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Problems of planning and carrying out commodity expert examinations of property and equipment for military purposes and armaments

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Abstract. In the period from 2014 to 2024, employees of institutions of forensic expertise emphasised the importance of conducting independent, qualified and objective examinations to ensure justice. This created a need to conduct forensic commodity examinations of property and equipment for military purposes and armaments. The purpose of the study was the analysis of the legal and methodological basis for the implementation of forensic commodity examinations property and equipment for military purposes and weapons, for the further development of a single approach to conducting research and guaranteeing the systematicity of expert practice, increasing the reliability of research results, used in the study the following methods: linguistic, system-functional, dialectical, systematisation, monographic, analysis and synthesis. The result of the study, which includes the practical component of forensic commodity examination, was an outline of the problems of planning and carrying out examinations of property and equipment for military purposes and weapons, which consist in: the absence

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of a unified terminological approach to the main concepts; the technical complexity of the investigated objects; limited access to information and documents that contain characteristics of research objects; the need to regulate the mechanism of interaction between expert institutions and entities involved in the production and/or implementation of these objects; the need to develop scientific and practical publications. It was highlighted in the work identification features of the relevant property and equipment, which contain information about the type, species, model, size, tactical and technical characteristics, category of quality (technical) condition, which will allow to systematise the expert's work in this direction. The rationale for choosing a methodical approach to determining market and non-market types of value was presented, taking into account the availability and completeness of the necessary initial data, in particular, the impracticality of using the income methodical approach were argued and the use of cost and/or comparative methodical approaches is recommended. The results of the scientific work are aimed at improving the quality of the performance of the forensic commodification examination on the issues of valuation of property and equipment for military purposes and weapons and will contribute to increasing the validity of the conducted commodification studies. The results of the research can be used for the further development of methodological support, which can be used by forensic experts to conduct research in specialty 12.5 "Evaluation of property and equipment for military purposes and armaments"

Keywords: military aid; munition; dual-use goods; cost; methodological approach; property assessment

Introduction

The military, economic, and political situation that has developed in Ukraine since 2014 has created challenges for the national criminal justice system and law enforcement agencies – to ensure effective counteraction to completely new, for prosecutors and investigators, types of crime, in particular, crimes of the full-scale Russian-Ukrainian war on the territory of Ukraine (war crimes, crimes of genocide; crimes against humanity; crimes of aggression; crimes of large-scale appropriation and destruction of property, committed illegally and intentionally and not justified by military actions; misappropriation, embezzlement of property during the performance of official duties, etc.), the number of which is increasing daily. With the introduction of martial law on February 24, 2022, the provision of a comprehensive, complete and adequate legal response to crimes committed during the armed conflict and war-related criminal offenses, their quality investigation, guaranteeing the effective protection of the state's interests, rights and human and citizen freedoms, Ukrainian society, humanity and the international legal order (Sokurenko, 2023). Achieving these goals puts on the agenda a priority task for the employees of the law enforcement sector of the state, both the detection and timely and complete documentation of criminal offenses related to Russia's armed aggression and their consequences, not only in the framework of a national investigation, but also in view of their further use in international judicial bodies is possible. At the same time, it was stated that in the conditions of the introduction of martial law on the territory of Ukraine, the employees of the prosecutor's office and pre-trial investigation have difficulties during the organisation and investigation of such crimes, which makes it necessary not only to apply a unified approach regarding the organisation of the actions of the employees of law enforcement agencies at the stage of pre-trial investigation, but also the involvement of judicial experts in the process of confirming the circumstances of the commission of crimes related to the armed aggression of the Russian Federation against Ukraine.

The increase in the level of crime, the discovery of new forms of committing offenses, new types of research objects led to the demand for new types of expert specialties to solve issues for which it is necessary to apply special, technical, scientific and/or other knowledge, methods and methods of research that lead to a more complete satisfaction of the needs of judicial and investigative practice. Among the introduced relatively new expert specialties is 12.5 "Evaluation of property and equipment for military purposes and weapons", which allows solving one of the most difficult tasks of forensic commodity examination (FCE). The problems of