation activities in areas other than forensic expertise (Dombrovska & Kylymnyk, 2017). But in the works of these and other authors there are no studies aimed at studying the process of bargaining for used goods in general, and establishing corrective coefficients for bargaining by forensic commodity experts, in their professional activities in particular.

In the process of buying and selling in any form of trading, there is a bargaining – "an action that corresponds in value to the concept of "bargaining" – agreeing on the price of buying and selling, concluding a trade agreement, seeking mutual concessions" (Busel, 2005). Since in the world practice of valuation activity, adjustment for bargaining is carried out by applying corrective coefficients for bargaining (bargaining coefficients, bargaining discounts), the theoretical scientific interest and practical value is to establish the numerical values of these coefficients for the needs of forensic commodity expertise, because:

- bargaining objectively exists and is an integral attribute in the sale or purchase of goods, regardless of the country of the world or form of trade;
- current methods of research, which are used by Ukrainian forensic commodity experts, so far do not provide for the use of corrective coefficients for bargaining;
- starting the application of corrective coefficients for bargaining does not contradict the requirements of current legal and regulatory documents, since it allows to reflect the size of the amendment to bring the value of similar objects (objects of comparison), which is originally indicated in the announcement, to true market value. And also has at least two positive consequences for modern practice and theory of forensic commodity expertise: increases the degree of objectivity of the conclusion of the forensic expert and reflects the actual (real) state of the commodity market.

The main purpose of the system study, one of the results of which is outlined in this article on the example of leather and haberdashery products, is to find digital values of corrective coefficients for bargaining based on a marketing study of the arrays of goods that are offered for sale in e-commerce. They are most often objects of comparison in determining the market value of goods by forensic commodity experts.

Achievement of this goal is carried out by solving a set of interrelated tasks:

- researching the offer of a separate type of leather and haberdashery goods – leather wallets on the electronic trading platform (online ads) OnLine eXchange (OLX), which is most often used by forensic commodity experts to find comparison objects in determining the market value of goods;
- the formation of a sample and the study of the content of the texts of ads on the sale of leather wallets that fell into the sample, and with the sellers of which a bargaining process will be carried out;
- calculation of the average arithmetic numerical value of the adjustment factor for bargaining, which is recommended for use by forensic commodity experts when establishing the market value of leather wallets.

Materials and methods

Scientific work consists of a number of logically related stages: the search and study of the supply of leather wallets on the OLX electronic trading platform; the formation of a sample and the study of the texts of advertisements for the sale of leather wallets that fell into the sample; conducting and fixing the bargaining process; setting absolute and relative numerical values of the bargaining result; calculation of arithmetic mean numerical value of correction factor for bargaining. Basic theoretical principles and practical recommendations for solving the problem of determining the market value of property, set out in the current regulatory (Order of the Ministry of Internal Affairs of Ukraine No. 591, 2017), regulatory and legal documents

(Resolution of the Cabinet of Ministers of Ukraine No. 1440, 2003) and in the works of individual authors. O.O. Syrota (2021) investigated mining equipment and factors that shape ASIC's market value.

General scientific analytical methods of obtaining objective data are applied in the study: tabular, grouping, analysis and synthesis of information, abstraction, formalisation, theoretical generalisation. A random selection strategy (randomisation) was used to obtain digital values of corrective bargaining factors for use by forensic commodity experts in establishing the market value of leather wallets. As well as a procedure in which the maximum possible number of research objects (all proposals for the sale of leather wallets on all pages on the OLX platform) is assigned an individual number and then the required number (80) of actually investigated products and, accordingly, sellers who took part in the questionnaire are selected. In this way, each offer to sell leather wallets on the OLX platform was given an equal chance to participate in the study.

It was advisable and possible to interview all the authors of ads, that is, sellers of goods with a small offer of researched goods on the OLX platform. The feasibility and possibility of such an action are determined, respectively, by the completeness of the coverage of the array of studied goods and the costs of time required for research. But if the supply of goods that need to be researched on the OLX platform is numerical, for example, is more than a thousand titles, then it is not rational to interview all the authors of ads because of the large costs of time. Therefore, when using numerical arrays to determine the digital values of correction coefficients for bargaining, the approach used in mathematics and marketing research is used. It makes it possible to significantly reduce the duration of the study and has no negative impact on the objectivity of the study result.

To determine the number of proposals of leather wallets (sample set, sample), which need to be investigated when determining the digital values of correction coefficients for bargaining, methods common in commodity research of non-food products of the light industry are used. These methods are included in the corresponding standards (DSTU 26167:2009, 2010) of the sample quantity tables when goods are accepted in trade depending on the size of their batch. This number corresponds to the number of leather wallet sellers to be interviewed for a discount when buying a specific leather wallet offer on an online ad platform.

Therefore, it is necessary to form a sample of 80 units, that is, to investigate 80 proposals (to conduct a questionnaire survey of 80 sellers) of this product to set the numerical values of correction coefficients for determining the market value of leather wallets when they are offered on the OLX online ad platform in the amount of 1189. The selection of units of products into the sample (that is, specific sellers of leather wallets who placed their sales ads on the OLX e-commerce platform) was carried out in two ways: according to the procedure specified in the standard (DSTU 26167:2009, 2010), when the first proposal (the first seller surveyed) is chosen arbitrarily, and the rest – with a certain step (interval), which is established by dividing the population number by the sample number (1189:80≈15); using a random number table or random number generator (Random number generator, 2024) – 578, 865, 324, 943, 299, 285, etc. A sample of 80 offers of leather wallets was formed by the specified algorithm using a random number generator.

To record the bargaining process, a questionnaire method was used – a personal survey of sellers of leather wallets on the OLX platform by author's questionnaire (Zaiats *et al*., 2023), as well as an audio recording of the digital media bargaining process (Zayats, 2022). An anonymous, absentee survey was conducted between January 18 and January 20, 2024, using the pre-compiled questionnaire telephone interview method; communication with each seller is carried out by phone numbers, which are indicated on the investigated OLX page and are freely available. The survey followed ethical guidelines when working with people who meet the requirements of the ICC/ESOMAR International Code of Procedure for Marketing and Social Research (Ukrainian academy of marketing, 2024), as well as the requirements of the Commission on Academic Integrity and Ethics (Regulations on the Commission on Ethics…, 2023) and the Ethical Code of the Lviv University of Trade and Economics (Code of Ethics…, 2023), which indicate that ethical approval is not mandatory for this type of study.

Results and discussions

The establishment of numerical values of corrective factors for the needs of forensic commodity expertise was carried out on the example of leather wallets – a classic type of goods included in the commodity group of household non-food goods, which in the science of goods in Ukraine (Tikhonova, 2003) is called "Leather and haberdashery goods".

The choice of this type of product is due to a practical need, since the analysis of the nomenclature of objects of forensic commodity examination confirms that it is the wallets of citizens that are one of the most common objects of theft (on the street, in transport, in public places, etc.) and, as a result, the current object of research in forensic commodity examination.

To determine the digital values of corrective coefficients for bargaining, an array of offers of leather wallets was used on one of the most common e-commerce platforms (online ads) OLX, the choice of which was due to three main reasons:

- presence of a numerical audience of sellers, which is calculated in millions (OLX Ukraine, 2021);
- full compliance with all marketing research requirements in terms of latitude and depth of market coverage (Senyshyn & Kryveshko, 2020);

• most often the use by forensic commodity experts of this platform to find comparison objects in determining the market value of goods (Zayats, 2020).

The offer of goods in accordance with the request "Leather wallet buy on OLX" has been investigated and the search limits "All Ukraine" have been selected to form a sample in order to establish numerical values of correction coefficients. A general analysis of the supply of leather wallets on the OLX bulletin board (Leather wallet on OLX) as of 18.01.2024 suggested the following:

• product offer was 25 pages of bulletin board;

• the total number of offers of goods amounted to 1250 units, among which there were 1189 offers of leather wallets;

• 61 offers consisted of other types of leather haberdashery goods – document covers, key cases, sets of leather haberdashery products (handbags with wallets, waist belts with wallets), etc.;

• leather wallets offered for sale had a price declared by sellers from 30 UAH (wallet used) to 7799 UAH (wallet new trademark "Loewe");

• the offer is significantly dominated by goods that were not in use (new);

• all ads placed (displayed) in 2023-2024.

According to the presented algorithm using a random number generator (Random number generator, 2024), a sample was formed – 80 proposals of leather wallets on the OLX electronic trading platform (Table 1). Numerical values of corrective coefficients for bargaining for the needs of forensic commodity expertise in determining the market value of leather wallets were established based on the results of the questionnaire of these sellers.

Table 1. *Data on leather wallets and bargaining results*

No.	PS	OAB	CG	RTF	No.	PS	OAB	CG	RTF
1	575		n	50 (8.9)	**41**	1999		n	99 (10.0)
2	600		n	50 (8.3)	**42**	1300		n	100 (7.7)
3	450	+	n	100 (22.3)	**43**	349		n	49 (14.1)
4	345		n	45 (13.1)	**44**	280		n	30 (10.8)
5	1450		n	150 (10.4)	**45**	850		n	50 (5.9)
6	2000		b/u	200 (10.0)	**46**	600		n	50 (8.3)
7	700	+	b/u	150 (21.5)	**47**	1450		n	150 (10.4)
8	745		n	45 (6.0)	**48**	565		n	65 (11.5)
9	200		n	0	**49**	400		b/u	50 (12.5)
10	6800		b/u	250 (3.7)	**50**	520	+	n	70 (17.5)
11	1800		n	150 (8.4)	**51**	500		n	50 (10.0)
12	900		n	50 (5.5)	**52**	927		n	27 (3.0)
13	600		b/u	100 (16.7)	**53**	1850		n	350 (18.9)
14	225	+	b/u	50 (22.3)	**54**	350		n	0
15	312	+	b/u	92 (29.5)	**55**	1000		n	100 (10.0)
16	200		n	0	**56**	1800		b/u	300 (16.7)
17	400		b/u	50 (12.5)	**57**	150		b/u	30 (20.0)
18	1450	+	n	350 (24.2)	**58**	790		n	50 (6.4)
19	200		b/u	25 (12.5)	**59**	550		n	in
20	700	+	n	200 (28.6)	**60**	220		b/u	20 (9.1)
21	180		n	0	**61**	550		n	50 (9.1)
22	550		n	in	**62**	525		n	25 (4.8)
23	650		n	50 (7.7)	**63**	500		b/u	50 (10.0)
24	160		n	0	**64**	3500		n	250 (7.2)
25	590	+	n	140 (23.8)	**65**	400		n	50 (12.5)
26	795		n	95 (19.5)	**66**	150		b/u	20 (13.4)
27	145		n	5 (3.4)	**67**	1850		n	200 (10.9)
28	2700		n	200 (7.4)	**68**	650		n	50 (7.7)
29	795		n	45 (5.7)	**69**	790		n	50 (6.4)
30	675		n	75 (11.1)	**70**	220		b/u	20 (9.1)
31	300	+	b/u	50 (16.7)	**71**	950		n	50 (5.3)
32	200	+	b/u	50 (25.0)	**72**	430		n	30 (7.0)
33	150		n	0	**73**	499		n	49 (9.9)
34	930		n	80 (8.6)	**74**	400		n	20 (5.0)
35	1250		n	150 (12.0)	**75**	2300		n	150 (6.6)
36	500	+	b/u	100 (20.0)	**76**	575		n	25 (4.3)

Table 1. Continued

No.	PS	OAB	CG	RTF	No.	PS	OAB	CG	RTF
37	650		n	50 (7.7)	**77**	350		n	50 (14.3)
38	550		b/u	50 (9.1)	**78**	1350		n	150 (11.2)
39	700		n	in	**79**	500	**+**	n	100 (20.0)
40	400	**+**	n	100 (25.0)	**80**	540	**+**	n	90 (16.7)
Total							**14**	**61**	**84.62 (11.2)[1]**

Note: *the following conventions are adopted in Table 1:*
No. – conditional sequence number of the sale announcement (sample of the product offered for sale) on the platform of online ads OLX;
PS – price on the website of ads for the sale of leather wallets, UAH;
OAB – there is an offer in the advertisement for sale, about bargaining or the conditions that the price is "Contractual";
CG – condition of the goods in relation to its use (n – not in use, new; b/u – the product was in use, operation);
RTF – actual result of bargaining (price reduction) after communication with the owner of the goods, UAH (%);
in – could not establish a telephone connection with the owner of the goods;
1 – mean effective value of RTF
Source: *developed by the authors based on a study of the offer of leather wallets on the OLX online ad platform (2024)*

Data from Table 1 shows that 80 offers of leather wallets from 145 UAH (No. 27) to 6800 UAH (No. 10) were investigated to establish numerical values of corrective coefficients for bargaining. 76.3% (or 61 offers) were non-used wallets and 23.7% (or 19 offers) were used wallets. This makes it possible to state that:

- the price structure of the sample is representative and sufficiently fully reflects the price structure of all 25 pages of ads for the sale of leather wallets on the OLX platform, since the average price between the most expensive and cheapest offers is, respectively, 3472.5 UAH (in the sample) and 3914.5 UAH (on the site), which should be considered positive to ensure the objectivity of establishing numerical values of correction factors;
- almost triple predominance of proposals for the sale of new goods on the Internet platform OLX, which most often offers used goods, is due to at least three factors: the specifics of the wallet as a type of leather-haberdashery product, its functional and intended purpose and the materials that are most often used for the manufacture of leather wallets (Tikhonova, 2003);
- availability of bargaining when selling relatively inexpensive leather wallets (the share of the offer of wallets declared value up to 1000 UAH is 76.3%) as a result of which the profit expected by the seller from the sale of his goods due to a decrease in its price is an additional factor in favour of the feasibility and objective need to introduce a correction coefficient for bargaining into the practice of forensic commodity experts in determining the market value of leather and haberdashery products.

Numerical values of bargaining results and corresponding correction factors were determined in two stages. At the first stage, which did not provide for personal communication with sellers of leather wallets, an analysis of the content of sales ads in the received sample was carried out – all 80 offers of the investigated goods:

a) with regard to the availability of data that the price declared by the owner of the goods can be considered by the potential buyer as "contractual" (on the announcement page OLX is indicated externally, under the announced price; information can be obtained without opening the ad text), as well as whether the seller's offer of bargaining is in the ad text (on the OLX ad page it is indicated only in the ad text);

b) regarding the presence in all components of the announcement (heading, title, text, notes) of information on the commodity condition of leather wallets (new or in use).

The obtained results suggest that almost every fifth owner of the product (14 sellers, or 17.5%) even when putting it up for sale on the market, clearly showed an unequivocal desire to negotiate with a potential buyer about a lower price than specified in OLX, that is, it provided an opportunity for a potential buyer to bargain. At the same time, there was a lack of determining or significant dependence between the commodity status of the wallets offered for sale (new or used) and the offer of their sellers for bargaining, since bargaining provided for 8 sellers (or 10% of sellers) of new wallets (No. 3, 18, 20, 25, 40, 50, 79, 80) and 6 sellers (or 7.5% of sellers) of wallets that were in use.

The further stage of work was to conduct a direct conversation by phone (actual bargaining process) on the questionnaire developed by the authors (Zaiats *et al.*, 2023) with all owners of leather wallets for sale (except for those with which it was not possible to establish telephone communication – sellers of goods No. 22, 39, 59) about the possibility of reducing the price announced on the site (OLX page), when buying of the relevant product. The obtained results confirmed that all owners, without exception, who indicated in the text of their announcement on the sale of leather wallets in advance that the value of the goods published by them is not final, but is considered as "Contractual", actually lay in the process of selling their goods the possibility

of bargaining in general and provide an opportunity for each potential buyer even before the start of the sale and purchase process.

In this aspect, the data of Table 1 indicate that the possibility of bargaining by sellers almost equally applies to expensive (No. 18) and cheap leather wallets (No. 14, 15, etc.), as well as new products (No. 3, 18, 20, 25, 40, 50, 79, 80) and those that were in use (No. 7, 14, 15, 31, 32, 36). Consequently, the obtained data prove that the offer of sellers of leather and haberdashery goods about bargaining does not depend on the initial price of goods announced by them and their commodity status in the conditions of the modern market.

It also found that only 6 (No. 9, 16, 21, 24, 33, 54) out of 80 sellers of leather wallets (or 7.5%), even if they bought the goods for sale, did not reduce the value announced on OLX. Commodity analysis of these proposals (organoleptic assessment of the offers of goods on photographic images on the site and the description in the text of the ad) suggests that the main reason for the refusal of these sellers to reduce the declared price is the low cost of goods (from 150 UAH (No. 33) – up to 350 UAH (No. 54) and commodity condition (all these wallets were not used); but the seller of a similar product (offer No. 27, the declared value of 145 UAH, the commodity condition is new) agreed to provide a symbolic discount of 5 UAH on the condition of buying his goods. In addition, telephone communication and, accordingly, interviewing three (or 3.7%) sellers of leather wallets could not be established during the questionnaire survey.

Consequently, the results of the survey of sellers of leather wallets on the OLX platform suggest that 92.2% of respondents or 88.8% of the total number of specified sellers are ready to provide a discount to potential buyers after the bargaining procedure. This is a sufficiently convincing digital argument to justify the feasibility and possibility of applying adjustment for bargaining in the practice of forensic experts of the expert specialty 12.1 when establishing the market value of leather and haberdashery goods. Overall, service, price, and communication have an impact on consumer purchasing decisions (Novanda & Medyawati, 2023). The results of the analysis of the data of Table 1 prove that the absolute discount that sellers agree to provide as a result of bargaining varies very widely in the array of sales of relatively cheap leather wallets: from 5 UAH (No. 27) to 350 UAH (No. 18, 53); most often it is up to 50 UAH inclusive (this is almost every second offer or 47.5% of the amount of goods studied). The relative discount that owners actually provide after the bargaining process also ranges widely: from 3.0% (No. 52) to 29.5% (No. 15); most often it is from 7.0% to 15.0% and within these limits covers almost half (48.8%) of the number of goods put up for sale. The amount of goods that the buyer wants to purchase significantly affects the absolute and relative size of the discount, since this section has small-scale offers (for example, No. 8, 45) from manufacturers of leather wallets. The average arithmetic value of the discount that the surveyed sellers of wallets provided as a result of bargaining is 84.62 UAH, or 11.2%.

Therefore, it is advisable to use a correction coefficient for bargaining in the amount of 11.2% when establishing the market value of leather wallets. This is proved by the results of commodity research and marketing research. This obtained result is a specific numerical value of the correction coefficient for bargaining, it cannot be compared with the corresponding data of other scientists. Open and confidential (from the sphere of state institutions of forensic expertise) information on completed research and obtained numerical characteristics of corrective coefficients for bargaining for the needs of forensic experts of expert specialty 12.1 "Determining the cost of machines, equipment, raw materials and consumer goods", as well as on research aimed at the development (calculation) of such coefficients is absent in Ukraine. Information on the results of similar studies abroad is also not available in the public domain.

At the same time, Yu.S. Olefir (2019) uses a similar concept of the development of forensic commodity expertise, focusing on the fact that the results of the constant development of scientific knowledge in the field of commodity science and tangent fields of knowledge must be used to improve research methods and methodological and technical support of forensic commodity expertise. Among other things, he notes that the tested methods in the expert study should only be used properly. Therefore, the introduction of corrective coefficients should be considered as fulfilling the requirement of this author to improve the scientific and methodological basis of forensic commodity expertise. Publication of the results of research on establishing corrective factors on authoritative forums of forensic specialists (Zaiats & Bednarchuk, 2019; Zaiats *et al*., 2023) is the fulfillment of the requirement for proper testing of techniques used in forensic commodity examination.

On the other hand, analysing the tasks, object and subject of forensic commodity expertise Yu.S. Olefir (2019) examines only certain principles of its methodology creation, but does not address the problem of improving the methodology for determining the market value of movable property by introducing corrective bargaining factors into the practice of evaluation commodity activity.

O.V. Pakholiuk & O.I. Peredriy (2021) emphasise the need to improve the process of examination of leather products (on the example of shoes) for the practical needs of expert institutions. The main attention in this study they focus on the peculiarities of the use of measuring and organoleptic methods of research of goods: for the search, identification and assessment of shortcomings (weaknesses and defects) of the materials

from which the product is made; to establish compliance of individual parts and components with the requirements set forth in the relevant state standards; to assess the overall appearance and features of the design of the study object. But these authors commodity analysis of the main consumer properties of the study objects is not associated with the problem of adjustment. They do not consider the further fate of the goods in which the shortcomings were identified from the points of adjustment of its market value to commodity condition and to bargaining.

The results presented differ from the research results of R.V. Boiko & D.G. Pavlichenko (2019) in direction and content. The difference in direction lies in the study by the authors of adjustment coefficients for bargaining, and other authors focused on adjustment coefficients for commodity status. The difference in content consists in obtaining a specific numerical value of the adjustment coefficient for bargaining for a particular product (leather wallets). The need to substantiate, systematise and compile tables with generalised numerical values of corrective coefficients was indicated only in the compared study.

This allows us to argue that this study is in line with the current problem of forensic commodity expertise in Ukraine, which is devoted to the development of adjustment coefficients, and solves the specific practical problem of establishing the numerical value of the adjustment coefficient for bargaining.

Conclusions

Bargaining is present on the commodity market as part of the process of selling and buying goods, but the current regulatory and methodological bases for the performance of forensic commodity examinations do not provide for taking into account the results of bargaining. Therefore, the use of corrective coefficients for bargaining in forensic commodity examination has a significant theoretical scientific interest and practical importance. The real state of the commodity market contributes to the objectivity, completeness and validity of the judicial expert's conclusion.

Numerical values of adjustment coefficients for bargaining have been established for the first time in the practice of forensic expert commodity studies and in theoretical commodity studies. A proposal was made for their use in determining the market value of leather wallets by forensic commodity experts. It is advisable to establish numerical values of these coefficients using a marketing study of arrays of goods in electronic trade, which are most often objects of comparison in determining the market value of goods by forensic commodity experts. The choice of leather wallets as a research object is defined by a practical need, since citizens' wallets are one of the most common objects of theft. The random selection strategy is used to obtain numerical values of correction coefficients for bargaining for leather wallets. Each of the 1189 available offers had an equal chance to participate in a study on the OLX e-commerce platform on the sale of this product.

A sample of 80 offers for sale of leather wallets was formed from 145 UAH to 6800 UAH, 76.3% of which were not in use. As a result of the questionnaire, it was found that 17.5% of sellers provide the possibility of bargaining to a potential buyer regardless of the commodity condition and the initial price of wallets offered for sale; 7.5% of sellers did not reduce the stated price on OLX when buying their goods; respondents or 88.8% of the total number of sellers; the absolute size of the discount ranges from 5 UAH to 350 UAH and is most often up to 50 UAH; the discount percentage is from 3.0% to 29.5% and most often (48.8%) is from 7.0% to 15.0%; average arithmetic value of the provided discount – 84.62 UAH. It is necessary to use a correction coefficient for bargaining in the amount of 11.2% in determining the market value of leather wallets by forensic commodity experts.

Further studies should be aimed at establishing corrective coefficients for bargaining for other types of leather and haberdashery goods. Such objects of forensic commodity expertise are most often handbags women's leather.

Conflict of interest

None.

Acknowledgements

The authors express their sincere gratitude to the director of the Lviv Scientific Research Expert and Forensic Center of the Ministry of Internal Affairs of Ukraine, Doctor of Law, Professor, Honored Lawyer of Ukraine, academician of the Ukrainian Academy of Sciences Roman Zayats for the idea and development of a new direction of expanding the evidence base of forensic commodity expertise by recording the process of bargaining on a digital medium. As well as for comprehensive support of studies aimed at introducing corrective coefficients for bargaining into the practice of forensic commodity expert activity.

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Коригувальні коефіцієнти на торг для судової товарознавчої експертизи шкіряно-галантерейних товарів

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Анотація. Актуальність роботи обумовлена потребою покращення рівня забезпечення вимог до повноти, обґрунтованості та об'єктивності висновку судового експерта-товарознавця за допомогою запровадження коригувальних коефіцієнтів на торг. Метою дослідження є встановлення числових значень коригувальних коефіцієнтів на торг, які необхідно застосовувати судовим експертам-товарознавцям при встановленні ринкової вартості гаманців шкіряних. У роботі використані загальнонаукові аналітичні методи (групування, табличний, теоретичного узагальнення, аналізу і синтезу інформації, абстрагування, формалізації); генерування випадкових чисел; анкетне опитування; аудіозапис процесу торгу. Встановлено, що пропозиція гаманців шкіряних на OLX складає 1189 одиниць ціною від 30 грн до 7799 грн. Сформована вибірка – 80 пропозицій гаманців шкіряних ціною від 145 грн до 6800 грн, з яких 76,3 % не були у вжитку. Виявлено, що 17,5 % продавців гаманців шкіряних надають можливість торгу потенційному покупцеві не залежно від товарного стану і початкової ціни пропонованих до продажу гаманців і лише 7,5 % продавців не зменшили оголошену ними ціну через незначну вартість (від 150 грн до 350 грн) та товарний стан «нові». З'ясовано, що після проведення процедури торгу знижку потенційним покупцям готові надати 92,2 % опитаних або 88,8 % загальної кількості продавців; абсолютний розмір цієї знижки – від 5 грн до 350 грн і найчастіше складає до 50 грн; відсоток знижки – від 3,0 % до 29,5 % і найчастіше (48,8 %) перебуває в межах від 7,0 % до 15,0 %; середнє арифметичне значення – 84,62 грн. Доведено, що при визначенні ринкової вартості гаманців шкіряних доцільно застосувати коригувальний коефіцієнт на торг у розмірі 11,2 %. Практична цінність роботи полягає у встановленні числового значення коригувального коефіцієнта на торг для потреб судових експертів-товарознавців та у позитивному впливі коригування на торг на ступінь об'єктивності висновків судових експертів

Ключові слова: гаманці шкіряні; процес купівлі-продажу товарів; товарознавче дослідження; висновок судового експерта; коригування

COMMODITY BULLETIN
Journal homepage: https://c-bulletin.com.ua/en
DOI: 10.62763/ef/1.2024.134

Article's History: Received: 31.12.2024 Revised: 20.03.2024 Accepted: 26.04.2024

Vol. 17, No. 1, 2024, 134-145

UDC 620.21:631.1

Global market trends of grain and industrial crops

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Abstract. Analysing the dynamics of cultivation and consumption of major agricultural crops worldwide is crucial for understanding trends and planning for sustainable food production. It is important to have an integrated approach that involves collaboration between scientists, and farmers to implement sustainable practices. The analysis of global market trends of grain and industrial crops is the goal of paper. Methods of analysis, synthesis, generalisation, forecasting and databases of the Food and Agricultural Organization of the United Nations were used in the process of work. Such crops as wheat, corn, sunflower and flax were chosen for the study, because they are the major food needs of the world population. They are grown for grain (seeds), and flax is a plant of complex use, in which both the stem and the grain are important. They provide essential nutrients such as carbohydrates, proteins, fats, vitamins, and minerals that are crucial for human health. Cultivating these crops has been integral to the food security and economic stability of many countries, supporting large populations. As a result of the conducted research, it was found that India, China, the USA and Canada remain the largest producers of wheat in the world, but only India increases the cultivated area. A global trend to increase corn production has been identified. It was established that Ukraine remains an important producer of sunflower seeds. In addition, a gradual increase in interest in flax was noted. Although the increase in cultivated area can help to meet the growing demand for food products, the problem of using the agricultural plant residues also increases proportionally. This is an international problem, so its solution is of global importance. It has been founded that current research is focused on improving agricultural plant residues processing to obtain goods of various applications. The new knowledge received in the paper will allow working on the improvement of processing wheat, corn, sunflower and flax, which will be able to adequately meet the food needs of the growing world population without harming the environment

Keywords: agricultural crops; population; food production; plant residues; processing; environmental

Suggested Citation:
Yaheliuk, S., Fomych, M., & Rechun, O. (2024). Global market trends of grain and industrial crops. *Commodity Bulletin*, 17(1), 134-145. doi: 10.62763/ef/1.2024.134.

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Introduction

The rapid increasing of the world population and the growing need for food causes new opportunities for the agriculture but aggravation environmental problems. The environmental impact of agriculture must be taken to ensure long-term food production. Study the production dynamics of grain and industrial crops such as wheat, corn, sunflower and flax on a global scale is relevant and important for understanding trends and ensuring sustainable food production and agricultural plant residues can be a valuable resource for the production of environment-friendly goods.

According to H. Ritchie *et al.* (2022), it can be noted that grains and industrial crops like wheat, corn, sunflower, and flax are very important for meeting humanity's nutrient needs. These crops have provided proteins, fats, vitamins, and minerals that are crucial for human nutrition. The cultivation of these crops has been integral to the agricultural systems of many countries, playing a crucial role in supporting populations and economies. Wheat is one of the oldest cultivated grain crop and has been a part of human diets for thousands of years. M.J. Iqbal *et al.* (2022) noted in their article that wheat contains proteins, carbohydrates, iron, B vitamins (riboflavin, niacin), soluble fiber and trace elements. Wheat is the leading source of vegetable protein in the human diet. Corn is one of the highest-yielding grain crops. R. Zhang *et al.* (2021) highlights corn provides about 85% of worldwide starch production. According to research, during the processing of starch, various by-products (corn germs, corn bran, and gluten) are formed. They are inexpensive and rich in proteins, oils, carbohydrates and minerals. Using these by-products is widely attractive from a nutritional and economic standpoint. Nowadays these by-products can often be found in feed production, nutrient extraction and other industries. B.S. Adeleke & O.O. Babalola (2020) notes the importance of sunflower – an oil crop. It is valued by consumers for its nutritional and medicinal properties. Sunflower contains dietary fibers, minerals, vitamins, flavonoids, phenolic acids, carotenoids, peptides. Organically grown sunflower has a special value. Due to its positive effects on health, sunflower is recognised as a functional food. I. Dudarev & V. Say (2020) are discussing the importance of preserving the flax stem integrity during the harvesting. Flax is a versatile crop. Traditionally, flax has been used for both its seeds (which yield linseed oil) and its fibers (which can be woven into linen fabric). The authors' research demonstrates that using new technologies for collecting flax can enhance the quality of the seed and fiber, making it more perspective for commercial use.

Common thing among wheat, corn, sunflower, and oilseed flax is that, traditionally, only the grain or seed is processed for consumption, while the rest of the plant, including the stem, is often treated as waste. According to the State Statistics Service of Ukraine (2021), the amount of agricultural crop waste generated only in Ukraine amounted to 10779 thousand tons, of which 1363 thousand tons are plant waste from agricultural production that needs to be disposed of. The increased production of crops can contribute to environmental problems, particularly when the disposal of agricultural waste involves burning. Burning agricultural crop residues releases a variety of pollutants into the air, including particulate matter, carbon monoxide, nitrogen oxides, and volatile organic compounds. Also, burning crop residues removes organic matter from the soil, which is essential for soil fertility. Balancing the need for increased food production with environmental conservation and social responsibility is a complex task that requires a holistic and integrated approach at local, national, and global levels.

Researchers are actively working on finding sustainable solutions to address this problem. R. Sadigov (2023) analyses and evaluates the problems that may be caused by the growth of the world population. One of the biggest problems is providing the population with food, which in turn leads to an increase in the production of agricultural crops and their waste.

According to S. Yaheliuk *et al.* (2021) the management and disposal of agricultural crop waste, become crucial for environmental sustainability. Proper disposal and recycling methods can help minimise the environmental impact associated with agricultural plants residues. The classification of the agricultural plants residues as for main characteristics is the first step in solving problem. By understanding the composition, volume, and potential uses of different types of agricultural waste, appropriate disposal and recycling methods can be identified.

The issue of processing crop residues is often raised by different scientists in the world. Research S. Yaheliuk *et al.* (2020) focus on developing sustainable methods for utilising agricultural crop residues such as bioenergy production. Converting crop residues into bioenergy solid fuel can provide an alternative and renewable energy source, reducing dependence on non-renewable resources. According to M. Grégoire *et al.* (2020) some crop residues can be used in the production of materials like textile, paper, or other biodegradable products, contributing to a circular economy. Research into the use of composite materials reinforced by natural fibers like flax, hemp has been a growing area of interest. These materials offer advantages such as being lightweight, renewable, and biodegradable. C. Baley *et al.* (2019) and S. Rangappa *et al.* (2022) explored the mechanical properties,

manufacturing processes, and potential applications of plant fiber-reinforced composites. The findings of this research could contribute to advancements in the development of eco-friendly composite materials.

Analysing the dynamics of cultivation and consumption of major agricultural crops globally is crucial for understanding trends, identifying challenges, and planning for sustainable food production. The strategy of managing the production of enough amount environmental safety food is based on informational training and the possession of data on the development trends of the world market of agricultural crops and processing them for consumes.

The information and data play a crucial role in the strategic management of agricultural crop production. Market trends and demand analysis, access to data on global and regional market trends, consumer preferences, and demand forecasts is essential for farmers and agribusinesses. Understanding market dynamics allows for better planning regarding which crops to grow, in what quantities. The goal of the paper is to research global trends in grain and industrial crop production, with a focus on analysing the trends to improve the processing of agricultural plant residues to obtain goods of various applications and reduce environmental impacts while meeting growing food demands.

Materials and methods

The research methodology encompasses a comprehensive approach that utilises various analytical methods, including analysis, synthesis, generalisation, forecasting method and graphic method, to investigate global production trends of major crops.

Analysis involves breaking down the research subject into its main components, such as crop production trends (specifically focusing on wheat, corn, sunflowers, and flax) and understanding what countries most related to these crops. Synthesis integrates the insights gained from the analysis to achieve specific goals, such as making informed decisions about crop cultivation and processing them for various applications. This step involves combining the findings from the analysis to develop strategies for optimising crop production, addressing food demand, and identifying opportunities for environmental processing.

The primary source of information for the study was FAOSTAT (2023) data used to analyse the harvested agricultural areas (wheat, corn, sunflower, flax). FAOSTAT (2023) data is utilised to compile a list of the most cultivated agricultural crops globally, helping to understand which crops are most significant in terms of production and consumption on a global scale. The State Statistics Service of Ukraine (2021) has provided important data on agricultural crop residues. The data of the State Statistics Service is used to determine the amount of waste generated after harvesting in Ukraine. This data contributes to understanding the environmental impact of agricultural practices. Furthermore, data from the United Nations Department of Economic and Social Affairs (2024) were also utilised. Using this data, the countries with the highest population growth rates were identified, which made it possible to understand in which regions the demand for agricultural products may increase due to population growth. These sources played a pivotal role in assessing various aspects of agricultural production and waste management practices within the study, contributing to a comprehensive analysis of the subject matter.

By selecting the timeframe of 1995 to 2021 the study allows analyse long-term trends in agricultural production and market dynamics. In addition to analysis and synthesis, graphical methods were employed to enhance the research process. The graphical representations, complemented by duplicated graphical dependencies, facilitated the tracking of production trends for each crop. The visual approach improved the comprehension of complex data and helped in identifying patterns and trends over time.

Utilising the forecasting method allowed the formation of assumptions regarding the future development of the wheat, corn, sunflowers and flax production. Overall, the forecasting method enables informed decision-making by providing insights into the potential future outcomes of the agricultural sector, food production and environmental.

Results

Wheat is a staple crop and one of the most widely grown cereals globally. It is rich in carbohydrates (mainly starch), protein (gluten), B vitamins, dietary fibers and minerals (iron, magnesium). Wheat is cultivated in a wide range of climates using various methods, including conventional tillage and precision agriculture. Improvements in seed varieties, irrigation techniques, and fertilisation contribute to increased yields. Wheat is a primary ingredient in various products, including bread, pasta and pastries. Consumption trends are influenced by population growth, dietary preferences, and changes in global trade. According to the data in Figure 1 and Table 1 the following conclusions are made. India, China, the USA, Canada and Ukraine have the largest area and production of wheat in the world (FAOSTAT, 2023).

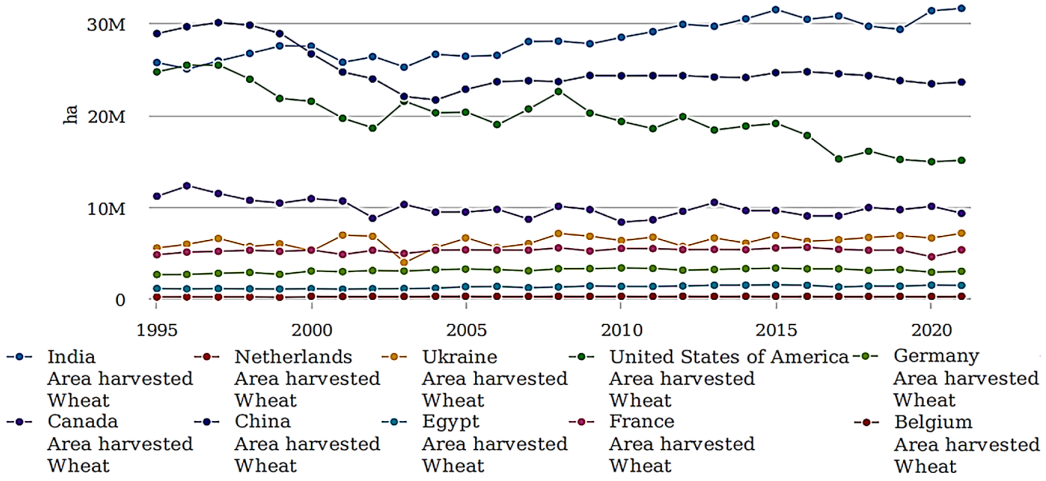

Figure 1. *Wheat cultivation area (thousand hectares)*

Source: *compiled by the authors based on data from the FAOSTAT (2023)*

Table 1. *Wheat cultivation area (thousand hectares)*

Country	Year										
	2000	2004	2007	2009	2012	2015	2017	2018	2019	2020	2021
China	26653326	21626074	23721070	24291081	24270311	24599116	24480542	24268721	23732560	23383000	23571400
India	26344700	26594700	27994500	27752400	29860000	31470000	30785230	29650590	29318780	31357020	31610000
USA	21474064	20221956	20638784	20191200	19797644	19058470	15198130	16030580	15132980	14888140	15039490
France	5248436	5237005	5238602	5147394	5297826	5480208	5332084	5234090	5244250	4512420	5276730
Ukraine	5161600	5533700	5951300	6752900	5629700	6839500	6377400	6619600	6825300	6564500	7099400
Canada	10854800	9388900	8616100	9660400	9479100	9558300	8983300	9880800	9655800	10017800	9247000
Belgium	213100	213035	199897	201768	217060	201628	197592	195690	203760	194660	209180
Egypt	1034985	1094741	1140979	1335295	1336234	1457506	1227611	1326401	1316678	1429684	1394558
Netherlands	136700	137287	140000	150888	151625	142468	115923	111660	120550	108910	118140
Germany	2968940	3111651	2992075	3226036	3056700	3282700	3202600	3036300	3118100	2835500	2939000

Source: *compiled by the authors based on data from the FAOSTAT (2023)*

India has been increasing its wheat production, as indicated by the expanding cultivation area – 3161000 hectares in 2021. This suggests a positive trend in wheat farming in the country. China wheat cultivation area in 2021 was 23571400 hectares. China has an extensive wheat cultivation area, and while the data doesn't explicitly mention production volumes, the vast acreage suggests a significant focus on wheat cultivation. The USA has a substantial wheat cultivation area (15039490 hectares), but the data suggests a reduction in the wheat cultivation area in 2012-2021. This could be due to various factors, including shifts in agricultural practices or changes in market demands. Similar to the USA, Canada has experienced a reduction in wheat cultivation area. Changes in land use, crop rotation, or market dynamics could be influencing this trend. The data shows Ukraine maintaining a significant wheat cultivation area. While the absolute numbers are lower than some other countries, Ukraine remains an important player in global wheat production. The increase in wheat area in India is consistent with the country's efforts to improve food security and meet growing demand for wheat. Reductions in wheat acreage in the United States, China, and Canada may indicate changes in agricultural practices, land use, or market dynamics.

Corn (Maize) is a versatile crop. Corn is consumed directly and is a key ingredient in livestock feed. It's also used in the production of biofuels, starch, and various industrial products. Corn is high in carbohydrates (mostly starch), fiber, protein, vitamins (B vitamins, vitamin C), and minerals (magnesium, potassium).

Cultivation techniques include crop rotation, conservation tillage, and genetic engineering for pest and disease resistance.

According to data (Table 2), China, the USA, India and Ukraine had the largest area and production of corn in the world in the early 2000s. According to data from the FAOSTAT (2023), in 2021, China planted 4335859 thousand hectares; USA – 34555670 thousand hectares; India – 9860000 thousand hectares; Ukraine – 5481800 thousand hectares. It can be seen that there is a tendency to increase the production of corn in the world (Fig. 2). China has a substantial corn cultivation area. The data suggests a continued focus on corn production, aligning with the country's demand for animal feed, food, and industrial uses. The USA is a major player in global corn production, and the data reflects a significant corn cultivation area. India has a notable corn cultivation area, and the data suggests a focus on corn production. Changes in dietary preferences, industrial uses, and livestock farming practices may contribute to this trend. The country's contribution to global corn production may be influenced by factors such as export demand, internal consumption, and livestock farming.

Table 2. *Corn (Maize) cultivation area (thousand hectares)*

Country	Year										
	2000	2004	2007	2009	2012	2015	2017	2018	2019	2020	2021
China	24310506	25467145	29496901	31203367	35046465	44995748	42429378	42158995	41309740	41292000	43355859
India	6581500	7430400	8117300	8261600	8710000	9258000	9633200	9380070	9027130	9569060	9860000
USA	27829720	29797730	35013780	32168810	35355740	32678310	33481220	32891580	32916270	33311250	34555670
France	1915822	1821419	1529775	1744416	1709936	1637081	1435699	1426260	1506100	1691130	1549520
Ukraine	1122800	2299600	1902800	2089100	4371900	4083500	4480700	4564200	4986900	5392100	5481800
Canada	1267500	1072300	1368700	1142000	1426100	1340400	1406200	1430700	1451200	1408200	1390500
Belgium	35800	52174	53238	66670	68500	58384	49005	53990	48640	51880	48220
Egypt	843029	788520	775910	983081	1041345	1060996	1096680	680025	1533571	976401	1027057
Netherlands	20300	22400	19300	18846	15505	11188	8671	13760	19010	19420	17200
Germany	360841	461697	403210	464333	526200	455500	432000	410900	416000	419300	430700

Source: *compiled by the authors based on data from the FAOSTAT (2023)*

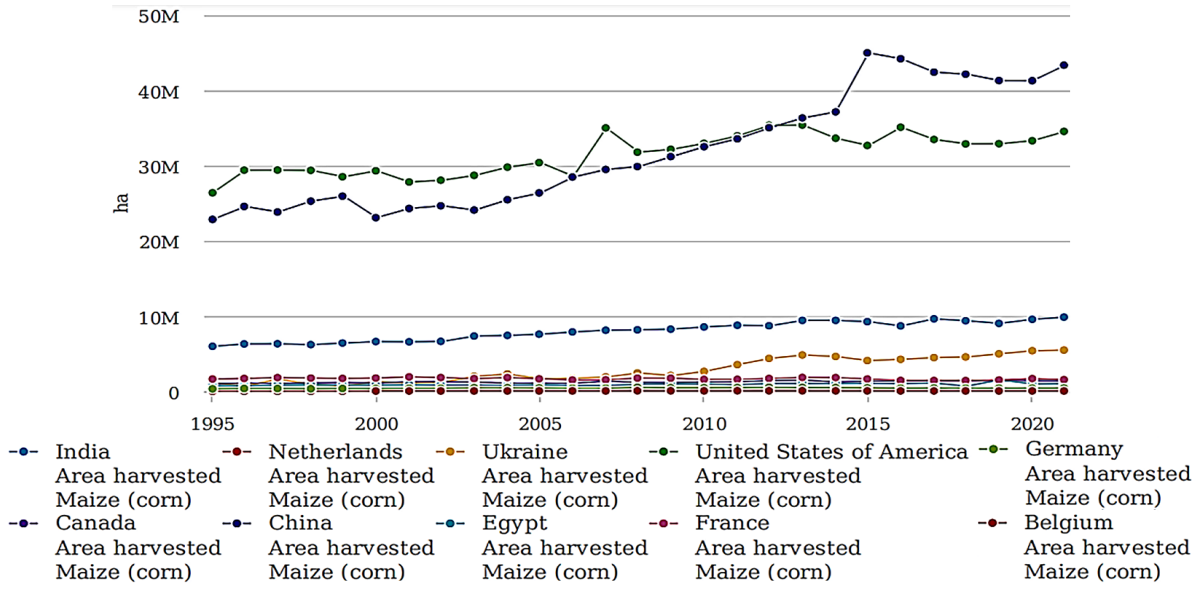

Figure 2. *Corn (Maize) cultivation area (thousand hectares)*

Source: *compiled by the authors based on data from the FAOSTAT (2023)*

Sunflower is cultivated for its seeds, which are a source of edible oil. Sunflower oil is widely used for cooking and as an ingredient in various food products. Trends in health consciousness and cooking habits influence consumption patterns. Sunflower contains healthy fats (mainly unsaturated fats), protein, dietary fiber, vitamin E, and minerals (copper, selenium). It grows well in sunny locations with well-drained soil.

Planting methods include direct seeding and transplanting. Breeding for high-yielding varieties and efficient nutrient management are common practices.

According to the data from the FAOSTAT (2023), in 2021, sunflowers were collected in a total volume of 58185633.69 tons in the world. From the early 2000s, Ukraine, China, India, France, and the USA has the largest area and production of sunflowers in the world (Table 3). According to the data of 2021, 6665100 thousand hectares were sown in Ukraine; China – 940000 hectares; France – 698360 thousand hectares; the USA – 503350 thousand hectares; India – 255869 thousand hectares. Ukraine has a substantial sunflower cultivation area, and the data suggests a significant focus on sunflower production. The observation of potential future increases indicates the country's continued emphasis on sunflower cultivation, likely due to factors such as export demand, climate suitability, and economic considerations. China has a notable but comparatively smaller sunflower cultivation area. France maintains a substantial sunflower cultivation area. The country's sunflower production is likely influenced by factors such as agricultural practices, market demand, and climate conditions. The data suggests that Ukraine is a major player in global sunflower production, with a substantial cultivation area (Fig. 3).

***Table 3**. Sunflower cultivation area (thousand hectares)*

Country	Year										
	2000	2004	2007	2009	2012	2015	2017	2018	2019	2020	2021
China	1229090	934900	719200	958730	888510	973000	1170750	921350	850000	910000	940000
India	1073800	2160600	1910000	1476600	820000	474000	381110	283510	262010	228280	255869
USA	1071210	692425	814236	790560	744630	619990	539780	492670	28800	674090	503350
France	728555	616169	519501	724843	679974	536962	586225	552070	603920	778400	698360
Ukraine	2841600	3427000	3411400	4193000	5081700	6086700	6060700	6166500	5958900	6480900	6665100
Canada	68800	55400	78100	63500	39700	27500	25500	26900	28800	45000	40300
Germany	25794	31557	19161	23600	26400	18400	18000	19500	22500	28200	38300

***Source:** compiled by the authors based on data from the FAOSTAT (2023)*

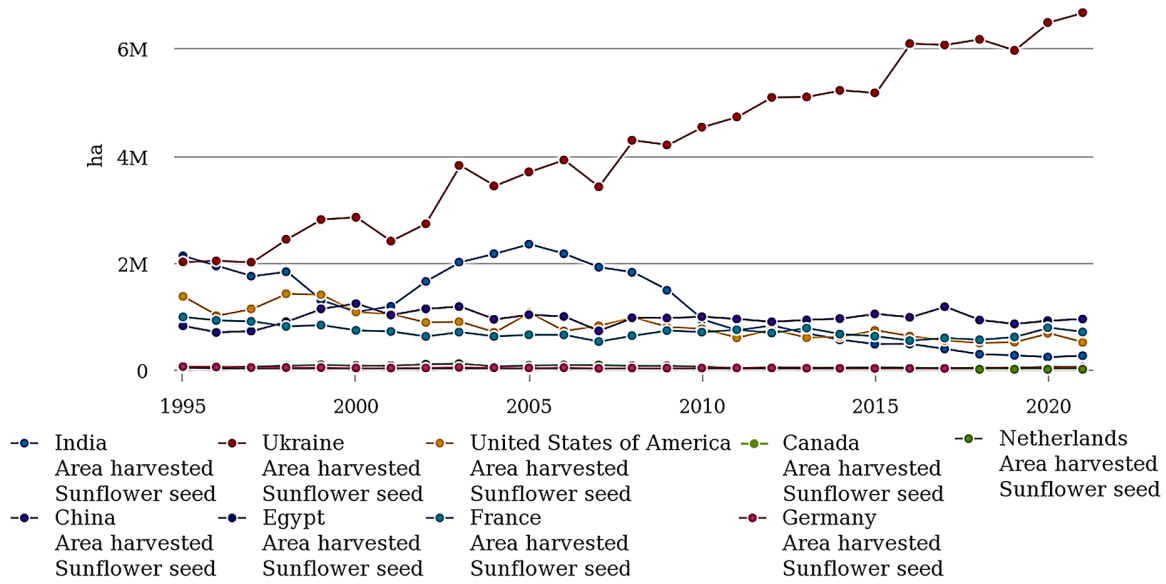

***Figure 3.** Sunflower cultivation area (thousand hectares)*
***Source:** compiled by the authors based on data from the FAOSTAT (2023)*

Flax is cultivated for its seeds (linseeds) and fibers. Flaxseeds are used for human consumption due to their nutritional benefits, including high Omega-3 fatty acids, lignin, dietary fiber, protein, vitamins (B vitamins), and minerals (manganese, magnesium). Flax fibers are used in textiles and various industrial applications. The dual-use nature of flax makes it an economically significant crop. Flax prefers cool, moist climates and well-drained soils. Cultivation method includes direct seeding. Selecting suitable varieties and optimising soil fertility are essential for successful flax production. The demand for flax-based products has grown,

particularly in the health food and sustainable textile markets, where consumers appreciate its natural and eco-friendly characteristics.

The total amount of flax was grown around the world was 333914518 tons in 2021 (FAOSTAT, 2023). According to the data of 2021 (Table 4), 403500 thousand ha were sown in Canada; China – 260000 ha; India – 183725 thousand hectares; USA – 10846. It can be seen that from the 2000s to 2019 there was a reduction in the sowing of flax, but in the following years the area of sowing of flax increased (Fig. 4). The global increase in flax cultivation areas in the years 2020-2021 suggests a potential shift or resurgence in interest in flax as a crop. Canada remains a major contributor to global flax cultivation, with a significant share of the total sown area.

Table 4. *Flax cultivation area (thousand hectares)*

Country	Year										
	2000	2004	2007	2009	2012	2015	2017	2018	2019	2020	2021
China	497870	500000	339900	336930	317860	292310	284000	279000	260000	250000	260000
India	593100	476500	426000	407900	323000	285000	325220	326180	172710	179900	183725
USA	209220	206800	141240	127070	135980	184540	110080	80130	114930	119790	10846
France	16239	6172	17030	9633	12077	22308	29116	24760	21840	32070	37500
Ukraine	20000	14000	24100	46800	52900	66700	47500	31800	16900	14000	27600
Canada	590900	518000	524000	623300	358200	626900	418900	341800	339300	371300	403500
Belgium	13700	20529	14297	11227	10581	12000	15000	90	60	110	130
Egypt	16000	17138	16000	5369	4276	3128	6000	5000	5000	5000	6000
Netherlands	4400	4485	3500	2163	2077	2405	2494	-	-	-	1800
Germany	102500	12900	6300	4100	4200	5000	4600	3800	3400	3900	5200

Source: *compiled by the authors based on data from the FAOSTAT (2023)*

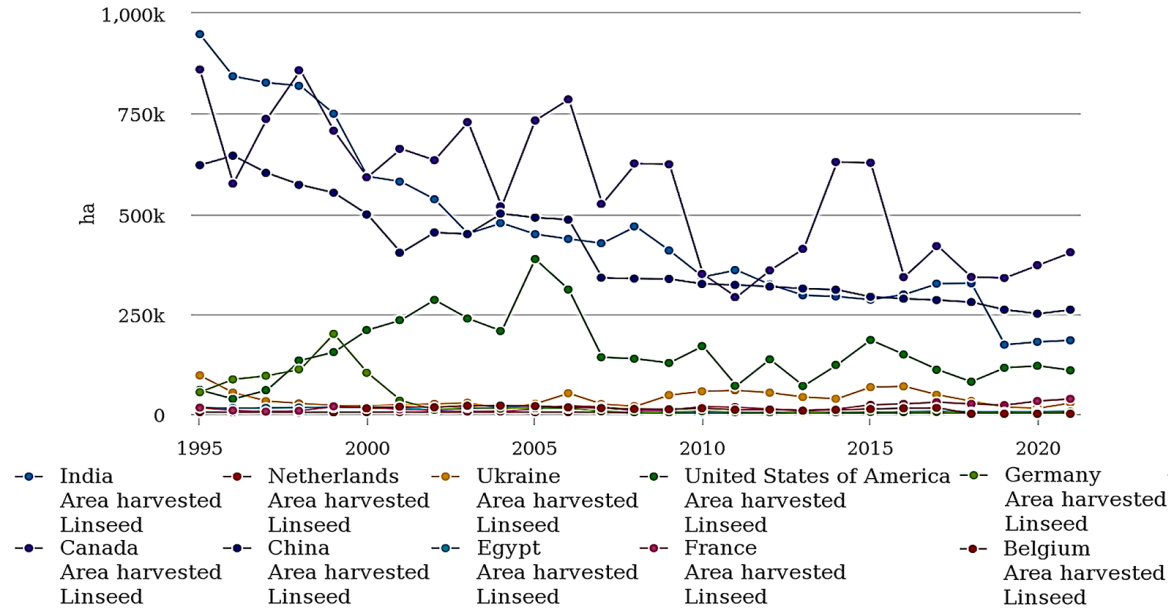

Figure 4. *Flax cultivation area (thousand hectares)*

Source: *compiled by the authors based on data from the FAOSTAT (2023)*

Economic viability of flax cultivation is influenced by factors such as commodity prices and global market trends. Advances in flax varieties, cultivation practices, and processing technologies could have influenced to farmers to reconsider flax as a viable crop. It's important to continue monitoring these trends and consider additional factors such as yield per hectare, technological advancements, and policy changes to gain a more comprehensive understanding of the dynamics in global flax cultivation.

Based on the results of the research, a histogram of the cultivated areas of wheat, corn (maize), sunflower and flax in the world was created (Fig. 5). The areas of cultivation of wheat, corn, sunflower and flax are constantly growing.

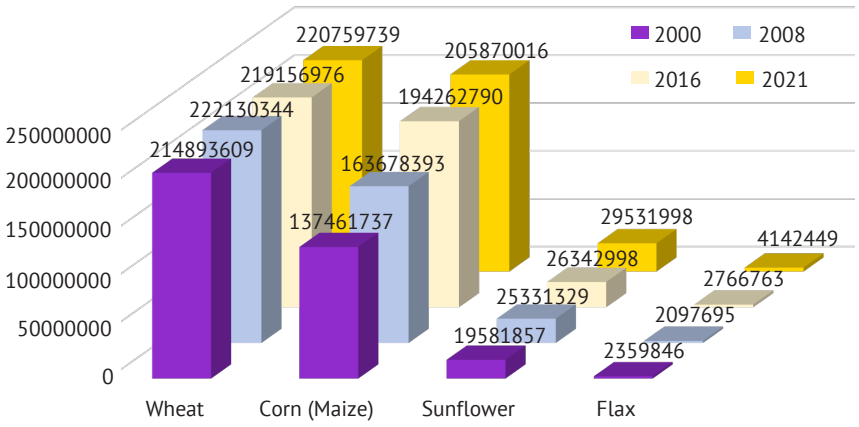

Figure 5. *Histogram of cultivated areas of agricultural crops in the world, thousand hectares*
Source: *compiled by the authors based on data from the FAOSTAT (2023)*

Large-scale cultivation of these crops can lead to habitat loss and biodiversity decline. Intensive irrigation practices for crop production can deplete water resources and contribute to water pollution through runoff. Chemical inputs used in crop cultivation can lead to soil degradation, water contamination, and harm to non-target organisms. Monoculture practices can reduce genetic diversity, making crops more susceptible to pests, diseases, and climate change.

While increasing cultivation areas can help meet growing demands, sustainable agricultural practices are essential to minimise environmental impact and ensure long-term food security. It's important to continue monitoring these trends and assess the impact of factors such as climate change, technological advancements, and global market dynamics on agricultural production. Overall, the histogram depicting the growth in cultivation areas provides valuable insights into the trends shaping global agriculture and highlights the importance of these crops in meeting diverse needs.

By understanding and addressing these aspects, scientists and farmers can work towards more sustainable and efficient cultivation, utilisation, and disposal of grain and technical crops, minimising their environmental impact. Stems, husks, and other plant residues can be used for animal feed, composting, or bioenergy production. Waste from grain and oil seed processing can be recycled or used as feedstock for other industries, such as animal feed or biofuel production (Fig. 6).

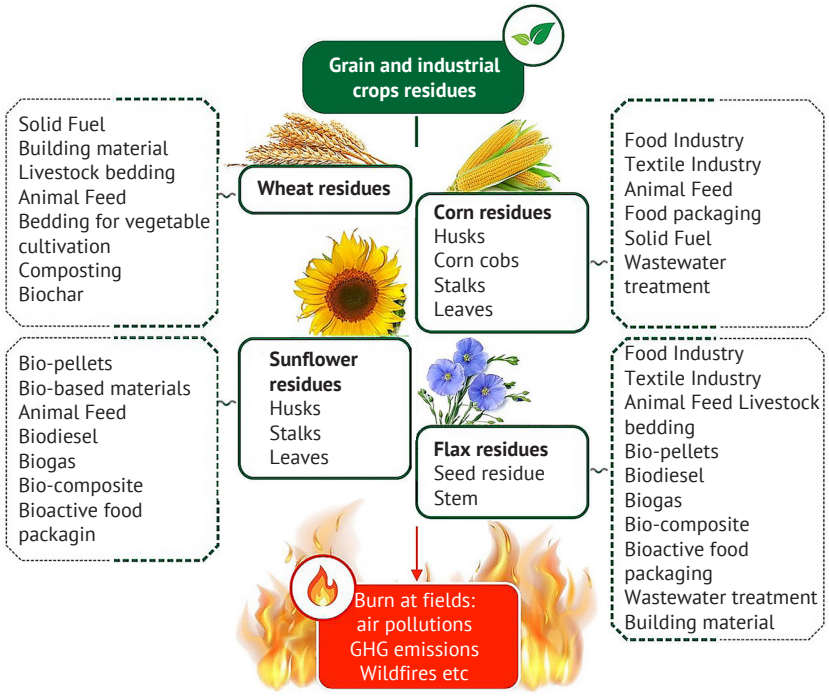

Figure 6. *Residues of grain and industrial crops and the possibilities of their processing to obtain goods of various applications*
Source: *created by the authors*

Wheat residues, for instance, can be used to obtain solid fuel, building materials, livestock bedding, animal feed, bedding for vegetable cultivation, and composting. Corn residues have a wide range of potential applications across various industries. Corn husks can be processed into ingredients for food products, such as fiber supplements or sweeteners. Fibers extracted from corn cobs can be used in textile production. Corn residues can serve as nutritious feed for livestock. Sunflower husks, stalks and leaves can be compacted into bio-pellets, providing a renewable source of energy. Components of sunflower residues can be used in the production of biodegradable materials, such as packaging or bioplastics. Sunflower husks can serve as a feedstock for biodiesel production. Extracts from sunflower residues may possess bioactive properties that can be incorporated into food packaging materials. Flax offers numerous possibilities for producing various application goods. From healthy foods to textiles, animal feed, composites, and solid fuels, the potential is vast. Harnessing these residues for multiple purposes not only maximises resource efficiency but also fosters innovation and creates new economic opportunities.

Future investigations are needed to examine also the impact of factors like yield per hectare, technological progress and environmental conditions on the formation of the global market for grain and industrial crops in order to gain a deeper understanding of the global production of wheat, corn, sunflower and flax, and strategies for waste processing.

Discussion

The obtained and analysed data indicate further global growth in the production of grain and technical crops, such as wheat, corn, sunflower, flax, which will be accompanied by an increase in crop waste. This prediction aligns with the ongoing trend of increasing agricultural production by factor such as population growth. The data from the United Nations Department of Economic and Social Affairs (2024) regarding population growth, especially in Asia and Africa, underscores the urgent need to address food security issues in the world. The demand for food products will increase as the population continues to grow and will reach an estimated 8264364509 people in 2026. This growing demand underscores the importance of addressing diverse interconnected issues, such as environmental sustainability, food safety, and technological advancements in agriculture.

Despite population growth, only Egypt is an active participant in the production of grain and industrial crops in Africa. This suggests that there is untapped potential for agricultural production in many other African countries. Researchers are paying attention to the possibilities of agricultural development on the African continent. Studies, such as those conducted by T. Allen *et al.* (2018) and L. Christiaensen & M. Maertens (2022) explore various aspects of agricultural development, including population demographics, employment patterns, and prospects for the agro-industrial complex. Aligns with global trends African countries are paying particular attention to the cultivation of oil crops.

An article by Y. Hayda & B. Shayniuk (2023) provides an in-depth analysis of the global grain market, focusing on supply, production volumes, and grain stocks. According to the analysis, there is a noticeable upward trend in grain production. To assess the qualitative characteristics of growth trend, the authors examined the balance between grain stocks and consumption on a global scale. An upward trend in this indicator may indicate an increase in global grain stocks relative to consumption, which may indicate improved food security or surplus production. This is confirmed by the research of S. Moshenskyi *et al.* (2024). In their work, they analysed statistical data characterising the latest trends in the development of the agricultural sector of Ukraine. After all, despite the war, Ukraine remains an active participant in the world grain market. Taking into account the difficulties that the parties face for the development of crop production in the conditions of war, separate recommendations were proposed for the formation of state policy. They include promoting the development of new agricultural technologies.

M. Tudi *et al.* (2021) research the environmental consequences of intensification of agricultural production. That is land degradation, water pollution, greenhouse gas emissions and biodiversity loss. Solving the issues is critical to decrease the negative impact on the environment and promoting sustainable agricultural development. In Ukraine, the task of rationalising the use of biomass of the stems of agricultural crops is regulated by the Order of the Cabinet of Ministers of Ukraine "On Approval of the National Waste Management Strategy in Ukraine until 2030" (2017). The implementation of a Waste Utilization Program in Ukraine suggests a strategic approach to dealing with agricultural waste, emphasising the importance of crop residues using.

Q. Yin *et al.* (2024) in their paper highlight the significant increase in crop waste and the low level of recycling in China. The researchers created a three-way model of interaction between local government, social capital and farmers. One of the factors for improving the processing of agricultural plant residues, researchers consider the strengthening of the sense of responsibility of local government and the introduction of engineering and technological innovations. The results of the research are of guiding importance for increasing the level of circular agriculture in China and other countries and forming a complete system of processing agricultural waste.

M. Grigore (2016) and O. Smith *et al.* (2019) emphasised the need for innovative technologies to ensure safe and ecological agricultural production. The new technologies may include recycling and processing of agricultural plants residues. By applying such technologies, farmers can optimise the use of resources, minimise environmental impact and increase productivity. Improved processing methods can reduce waste, energy consumption and environmental pollution while improving product quality and market competitiveness. A. Gomez-Campos *et al.* (2021) discuss the environmental benefits of increased production of flax. Flax is known for its comprehensive zero-waste use, as different parts of the plant can be used for different purposes, including fibers for textiles, seeds for oil production, and by-products for animal feed or industrial applications. Increasing the production of flax products can decrease of agricultural plants residues generation. R. Kumar *et al.* (2023) unravel the ecological issues of agricultural plant residues in India. Air pollution and renewable energy are critical issues in India. The authors suggest using the remains of agricultural plants for the production of fuel. Using local agricultural plant residues can be a sustainable solution to reducing air pollution and energy poverty. However, the formation of any recycling strategy and its practical implementation requires an understanding of the available and projected amount of resources for processing.

The acknowledgement of these trends aligns with the conclusions of Global Trends 2040. A more contested world (2021). It shows the urgency of adopting sustainable practices and modern agricultural technology to meet the growing demand for food while mitigating environmental impacts and ensuring food safety.

Conclusions

Global trends in grain and industrial crops production were studied in the paper. The analysis of wheat, corn, and sunflower cultivation areas showed steady growth in 2000-2021. The data obtained from the research show a gradual increase of the flax cultivated area in the world after a significant decline. Significant intensification of wheat production is observed in India. Other global producers, such as China, the United States, and Canada, are altering their farming methods and technologies. They aim to boost yields while preserving the area under cultivation. The importance of the China, the USA, India, and Ukraine in the world corn market is evidenced by the large areas of corn crops in these countries. The observed global trend toward increased corn production is consistent with the diverse uses of corn, including food, animal feed and industrial applications such as biofuel production. The potential increase in sunflower crops in Ukraine is consistent with the country's recognition of the economic value and export demand for sunflower products. As the cultivation area of major crops increases to meet growing food demands, the challenge of effective utilisation of agricultural plant residues is also increasing.

Agricultural plant residues can be a valuable resource for the production of environmentally friendly goods. Further research on processing agricultural plant residues to obtain goods for various applications holds global promise and relevance. It's crucial to consider additional factors such as yield per hectare, technological advancements and climate conditions to gain a more comprehensive understanding of opportunities in global grain and industrial crops production and processing dynamics.

Conflict of interest

None.

Acknowledgements

None.

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Тенденції світового ринку зернових та технічних культур

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Анотація. Аналіз динаміки вирощування та споживання основних сільськогосподарських культур у світі має вирішальне значення для розуміння тенденцій та планування сталого виробництва продовольства. Важливим є комплексний підхід, який передбачає співпрацю між науковцями та фермерами для впровадження сталих практик. Метою роботи є аналіз тенденцій світового ринку зернових та технічних культур. У процесі роботи були використані методи аналізу, синтезу, узагальнення, прогнозування, бази даних продовольчої та сільськогосподарської організації ООН. Для дослідження було обрано такі культури, як пшениця, кукурудза, соняшник та льон, оскільки вони є основними продуктами харчування для населення планети. Їх вирощують заради зерна (насіння), а льон – рослина комплексного використання, в якій важливе значення має як стебло, так і зерно. Вони забезпечують основні поживні речовини, такі як вуглеводи, білки, жири, вітаміни та мінерали, які мають вирішальне значення для здоров'я людини. Вирощування цих культур є невід'ємною частиною продовольчої безпеки та економічної стабільності багатьох країн, вони підтримують велику кількість населення. В результаті проведеного дослідження було виявлено, що Індія, Китай, США та Канада залишаються найбільшими виробниками пшениці у світі, але тільки Індія збільшує посівні площі. Виявлено глобальну тенденцію до збільшення виробництва кукурудзи. Встановлено, що Україна залишається важливим виробником насіння соняшнику. Крім того, відзначено поступове зростання інтересу до льону. Хоча збільшення посівних площ може допомогти задовольнити зростаючий попит на продукти харчування, пропорційно зростає і проблема використання рослинних залишків. Це міжнародна проблема, тому її вирішення має глобальне значення. Встановлено, що сучасні дослідження спрямовані на вдосконалення переробки сільськогосподарських рослинних решток з метою отримання продуктів різного призначення. Нові знання, отримані в статті, дозволять працювати над удосконаленням переробки пшениці, кукурудзи, соняшнику та льону, що дасть змогу адекватно задовольнити продовольчі потреби населення планети, що зростає, не завдаючи шкоди навколишньому середовищу

Ключові слова: сільськогосподарські культури; населення; виробництво продуктів харчування; рослинні рештки; переробка; екологія

COMMODITY BULLETIN
Journal homepage: https://c-bulletin.com.ua/en
DOI: 10.62763/ef/1.2024.146

Article's History: Received: 06.11.2024 Revised: 17.01.2024 Accepted: 26.04.2024

Vol. 17, No. 1, 2024, 146-153

UDC 678.046:687

Research on the safety level of special-purpose knitwear products

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Abstract. Environmental consciousness has become an essential component of human life in 2015-2024. Therefore, innovative textile and knitwear products made from environmentally-friendly fibers are becoming popular. Such products are safe for health and have less negative impact on the environment. The safety research problem of special-purpose knitwear products remains relevant, as they are used in special conditions, in direct contact with human skin. The aim of the study was to assess the safety indicators of textile products for the manufacture of workwear entering the Ukrainian market. The study used the method of atomic absorption spectrometry to determine the presence of heavy metals and pesticides in the products. The study determined the gross content of heavy metals that are harmful to human health: cobalt, chromium, copper, nickel, tin, cadmium, arsenic, and mercury. Three knitwear fabrics made in China, Ukraine and the Netherlands were selected as samples. The pesticide content was found to be inconsistent with the regulated requirements of Oeko-Tex-100. In the fabric made in China, the level of dieldrin exceeds the permitted limit and reaches 46 μg/kg, while the norm is 0.2 μg/kg. The fabric made in Ukraine contains an unacceptable amount of heptachlor (0.75 μg/kg at a norm of 0.5 μg/kg) and lindane (β-GCG) – 3.68 μg/kg at a norm of 1.0 μg/kg. The highest level of pesticides exceeding the established norms was found in the fabric made in the Netherlands. DDE exceeded almost 4 times – 3.75 μg/kg at the norm of 1.0 μg/kg; heptachlor almost 7 times – 3.19 μg/kg at the norm of 0.5 μg/kg, lindane γ-GCG – 1.51 μg/kg at the norm of 1.0 μg/kg and β-GCG – 15.7 μg/kg at the norm of 1.0 μg/kg. It is proposed to increase the level of control of environmental certification and standardisation with the introduction of mandatory eco-labeling of workwear, and to strengthen control by customs authorities when

Suggested Citation:
Martirosyan, I., Garbazhiy, K., Voitsekhivskyi, V., & Nikolaichuk, L. (2024). Research on the safety level of special-purpose knitwear products. *Commodity Bulletin*, 17(1), 146-153. doi: 10.62763/ef/1.2024.146

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importing special-purpose products into the customs territory of Ukraine. The results of the study can be used by customers of workwear, wholesale and retail trade entrepreneurs, and can serve as a basis for strengthening control by customs authorities and certifying bodies over the entry of special-purpose knitwear of inadequate quality and safety level into the Ukrainian market

Keywords: heavy metals; hygiene requirements; pesticides; knitwear production; environmental safety

Introduction

In 2015-2023, the issue of ecologising the textile industry has become an urgent problem being addressed by scientists and specialists from different countries. This trend is driven by increasing requirements for the safety and hygiene of clothing, including special-purpose clothing. Scientists face new challenges in shaping and optimising the range of workwear and products. Each year, materials and fabrics with special types of processing and properties emerge, and scientists continue to work on the environmental safety of clothing and products. Among them, nanotechnologies occupy a significant place. The study by L. Nikolaichuk *et al.* (2020) substantiated the criteria for assessing the level of safety of nanotextiles and proposed a methodology for testing textiles for various purposes in the Ukrainian commodity market. The author investigated the role of nanotextiles and the issues of environmental friendliness and safety of military clothing. The work of I.A. Martyrosian *et al.* (2022) mentions eco-friendly textiles with antimicrobial properties. The research aimed to obtain a resource-saving method of applying biocidal preparations of thiosulfonate structure, which increases the wear resistance and microbiological resistance of overalls. H.E. Emam (2019) directed his research to improve the durability and mechanical properties of cellulose-containing textiles through biocidal treatment. The author also studied the interaction between cellulose and organometallic reagents, the mechanisms of biological action and the factors affecting biocidal action. In work I. Perelshtein *et al.* (2019) presented studies on the functionalisation of textiles with inorganic CuO, ZnO, MgO nanoparticles and a new Zn-CuO by sonochemical method. This mechanism makes sonochemistry a promising tool for highly stable and environmentally friendly textiles. The author also outlined the role of nanotechnology in the development of antibacterial textiles.

The importance of the environmental safety issue of textile materials is confirmed by the increased interest of scientists and is reflected in many scientific publications for 2018-2023. In scientific articles by S. Yasin & D. Sun (2019) and S. Velusamy *et al.* (2021) various types of textile dyes, including metal-containing ones, are considered. They also present studies on heavy metal pollution in wastewater and the overall environmental impact of technical and conventional textile waste.

Prior to 2018, the environmental safety of textile products in Ukraine was regulated by the Resolution of the Cabinet of Ministers of Ukraine No. 529 "On Approval of the Technical Regulation on Environmental Criteria for Eco-Labeling of Textile Products" (2011). However, by the Resolution of the Cabinet of Ministers of Ukraine No. 3 of January 11, 2018, the Technical Regulation on Ecolabeling lost its validity (Resolution of the Cabinet of Ministers of Ukraine No. 3, 2018). In 2013, the State Sanitary Norms and Rules "Materials and Products of Textile, Leather and Fur. Basic Hygienic Requirements" (Order of the Ministry of Health of Ukraine No. 1138, 2012), have been in effect. These norms and rules were developed as part of the harmonisation of Ukrainian standards with the standards of the International Association for Research and Testing in the Field of Textile Ecology (Oeko-Tex Standard 100, 1992). According to regulatory documents, the content of chemicals in the products is regulated; the content of harmful substances and their migration from the products to the human body and the environment (the content of free and partially releasable formaldehyde; residues of heavy metals that can be extracted, pesticides; the content of pentachlorophenol, azo dyes and organochlorine carriers; the presence of odour, etc.), and the absence of allergic effects is also controlled. After all, textile and knitwear production is associated with various sources of hazards. Harmful chemical dyes, which may contain heavy metals, pose a danger, as these substances migrate from the fabrics and accumulate in the human body. Azo dyes, on the other hand, cause skin diseases and allergic reactions. Moreover, raw materials and products of natural origin are treated with fungicides and insecticides to protect them from microorganisms, moths, and rodents. Natural fibers may also contain pesticides or harmful chemicals that get into the raw material through the soil. Even plant-based dust generated during cotton processing can cause bronchopulmonary pathology. There is also the fact that metals can accumulate in bones and various organs, causing their dysfunction; lead to cancer, acute and chronic kidney failure, diseases of the cardiovascular and nervous systems, autism, fetal death, metabolic disorders, etc. The mechanism of toxic effects of metals and semi-metals, as well as their consequences, varies. In the work of W. Zhou *et al.* (2023) describes the impact of various metals on human health. For example, arsenic (As) harms the liver and hearing, and has carcinogenic effects (including skin, liver, prostate, and Kupffer's cell cancers). Prolonged inhalation of cadmium (Cd) vapours leads to chronic bronchitis, emphysema,

and even lung cancer. Contact with chromium (Cr) can contribute to eczema and allergies. In case of chronic poisoning (occupational exposure), changes in the kidneys, digestive system and circulatory system can be observed. Skin itching and dermatitis can result from exposure to copper (Cu) compounds, which also cause conjunctivitis, ulcers and clouding of the cornea or throat, and also damage liver function. Lead (Pb) leads to anemia, which is more common in children. In addition to disorders of the hematopoietic system, this metal damages the nervous system and negatively affects the digestive system and kidneys. An excess of Zn leads to reduced iron absorption and, at the same time, prolonged excretion of this element from the body.

The purpose of the study was to investigate the presence of hazardous substances in knitwear products entering the Ukrainian market that can be harmful to the health of workers and the environment.

Materials and methods

Pure cotton knitwear products for special-purposes were chosen as the objects of study, since these products have direct contact with human skin. The selection of objects is also due to specific operating conditions, where the fabrics are more exposed to various chemical and biological factors. The characteristics of the investigated knitwear products are shown in Table 1.

Table 1. *Characteristics of investigated knitwear products*

Variant number	Name	Fiber composition, %	Type weave	Surface density, g/m2	Colour, country of origin
1	Knitted fabric taken from a short-sleeved jacket	Cotton 100	single jersey	171	Black, unknown paint brand, China
2	Knitted fabric taken from a short-sleeved jacket	Cotton 100	single jersey	150	Red, unknown paint brand, Ukraine
3	Knitted fabric taken from a short-sleeved jacket	Cotton 100	single jersey	150	Green, unknown paint brand, Netherlands

Source: *developed by the authors*

The tests were carried out in the laboratory of chemical and analytical research of the Ukrainian Scientific Center for Ecology (Odessa) under the Ministry of Ecology and Natural Resources of Ukraine. The concentrations of heavy metals were studied by atomic absorption spectrometry (AAS) using a ZEENIT 650P spectrometer (Analytik Jena AG, Germany), including division/preconcentration, solid phase extraction and co-precipitation procedures. The principle of the spectrometer is based on atomiation of the sample, measurement of the optical density of atomic vapours, and subsequent determination of the mass concentration of elements determined by calibration curves. The pesticide content was determined using an Agilent 4200 MP-AES (Agilent Technologies, USA), an electron capture detector (temperature rise of 1.2°C per min).

Results and discussion

The study took into account the fact that the main pollutants are cadmium, cobalt, bismuth, manganese, copper, nickel, mercury, zinc, lead, antimony, tin, and chromium. From this list, mercury, lead and cadmium are classified as global environmental pollutants of the first class of danger, as they can remain in the structure or on the surface of the fabric, causing various biological effects. The results of the chemical analysis of the presence of heavy metals in the knitwear products under study are shown in Table 2.

Table 2. *Heavy metal content in the investigated knitwear products*

No.	Metal name (concentration of heavy metals in the extract 0.07M HCL)	Displayed in knitted fabrics			Requirements of Oeko-Tex-100 not more than
		Variant No. 1 (black)	Variant No. 2 (red)	Variant No. 3 (green)	
1	Co (cobalt)	<0.05	<0.05	<0.05	4.0
2	Cr (chromium)	0.415	0.087	0.076	2.0
3	Cu (copper)	7.98	0.488	0.242	50.0
4	Ni (nickel)	0.672	0.326	0.068	4.0
5	Pb (tin)	0.897	0.241	0.160	1.0
6	Cd (cadmium)	0.095	0.231	0.050	0.1
7	As (arsenic)	<0.05	<0.05	<0.05	1.0
8	Hg (mercury)	<0.010	<0.010	<0.010	0.02

Source: *developed by the authors*

From the data in Table 2, it can be seen that the concentration of heavy metals in the extract is within the minimum permissible limits. It is worth noting that the content of heavy metals in the fabric of variant 1 (country of origin: China) is the highest compared to the others, while the lowest is observed in variant 3 (country of origin: Netherlands). In all three variants of the fabrics, the levels of cobalt, arsenic and mercury were significantly

lower than the norms regulated by Oeko-Tex-100. Control of pesticide content is also a prerequisite for the environmental safety of clothing and products, as these compounds are among the top priorities for ecosystem pollution. They are persistent and remain for a long time not only in the soil but also in natural raw materials, i.e. in natural fibers. The results of the tests for the presence of organochlorine pesticides are shown in Table 3.

Table 3. *Content of organochlorine pesticides in knitwear, (μg/kg)*

No.	Pesticide name	Variant No. 1 (black)	Variant No. 2 (red)	Variant No. 3 (green)	Requirements of Oeko-Tex-100 not more than
1	DDT	<0.10	<0.05	0.86	1.0
2	DDD	0.011	0.42	0.05	1.0
3	DDE	0.49	0.85	**3.75**	1.0
4	Heptachlor	<0.10	**0.75**	**3.19**	0.5
5	Lindane (γ-GCG)	<0.10	0.24	**1.51**	1.0
6	(α-HCCG)	<0.10	0.15	0.51	1.0
7	(β-HCCG)	<0.10	**3.68**	**15.7**	1.0
8	Aldrin	<0.10	<0.05	<0.05	0.2
9	Dieldrin	**46.2**	<0.05	<0.05	0.2

Note: *DDT – dichlorodiphenyl trichloromethylmethane; DDD – dichlorodiphenyl dichloroethane; DDE – dichlorodiphenyl dichloroethylene*
Source: *developed by the authors*

The data in Table 3 show that all three variants of knitted fabrics from different countries of origin do not meet the requirements of Oeko-Tex-100. For example, in the Chinese-made fabric (variant 1), the dieldrin value, at a norm of No more than 0.2, exceeds the established value by 46 μg/kg. In a knitted fabric made in Ukraine (variant 2), heptachlor exceeds the norms by 0.25 μg/kg, and lindane (β-GCG) by 2.68 μg/kg. Heptachlor is a highly effective insect repellent, so it is used for plants, but as of 2024, its levels are at the lowest concentrations in accordance with the Stockholm Convention on Persistent Organic Pollutants (2001). The results of the chemical analysis of Dutch-made knitted fabric (variant 3) are of particular interest, which also revealed non-compliance with the standard requirements for DDE (1.1-di(4'-chlorophenyl)-2.2-dichloroethylene), heptachlor, lindane γ-GCCH and (β-GCCH) – the content of pesticides significantly exceeds the permissible limits for all of these indicators.

Similar studies are presented in the work of E. Bielak & E. Marcinkowska (2022) to identify heavy metals in textiles and artificial leather sold on the Polish market. The objects were children's products, and the research was conducted to assess the compliance of textiles with the Oeko-Tex-100 requirements for arsenic, cadmium, chromium, copper, tin, and zinc. The results showed that all of the above heavy metals were present in the textile samples, but within the permissible limits of the standard.

M.F. Sima (2022) also dedicated a study to quantifying the content of heavy metals in knitwear products, in particular T-shirts dyed in various bright colours. In this research, the concentrations of heavy metals (Co, Cu, Cr, Cd, and Pb) were analysed in contact with the skin. The results of the research showed high levels of copper (Cu) in black, green, blue and red T-shirts ranging from 26.726-179.315 mg/kg. All T-shirt samples had low cobalt content. In this research, the concentrations of Pb, Cu and Cr in the red and green T-shirt samples exceeded Oeko-Tex.

During the research, I. Rujido-Santos *et al.* (2022) also found that the textile materials under study did not meet the requirements of European Regulation 1906/2006 (Regulation (EC) No 1906/2006, 2006) for the content of heavy metals. The determination of metals in the fabrics was carried out using inductively coupled plasma mass spectrometry (ICP-MS) after acid digestion using microwaves. The results showed that the arsenic content in one and the lead content in 3 fabric samples exceeded the maximum limits. The other 3 samples also contained high levels of mercury. Thus, the test samples of fabrics commercialised in Europe did not meet the requirements of the European Regulation.

H. Chen *et al.* (2021) selected preschool children's clothing made in four Asian regions as the object of their research, where the concentrations of Pb, Cd, Co, Zn, Cr, As, Cu and Ni were investigated. The test results showed that the children's clothing had high levels of Ni and Cr, while the levels of Pb and Cd were not significant within the normal range. Cd concentrations were higher in black garments than in white and coloured samples. Samples without cotton contained unacceptable concentrations of Co. Pb concentrations in samples made in China were significantly higher than in the other three regions. The authors also estimated the doses of skin exposure to these metals and calculated the corresponding risks. The results showed that the health risks from the impact of these metals on children's clothing were within the acceptable limits.

In terms of textile safety, one of the most important indicators is the content of heavy metals and toxic

substances that enter products from various sources. In particular, scientists E. Bielak & E. Marcinkowska (2022) conducted experimental studies on the content of heavy metals in textile materials and artificial leather. The study presents the results of verifying the compliance of the quantitative content of heavy metals with the requirements of Oeko-Tex Standard 100 (1992) by atomic absorption spectrometry. J. Kaur *et al.* (2021), A.E. Apsari & H. Purnomo (2020), Ö. Canpolat & M. Çalta (2020) dedicated their research to the assessment of heavy metal content in untreated water during textile production in the vicinity of India. N. Singh & O. Sahu (2019) studied sustainable ways to develop new textiles with improved properties. Scientists such as G.O. Odubanjo *et al.* (2021), J. Ahmed *et al.* (2021) and D. Astuti *et al.* (2023) in their works have focused on the potential risk of heavy metals to human health and the environment during textile production. Impacts on human health and the environment have been studied and discussed in D. Massella *et al.* (2019), G.A. Engwa *et al.* (2019), and W. Ahmad *et al.* (2021). However, despite the numerous available studies and scientific inventions, the issue of environmental safety remains open and requires the search for more universal, environmentally-friendly and economical solutions. In turn, the author O.V. Pakholiuk *et al.* (2019) investigated the role of vegetable dyes in improving the environmental safety of clothing fabrics and the study of low-toxic synthetic and vegetable dyes for dyeing flax-containing textiles. A. Hanczvikkel *et al.* (2019) studied the problem of microbiological safety of textiles in medical institutions, comparing the results of medical strains with multidrug resistance and antibiotic-sensitive standard strains. The research aimed to find safe and environmentally-friendly biocidal products that can inhibit the development of microorganisms.

The test results and analysis of other researchers' studies confirm the relevance of controlling the safety level of textile materials in the pre-sale period. The data shows that large volumes of textiles and clothing get into unauthorised circulation and are not properly controlled by the relevant authorities not only in the Ukrainian but also in the European and Asian markets. The research shows that hazardous substances, such as heavy metals, chemical pollutants and carcinogens, can be present in textiles in high concentrations, which can lead to harmful effects on human health through skin contact or inhalation. In addition, insufficient control over product safety in the pre-sale period contributes to the proliferation of counterfeit and fake products, which poses a threat not only to consumer health but also to economic stability and market confidence.

Conclusions

According to the results of the research on determining the content of heavy metals in special-purpose knitwear products, it has been established that all three product variants meet the established hygienic requirements of Ukrainian and European regulatory documents. All concentrations of heavy metals in the 0.07M HCL extract are within the permissible limits. The chemical analysis of pesticides showed that all the tested knitwear products did not meet the Oeko-Tex-100 requirements due to the high level of pesticides, in particular, a high content of dieldrin was found in a Chinese-made knitwear product, while variant 2 of Ukrainian production showed a slight increase in the content of heptachlor and an excess of lindane. Variant 3 (produced in the Netherlands) does not meet the safety indicators for several substances: DDE, heptachlor, γ-GCG and β-GCG lindane.

The obtained data indicate inadequate control by state authorities of both producing and exporting country. As Ukraine has been increasing its export potential of textile and knitwear products since 2018, there is a need to strengthen environmental control by customs authorities. Although Ukraine has a harmonised regulatory framework, technical regulation is at a low state level. It would be effective to increase the level of environmental certification and standardisation with the introduction of mandatory eco-labeling for certain types of products and clothing, including special-purpose clothing.

The study determined that the environmental safety of textile products is of crucial importance in shaping the Ukrainian eco-textile market. Further scientific research in this area should focus on developing clear criteria for hygiene requirements and regulatory documentation that would regulate environmental quality assessment indicators. The results of the research may serve as a basis for strengthening control over the quality and safety of textile products entering the Ukrainian market.

In the future, it is planned to conduct experimental tests on the content of toxic substances in knitwear products, including formaldehyde, alcohols, hexamethylenediamine, benzene, toluene, xylene, etc. It is also planned to conduct research on the impact of biocidal treatment on the environmental safety of special-purpose knitwear products and experimental studies in production conditions.

Conflict of interest

None.

Acknowledgements

We express our gratitude to Olena Pakholiuk for fruitful cooperation.

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Дослідження рівня безпеки трикотажних виробів спеціального призначення

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Анотація. Екологічна свідомість за 2015-2024 роки стала важливою складовою життя людини, тому інноваційні текстильні та трикотажні вироби, створені з екологічно чистих волокон, стають популярними. Такі вироби безпечні для здоров'я та мають менший негативний вплив на довкілля. Проблема дослідження безпечності трикотажних виробів спеціального призначення залишається актуальною, оскільки вони експлуатуються в особливих умовах, безпосередньо контактуючи зі шкірою людини. Метою роботи була оцінка показників безпечності текстильних виробів для виготовлення спецодягу, що надходить на український ринок. У дослідженні був використаний метод атомно-абсорбційної спектрометрії щодо наявності важких металів та пестицидів у складі виробів. В роботі визначено валовий вміст важких металів, які шкідливі для здоров'я людини: кобальт, хром, мідь, нікель, олово, кадмій, миш'як, ртуть. Досліджено наявність пестицидів у складі виробів. В ролі зразків обрано 3 трикотажних полотна китайського, українського та голландського виробництва. Встановлено невідповідність за вмістом пестицидів регламентованим нормативним вимогам Oeko-Tex-100. У полотні китайського виробництва показник дилдрину перевищує дозволену межу і досягає 46 мкг/кг при нормі 0,2 мкг/кг. Полотно українського виробництва містить недопустиму кількість гептахлору (0,75 мкг/кг при нормі 0,5 мкг/кг) та линдану (β-ГХЦГ) – 3,68 мкг/кг при нормі 1,0 мкг/кг. У полотні голландського виробництва виявлено найбільший рівень пестицидів, що перевищують встановлені норми. ДДЕ перевищений майже в 4 рази – 3,75 мкг/кг при нормі 1,0 мкг/кг; гептахлор майже в 7 разів – 3,19 мкг/кг при нормі 0,5 мкг/кг, линдан γ-ГХЦГ – 1,51 мкг/кг при нормі 1,0 мкг/кг та β-ГХЦГ – 15,7 мкг/кг при нормі 1,0 мкг/кг. Запропоновано підвищити рівень контролю екологічної сертифікації та стандартизації із введенням обов'язкового еко-маркування спецодягу, посилити контроль з боку митних органів під час імпорту на митну територію України виробів спеціального призначення. Результати дослідження можуть бути використані замовниками спецодягу, підприємцями оптової та роздрібної торгівлі, бути підставою для посилення контролю з боку митних органів та органів сертифікації щодо надходження на ринок України трикотажних виробів спеціального призначення неналежної якості та рівня безпечності

Ключові слова: важкі метали; вимоги до гігієни; пестициди; трикотажне виробництво; екологічна безпека

COMMODITY BULLETIN
Journal homepage: https://c-bulletin.com.ua/en
DOI: 10.62763/ef/1.2024.154

Article's History: Received: 20.12.2023 Revised: 18.03.2024 Accepted: 26.04.2024

Vol. 17, No. 1, 2024, 154-164

UDC 677.11.021

Research of the Ukrainian market and quality of home and sleepwear

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Abstract. The study of demand, supply, and assortment of clothing indicates the need to improve production control, select high-quality raw materials to increase competitiveness and meet consumer needs in this market segment. The purpose of the study was to analyse supply and demand in the Ukrainian market of home and sleepwear and its range. The study assessed the supply and demand market with the help of information resources and search services on the Internet. In the conditions of the enterprise ELLEN GROUP LLC, organoleptic, instrumental methods of assessing the quality of consumer properties of raw materials and finished products were used during production control using regulatory documentation. The factors influencing the formation of high quality of finished products, namely the manufacturing process, stages of production quality control, regulatory documents and consumer properties, were investigated. The analysis of fashion trends and market offers allowed to determine the demand and create a modern classification system for home and sleepwear that meets modern consumer requirements. The main factors that shape the quality level of finished products are highlighted. It is determined that the high quality of garments is achieved by observing a clear technological

Suggested Citation:
Holovenko, T., Kuzmina, T., Berezovskyi, Yu., Shovkomud, O., & Martyniuk, A. (2024). Research of the Ukrainian market and quality of home and sleepwear. *Commodity Bulletin*, 17(1), 154-164. doi: 10.62763/ef/1.2024.154

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process of their manufacture. The quality is governed by the rules and regulations of the state standards and normative documents and the use of high-quality raw materials. Recommendations are provided to guide the choice of high-quality clothing for home and sleep with ensuring comfort and safety of the consumer during use. A classification system has been developed, taking into account current market offers, different needs and requirements of consumers. The factors influencing the formation of high-quality clothing for home and sleep are identified. They are the technological process of manufacturing, during which aesthetic, ergonomic properties are formed and the choice of raw materials with high-quality indicators, which ensures an appropriate level of consumer properties such as hygiene and safety of finished products. To achieve optimal everyday comfort and quality sleep, the main aspects and effective solutions that should be followed when choosing clothes for home and sleep are outlined. The results of the study should increase the competitiveness of enterprises, improve the quality of life of consumers, in particular in the field of home and sleepwear

Keywords: assortment; brand; supply market; consumer demand; consumer properties

Introduction

As of 2024, Ukraine is under russian aggression, and the ongoing hostilities have a significant impact on the lives of citizens. The hostilities have effectively overlapped with the challenges posed by the Covid-19 pandemic, social and environmental crisis. Ukrainians are experiencing double pressure on their physical and psychological lives, which requires improvement in the overall situation. Sleep is a key element of a person's mental and physical health, balanced well-being, increased productivity and overall quality of life. An important guarantee of a good night's rest is the rational choice of home sleepwear. The chosen garment should not only be comfortable, but also fully meet the individual needs of the consumer and ensure optimal heat exchange to regulate body temperature, i.e. meet quality consumer properties. Therefore, in 2024, research on the range of market offerings of homewear in Ukraine and its quality is important and relevant.

Scientists T. Ahmed *et al.* (2022), Md.R. Islam *et al.* (2023) note in their research papers that knitwear has been incredibly successful in the field of leisure and sleepwear over the period 2013-2023. Especially high demand among consumers is for loungewear and sleepwear made from knitted fabrics based on blended yarns.

In studies of the effect of pure and linen blends on the comfort properties of bedding fabrics, scientist U. Bilen (2021) found that the thermal characteristics of fabrics made from a blend of linen and artificial cellulose fibres did not have a significant difference in heat absorption, but consumer properties such as breathability, flexibility, compression and slipperiness increased. He also noted that the fabric made with 80% lyocell and 20% linen fibre in the weft has the highest heat and vapour permeability and elongation, as well as the fabric with 100% cotton fibre. In summary, the research results showed that a fabric made from 80% lyocell and 20% linen will provide good thermal and bedding comfort.

In the works of researchers N.A.K.S. Senthil & B. Dhurai (2021) is noted that knitwear composed of linen fibres is in high demand in the global market, as it has high tensile strength, medium stiffness, high hygroscopicity and moisture resistance, significant cooling effect, comfort and aesthetics in use.

Given the increase in population, which leads to an increase in demand for home and sleepwear products and the observed limitation in the amount of resources and economic instability, there is a need to find an alternative to traditional types of natural fibres for the production of light industry products. To address this issue, Md.R. Islam *et al.* (2023) investigated the general concept of fibre blending in the manufacture of fabrics, the specifics of using okra fibre for the production of fashionable knitwear with high strength and thermal characteristics. The blending of natural and synthetic fibres is an innovative concept of achieving comfort and functional properties at the same time, which is necessary in leisure and sleepwear or underwear, i.e. the group of clothing that is in maximum contact with the human body. These issues have been addressed by scientists M.S. Sk *et al.* (2021), M.M. Rahman *et al.* (2021) and M. Chowdhury *et al.* (2022). Scientists L. Navone *et al.* (2020) and N.P. Bukhonka (2023) studied the effect of mixing natural and synthetic fibres on improving the consumer properties of the resulting materials, which is carried out to achieve a high level of comfort and functionality of finished textile and knitted products.

The purpose of the study was to examine the assortment groups of clothing for home, leisure and sleep, as well as their consumer properties. To do this, the following tasks were identified: to analyse the factors influencing the formation of quality properties of finished products; to identify the range of sleepwear that is in the greatest demand among consumers in the Ukrainian market and to systematise it into a commodity classification.

Materials and methods

The tasks were carried out during 2023 in the laboratory of the clothing industry of the Department of Light Industry Technologies of Lutsk National Technical University and in the production facilities of ELLEN GROUP LLC. The scientific work investigated consumer requests for home, leisure and sleepwear in the context of modern requirements and formed a scientific concept for systematising the assortment matrix of this group of goods. To study the assortment of clothing for home, leisure and sleep, the study first identified the current requirements of the current regulatory documents used in Ukraine, conducted an in-depth analysis of the demand and requirements of the modern consumer regarding the development of trends for the future, and identified the valuable properties of the products in demand. Based on the combination of modern consumer requirements and factors of forming a proper conformity assessment of clothing for home and sleep, valuable recommendations are identified that should be used when choosing this group of clothing, meeting consumer needs and increasing their level of stress resistance. For this purpose, the research used methods of scientific knowledge, namely theoretical generalisation and comparison, analysis and synthesis.

In addressing these issues, detailed analytical studies of data on the current assortment, as well as the market for supply and demand of home and sleepwear were carried out using information resources and the Internet search service. The production of home and sleepwear at the studied enterprise was carried out in compliance with the rules and regulations of the state standards of Ukraine (DSTU GOST 30383-95, 2000; DSTU GOST 25296:2005, 2005; DSTU GOS 31405:2014, 2014). Using organoleptic and instrumental methods of quality control in accordance with regulatory (DSTU 2201-93, 1993; DSTU ISO 3635:2004, 2004) and technical documentation, the consumer properties of raw materials and finished products were assessed.

The object of the research was the factors of forming a proper assessment of conformity and the necessary level of quality of clothing for home and sleep: technological manufacturing process (involves the creation of a model (in the case of a new model), cutting of product details from ready-made patterns, stitching, cleaning operations, wet-heat treatment, quality control and packaging of finished products), consumer properties (aesthetic, ergonomic (anthropometric), hygienic (hygroscopicity, breathability, thermal insulation and electrification characteristics), product safety); materials used at the researched enterprise for the manufacture of goods from the group of clothes for home, sleep and leisure (cotton, viscose and modal fabric and accessories: rings, regulators, silicone, lace, edging, silicone, elastic, buttons, fasteners, ribbon elastic, elastic strap), norms and quality requirements according to state standards.

Results

The market of textile products, clothing, is an important component of the commodity market, which meets the needs of all segments of the population. A detailed analysis of the Ukrainian market of home sleepwear of various assortments, as well as specialised production, shows their significant popularity and rather rapid development, respectively (Kokorina & Morozova, 2012; Navone *et al.*, 2020; Made in Ukraine. Catalogue of Ukrainian manufacturers. Clothing, 2024).

A significant number of brands develop fashion collections and create their own designer clothes (Chuprina, 2015; Ditkovska, 2018). Modernisation of models significantly increases consumer demand in the market for this group of goods. The market of home wear is represented by many foreign (Turkey, Italy, and Poland) and Ukrainian producers and is characterised by different levels of quality. Internationally renowned clothing brands such as Donna Karan, McCartney, Calvin Klein, Stella, Emilio Pucci (Senthil & Dhurai, 2021; Official website of the Ukrainian Association of Light Industry Enterprises, 2024) also present new collections of sleepwear every season.

Ukrainian manufacturers of home and sleepwear offer a fairly wide range of products, in line with current fashion trends, taking into account aesthetic, ergonomic, hygienic and functional properties (Clothing market in Ukraine: Home fashion and shopping trends, 2020). The high quality of consumer properties of clothing for home and sleep, optimal comfort, a variety of styles and design solutions expand the possibilities of using it during various home activities, such as fitness, relaxation, film viewing, professional and educational activities in an online format, computer work, etc.

A variety of textile materials with different price segments are used to make stylish clothes with maximum comfort, from expensive Italian fabrics to more affordable ones locally produced in India, China, Turkey, etc. (How to choose a fabric for a nightgown, 2024). For sleepwear, natural, artificial, and synthetic fabrics are used: tencel, modal, viscose (viscose with wool), cotton, linen, hemp, etc., both with 100% raw materials and in a mixture of certain compositions (Here's why quality sleepwear is important for good sleep, 2022). Depending on the season, thin and dense fabrics are used (Vanishree *et al.*, 2018)

The number of manufacturers of sleepwear on the Ukrainian market is increasing every year (Catalogue of enterprises of Ukraine. Production of work clothes, 2024). For example, well-known brands and leading manufacturers of sleepwear are BARWA garments, Harper's Homewear, DARI CO, Balcony Garment, Ellen, Jeff & Fa Zagrava, Kiss My Eyes, Komilfo, MiaNaGreen, Modena, Kotovich, Ozone, Skif Textile, Sleeper, VP Violet delux, Zen Wear, Mashsh, Costa, Ladan, Nash odiah, Pani Yanovska, Roksana, Natalux, Kruta Pizhama, Masky Karnaval, Jasmine Lingerie and Edelvika. As of 2024, these products are sold in stationary outlets and online stores (Tausif *et al.*, 2015; Shatska, 2016; Ukrainian brands with comfortable and stylish home clothes, 2022). The types of home and sleepwear of some brand representatives are shown in Figure 1.

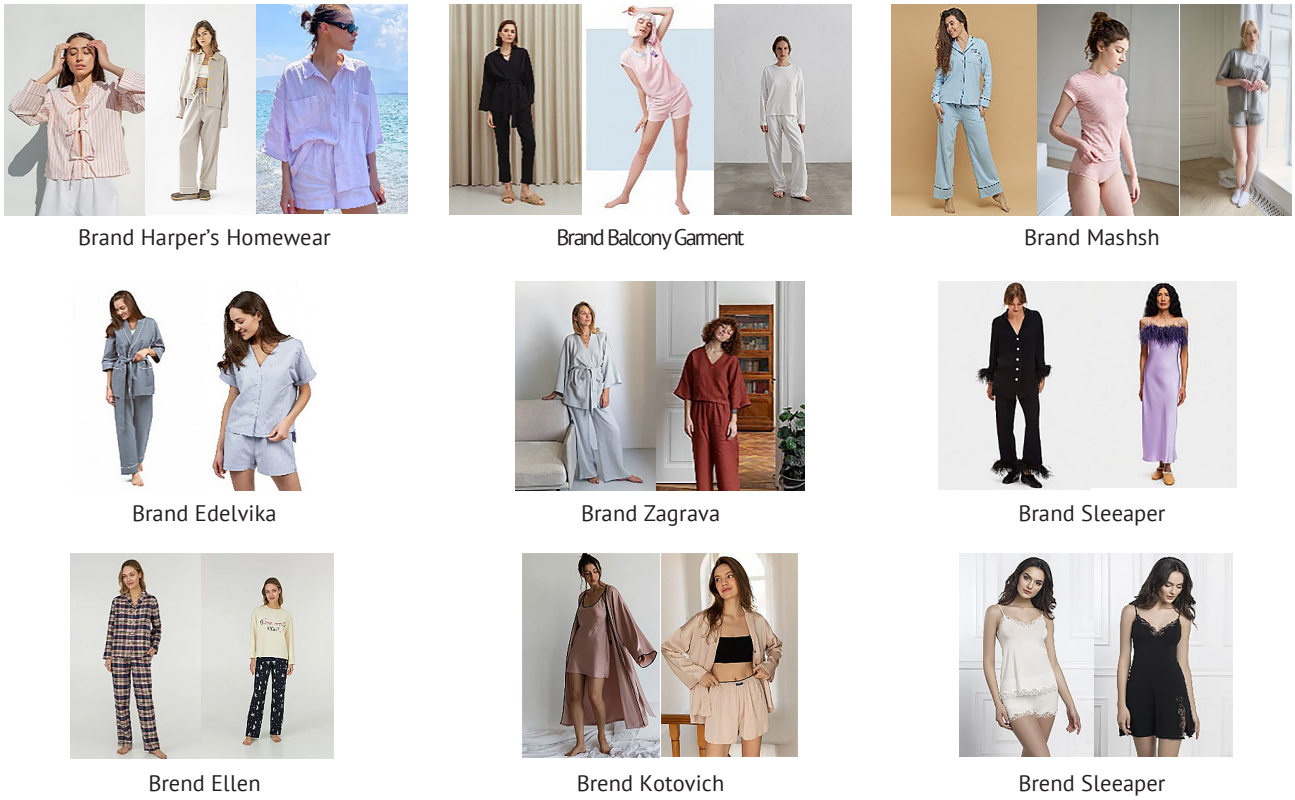

Figure 1. *Modern range of home and sleepwear by Ukrainian brands*
Source: *developed by the authors*

The designs of the studied products range from graphic elements and logos to sophisticated modern styles, allowing you to find a suitable option according to your individual preferences and financial capacity. In 2024, minimalist design and geometric shapes are becoming more popular, reflecting the trend towards simplicity and elegance. Experiments with the structure and texture of fabrics using innovative technologies in the production of home and sleepwear are also relevant design trends (Vigneswaran *et al.*, 2009).

Sleepwear is divided into two main categories: nightgowns and pyjamas. By gender, they are divided into women's and men's, and by age – children's, teenagers and adults. Men's pyjamas do not have many types of models, but usually consist of sets of trousers (shorts) and shirts (T-shirts, longsleeves). Women's sleepwear is represented by a much wider range of products – pyjamas, children's pyjamas, overalls, nightgowns, combinations, house dresses, bathrobes, T-shirts of various types, etc. (Senthil *et al.*, 2021).

Other aspects that extend the classification of sleepwear were also studied, namely by age category, specific purpose, seasonality, service life status, origin of textile materials and design. The results of the analysis are systematised and summarised in the developed classification system for sleepwear, which takes into account the modern assortment matrix depending on the different needs and requirements of consumers (Fig. 2).

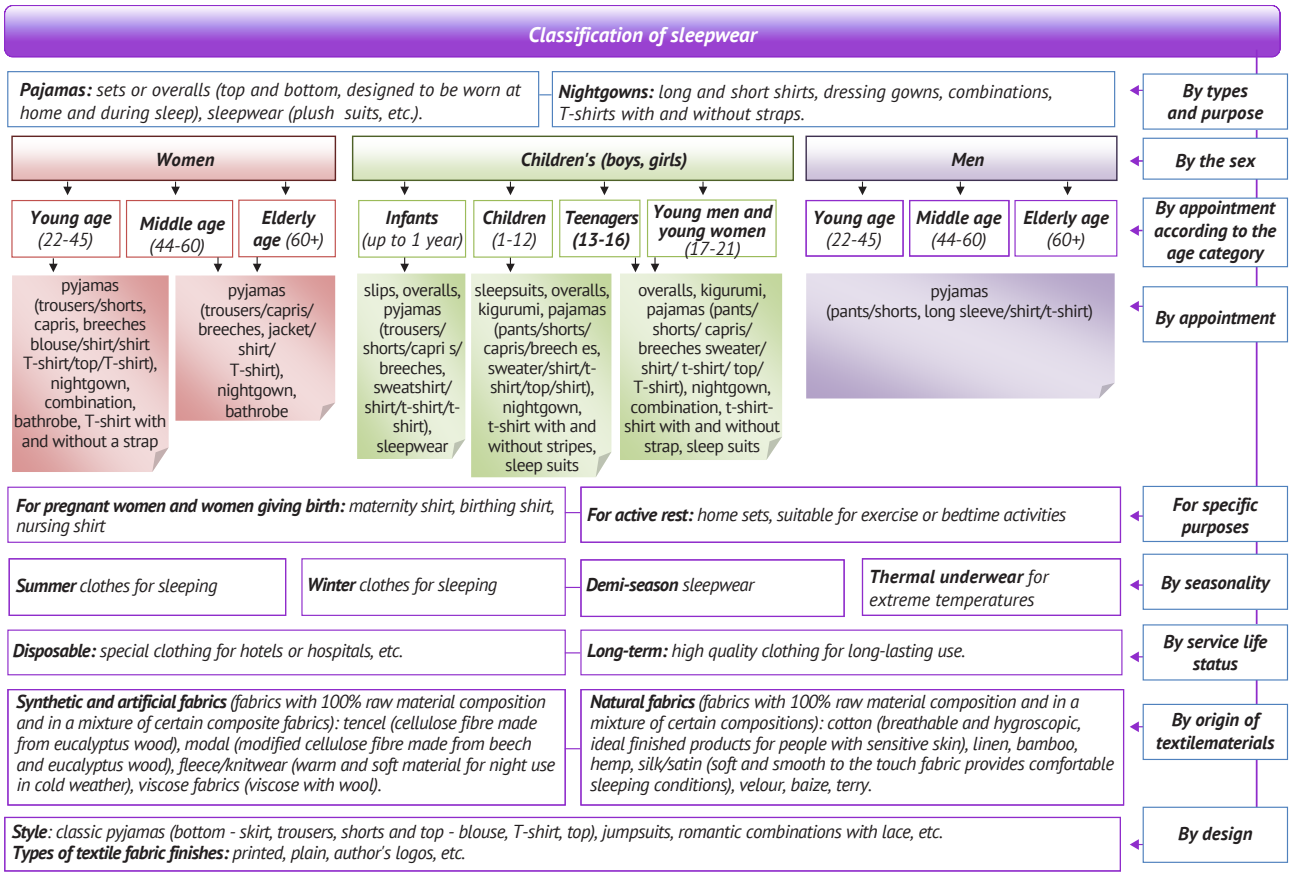

Figure 2. *Classification of sleepwear*

Source: *developed by the authors*

The main factors on which the high quality of finished products depends are compliance with the norms and rules of the manufacturing process (aesthetic, ergonomic properties and safety of products are formed) and the level of quality of consumer properties of the material, fabric and accessories (hygienic properties, hygroscopicity, breathability, heat protection and electrical characteristics are ensured). These factors were studied in detail in the real conditions of the Ukrainian company ELLEN GROUP (Lutsk, Volyn region). This production facility is a Ukrainian brand of TM Ellen for women's clothing for home, leisure, sleep and underwear of high quality. Women's sleepwear is represented by long and short nightgowns of various cuts, modern lightweight models of suits, sets (shorts and T-shirt), overalls, etc.

Nightgowns for everyday use should be as natural as possible, with high hygroscopic, performance, hygienic and hypoallergenic properties. These properties are met by cotton fabrics. Cotton fabrics are used to make strapless shirts decorated with lace ribbon, guipure shirts, collared shirts, nursing shirts and a T-shirt with a placket. Viscose fabrics are used to create sets of nightgowns and aesthetic bathrobes, both laconic, elegant models and more open styles decorated with lace. Viscose products have their own advantages:

- lightness of the material, which ensures weightlessness of the garment on the body;
- high breathability, which guarantees comfort in use;
- the fabric does not electrify and does not roll;
- high colour fastness;
- high degree of heat regulation.

However, the material's low maintenance is a disadvantage. Viscose products are prone to fading, should be washed only at low temperatures without spinning, with mild detergents, and dried horizontally to avoid deformation (Vanishree *et al.*, 2018).

Modal is used in this production to make nightgowns, which makes the finished products aesthetically pleasing and elegant. The high-cost fabric has a sufficient list of advantages: it does not lose colour, does not shrink, is resistant to washing, soft and pleasant to the touch (Vigneswaran *et al.*, 2009). The combination of the modal with lace gives lightness and translucency to the finished products. Table 1 presents in detail the selection of materials and accessories used to produce a certain range of sleepwear in the conditions of the studied enterprise. In the production, the largest number of units are made specifically of nightgowns of various assortments. In general, from the creation of the model (sketches) to mass production, the model is developed in six stages, which are presented in Figure 3.

Table 1. *The range of sleep shirts produced in the conditions of the studied enterprise*

No.	Types of sleep shirts	Materials	Accessories
1	Shirt with straps	cotton, modal	rings, regulators, silicone, lace
	Sets (nightgowns and dressing gowns)	viscose	lace, edging
2	Guipure nightie	cotton, modal	silicone, rubber band, lace
3	Shirt with collar	cotton	edging, buttons
4	T-shirt with a strap	cotton	buttons
5	Nursing shirt	cotton	fasteners, elastic band, elastic strap, lace

Source: *developed by the authors*

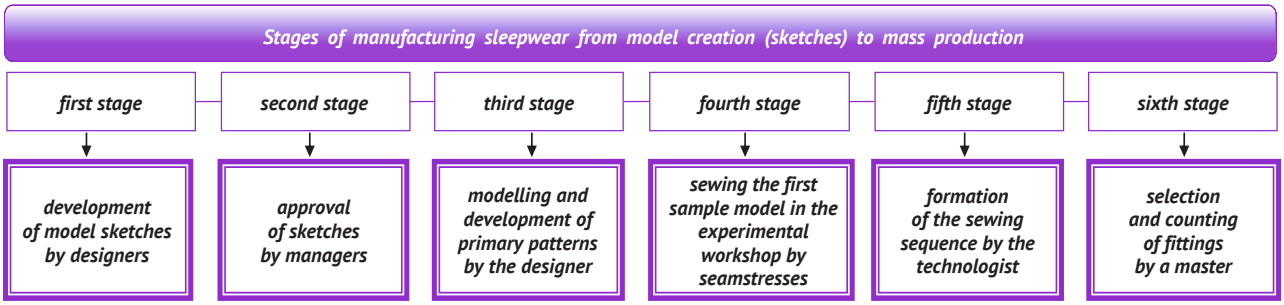

Figure 3. *Stages of manufacturing sleepwear from model creation (sketches) to mass production*
Source: *developed by the authors*

In the case of approval of the technological process of manufacturing the model and approval of its mass production, the finishing shop starts work, where the parts of the product are cut out according to the ready-made patterns, which are sorted by the stage of sewing the parts and numbered. Next, the finished parts are sent to the sewing shop, where seamstresses and technologists sew up the model batches. The sewn product is sent to cleaning operations to remove excess threads. The technological process is completed by wet-heat treatment of finished products, quality control and their packaging in branded packaging. According to this sequence of the technological process, other models of clothing for home, recreation, sleep and underwear are also manufactured at the production facility. In order to achieve high quality of finished products, quality control is carried out at all stages of production.

The first stage of production control is acceptance (incoming) control, where purchase raw materials (materials and accessories) are rejected according to DSTU 2201-93 (1993). At the investigated enterprise, possible defects or undesirable properties of the raw material sample are evaluated and predicted using the organoleptic method. Then, using the instrumental method, with the help of special equipment, selected samples of raw materials are examined for the presence of all defects and deficiencies: tears, unevenness of colour, point defects, distortions and evenness of the edge. As practice shows, incoming quality control is an important stage, which depends on the level of hygienic properties (hygroscopicity, breathability, thermal insulation and electrification properties) and safety of the potential finished product. As a result of this control, the manager of procurement and quality of materials makes a decision on the further supply of raw materials.

In the experimental workshop, the clarity of the design of the models and the technological map is evaluated, which depends on the fit of the finished products and their aesthetics in general. The finished product is put on a figure or mannequin with all buttons fastened and a belt tied (if available), and the quality of fit is determined by the organoleptic method. At this stage, in accordance with the rules and requirements of DSTU ISO 3635:2004 (2004), the anthropometric properties of clothes are controlled, that is, their compliance with the dimensional characteristics of consumers (human body dimensions according to age and gender), which are an essential aspect of the formation of quality consumer properties of ready-made garments mass production. Aesthetic properties are evaluated: information expressiveness (compliance with modern fashion trends with market demand forecasting, iconicity, originality and expressiveness of style), integrity of the composition, rationality of the form, perfection of production execution and stability of the product type. Determine the presence of structural defects: vertical, horizontal and diagonal folds, corner folds, violations of symmetry and general balance of the model, convenience and comfort when using small details (pockets, valves, belts, fasteners, etc.).

The cutting shop performs quality control of the finished cutting materials. In case of defects, they mark them and send the defective part for re-cutting. In the Sewing Department, technologists and supervisors of the Technical Control Department carry out operational control during the execution and completion of

technological operations. The main types of operational control are:

- periodic control of all technological operations, during which, at set intervals, information is received on the quality of the controlled operations;
- self-control – the seamstress controls the quality of her operation;
- mutual control – the quality of the previous operation is controlled.

The quality of the finished product manufacturing technology is determined by organoleptic and measuring methods on a special table. The quality of the product is assessed organoleptically from the wrong side and then from the front. The presence of textile defects (thinning, stains), symmetry of paired parts, quality of stitches, stitching, seams, joints (glue, thread) and moisture and heat treatment are determined. The measuring method determines the size of defects and the symmetry of paired parts. After a successful inspection, the products are sent to the packaging department and a common batch is formed.

To ensure that clothing has anti-allergenic qualities, it is important to observe such aspects as loose fitting, the absence of aggressive chemicals in the raw materials from which the products are made, and their allergenic testing. After all, hypoallergenic clothing for home and sleep creates a safe and comfortable environment, especially for those consumers who are prone to allergies or have sensitive skin (Vigneswaran *et al.*, 2009).

Therefore, in order to achieve optimal everyday comfort and quality sleep, it is necessary to choose the right clothing for the intended purpose with high-quality consumer properties. To achieve this goal, when choosing clothes for home and sleep, it is proposed to be guided by the following rules: the fabric of the product should be anti-allergenic and as natural as possible; clothes should not stretch, lose colour or fade after washing; the design should not contain a large number of small elements, buttons, ties and elastic bands, especially in children's clothing; the neck should be easy to stretch or have special fasteners; clothes for home and sleep should be free and comfortable. The combination of these components will significantly improve the overall health, comfort and ensure high performance.

Discussion

Following the transition to remote work and distance learning due to the global Covid-19 pandemic (2020) and russia's full-scale invasion of Ukraine (since 24 February 2022), people are spending more time at home. These factors have led to a significant increase in consumer demand for sports and home wear. For example, in March 2020, sales of pyjamas increased by 143%, while sales of bras decreased by 13%. By the last quarter of 2020, clothing retailers noted that comfort had become a key factor for consumers (Navone *et al.*, 2020; Made in Ukraine. Catalogue of Ukrainian manufacturers. Clothing, 2024).

There is another side to the issue under study. Analytical studies by experts of the Ukrainian Association of Light Industry Enterprises (Official website of the Ukrainian Association of Light Industry Enterprises, 2024) indicate that, compared to the period of 2021-2022, in 2023, consumers' demand for fashionable clothes increased, changing it from everyday and home clothes, expressing a desire to update their wardrobe and get psychological satisfaction. Analytical research by NPD Group (Official website of the Ukrainian Association of Light Industry Enterprises, 2024) and B. Riley Securities (Polkovnychenko & Korovinchenko, 2021; Official website of the Ukrainian Association of Light Industry Enterprises, 2024) also show that in 2024, there may be high demand for light industry categories – trendy trends of a particular season that were in crisis during the pandemic and full-scale invasion, and product categories such as home and sleepwear that were in high demand in the relevant periods may lose sales momentum. At the same time, as required by the circumstances over a significant period of time, for the sake of the economic balance of enterprises, organisations, institutions and the country as a whole, a significant number of professional and educational activities continued to operate, and some of them were established and successfully operated in an online format on an ongoing basis and have established themselves as an additional area of financial income and training, respectively (Navone *et al.*, 2020; Polkovnychenko & Korovinchenko, 2021; Made in Ukraine. Catalogue of Ukrainian manufacturers. Clothing, 2024). Therefore, it is quite predictable that this trend will continue in the long term and will develop in different directions.

In the process of conducting information and literature analysis, it was found that the issues of optimising the range of modern clothing for home, sleep and leisure, as well as establishing the factors for forming a proper conformity assessment and their required level of quality, have not been studied at the scientific level. Blended yarn manufacturing technologies make it possible to improve, predict and obtain the necessary consumer characteristics of finished products, enrich and expand the product range, and regulate their cost. These technological solutions are quite popular and relevant in the spinning industry, and the latest composite solutions in fibre blends are being developed on their basis.

The combination of natural and synthetic fibres is a proven trend to achieve both comfort and functionality in finished textile and knitwear products. To obtain high heat-resistant properties of knitted fabrics, C. Vigneswaran *et al.* (2009) investigated a blend of jute and cotton. Combining the valuable properties of natural fibres with the practical properties of synthetic fibres is a relevant and correct strategy for obtaining household products with high performance properties that meet consumer requirements. This practice of combining

the properties of natural and synthetic fibres was followed in their research by U. Hussain *et al.* (2015), M. Tausif *et al.* (2015).

It is worth noting that Ukrainian scientists G.V. Kokorina & S.N. Morozova (2012), T.I. Godunok & T.V. Tsymbal (2016) conducted research in this area, but they dealt with the design of clothing for sleep and leisure. These works outline a number of unresolved problems that complicate the overall process of model building, namely: the lack of an expanded modern classification of sleepwear, systematisation of existing types and requirements for it, as well as a database of dynamic indicators to determine the system of constructive allowances. In the context of the availability of meeting the needs of the textile industry to create textile products taking into account their environmental sustainability, biodegradability, and the possibility of easy processing, researchers point to the need to prioritise the use of numerous biodegradable natural fibres (Vinod *et al.*, 2020).

In order to meet the growing needs of demanding home textile consumers, scientists are conducting applied research to provide fabrics with special properties that are particularly delicate and demanding from the textile technology point of view, and even some indicators are in some contradiction. Any single natural or chemical fibres cannot meet the complex requirements, and only by using a certain complex of multifibre chemicals can the appropriate functionality be achieved (Bentis *et al.*, 2023). For example, the authors C. Fu *et al.* (2021) in their scientific work reveal research on the coating of linen fabrics with polysiloxane using a hydrosilylation reaction in the presence of a Carstedt catalyst at room temperature. It is stated that such fabrics have shown high and durable hydrophobic properties (contact angle and slip angle are approximately 145° and 23°, respectively) with a proper ability to self-clean from certain pollutants. In their works, P. Chauhan *et al.* (2019), B.K. Tudu *et al.* (2020) and W. Li *et al.* (2022) address the issue of self-cleaning materials, which provides high physical dust repellency of the material intended for the manufacture of home textiles and clothing. At that time, researchers J. Huang *et al.* (2022), D. Song *et al.* (2023) outline the factors for improving the antibacterial characteristics of textile fabrics used for the manufacture of home textiles.

As a result of a critical analysis of information sources, it should be noted that high competition enables enterprises to survive in the market by entering it with high quality goods and satisfying consumer needs. The analysed studies of scientists do not address the issues of analysing the factors influencing the formation of quality properties of finished products, identifying the range of sleepwear that is in the greatest demand among consumers in the Ukrainian market and presenting the classification of this group of clothing. Since, as of 2024, many enterprises and educational institutions continue the practice of distance work and study, respectively, and a sufficient number of consumers use such conditions of professional and educational interaction, the purpose and objectives of this scientific work are relevant.

Conclusions

The main purpose of the research was to identify the modern assortment of sleepwear and determine the factors influencing the formation of quality properties of finished products. To solve the tasks, detailed research of global and Ukrainian scientific papers was carried out, which revealed the lack of analysis of factors influencing the formation of quality properties of finished products and systematisation of the modern range of sleepwear in demand in the Ukrainian market. The analysed research papers generally dealt with the production of household products with high performance properties that meet consumer requirements by combining the valuable properties of natural fibres with the practical properties of synthetic fibres. Such technological processes in the spinning industry make it possible to improve, predict and obtain the necessary consumer characteristics of finished products, enrich and expand the range of products, and regulate their cost. As of 2024, many enterprises and educational institutions, following the emergency introduction of remote professional and educational activities (the global Covid-19 pandemic and russia's military aggression in Ukraine), have implemented and abandoned the practice of remote work and study, and consumers successfully use such conditions of professional and educational interaction. Therefore, the home, leisure and sleepwear group will consistently have a successful marketing position in the commodity market.

As a result of the conducted research, it was determined that this group of textile products – clothing for home and sleep – has a significant and stable demand in the Ukrainian market, and their assortment, in accordance with modern fashion trends, consumer requirements and with different price segments, is provided by well-known international brands and Ukrainian manufacturers. Based on the carried out analysis, the assortment matrix of sleepwear is systematised and a classification is developed according to the following items: types and purpose, gender, age category and purpose according to age category, specific purpose, seasonality, service life status, origin of textile materials and design. The main aspects and effective solutions when choosing clothes for home are proposed.

In the context of the analysis of the enterprise ELLEN GROUP, the factors of influence that form the high consumer properties of finished products were identified. The high quality of goods is guaranteed provided that a clear technological process of manufacturing garments is followed, governed by the rules and regulations of state standards and regulatory documents, as well as the use of high-quality raw materials. The study found that the manufacturing process forms the

aesthetic and ergonomic properties of goods, and the choice of high quality raw materials ensures an appropriate level of hygiene and safety of products.

Prospects for further research include the development of targeted, regulatory and technical documentation on quality control and conformity assessment for new models created in response to the demands of time and consumer requests. This will regulate the requirements for effective solutions and key aspects when consumers choose clothing for home, leisure and sleep; creation of a modern system of anthropometric data, taking into account the new range of clothing for home, leisure and sleep, as well as the parameters of a typical figure.

Conflict of interest

None.

Aknowledgements

None.

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Дослідження українського ринку та якості одягу для дому та сну

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Анотація. Дослідження попиту, пропозицій, асортименту одягу вказує на необхідність покращення виробничого контролю, вибору якісної сировини для підвищення конкурентоспроможності та задоволення потреб споживачів в цьому сегменті ринку. Метою дослідження був аналіз попиту та пропозицій на українському ринку одягу для дому та сну та його асортименту. У дослідженні здійснювалася оцінка ринку попиту і пропозицій за допомогою інформаційних ресурсів, пошукових сервісів в комп'ютерній мережі Internet. В умовах підприємства ТОВ «ЕЛЛЕН ГРУП» під час виробничого контролю використовувалися органолептичні, інструментальні методи оцінки якості споживчих властивостей сировини та готових виробів з використанням нормативної документації. Досліджено фактори впливу на формування високої якості готових виробів, а саме технологічний процес виготовлення, етапи виробничого контролю якості, нормативні документи та споживчі властивості. Аналіз модних тенденцій і ринкових пропозицій дозволив визначити попит та створити сучасну систему класифікації одягу для дому та сну, що відповідає сучасним вимогам споживачів. Висвітлено основні чинники, які формують рівень якості готових виробів. Визначено, що висока якість швейних виробів досягається дотриманням чіткого технологічного процесу їх виготовлення, керованого нормами і правилами державних стандартів та нормативних документів та застосуванням високоякісної сировини. Надано рекомендації, якими запропоновано керуватися під час вибору одягу для дому та сну високої якості із забезпеченням комфортності, безпечності споживача під час експлуатації. Розроблено систему класифікації з врахуванням сучасних ринкових пропозицій, різних потреб та вимог споживачів. Визначено фактори впливу на формування високої якості одягу для дому та сну: технологічний процес виготовлення, в ході якого формуються естетичні, ергономічні властивості і вибір сировини з високими якісними показниками, що забезпечує відповідний рівень таких споживчих властивостей, як гігієнічність та безпечність готових виробів. Для досягнення оптимального повсякденного комфорту та якісного сну окреслено основні аспекти та ефективні рішення, якими необхідно керуватися під час вибору одягу для дому та сну. Результати дослідження мають підвищити конкурентоспроможність підприємств, поліпшити якість життя споживачів, зокрема в галузі одягу для дому та сну

Ключові слова: асортимент; бренд; ринок пропозицій; попит споживачів; споживчі властивості

Журнал
«ТОВАРОЗНАВЧИЙ ВІСНИК»

Том 17, № 1
2024

(Англійською мовою)

Редагування англомовних текстів:
С. Воровський

Відповідальний редактор:
К. Халімон

Комп'ютерна верстка:
К. Пилипенко

Підписано до друку з оригінал-макета 26.04.2024
Ум. друк. арк. 19,3

Контактна адреса:
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Journal
“COMMODITY BULLETIN”

Volume 17, No. 1
2024

Editing English-Language Texts:
S. Vorovsky

Managing Editor:
K. Khalimon

Desktop Publishing:
K. Pylypenko

Signed to the print with the original layout 26.04.2024
Conventional Printed Sheet 19.3

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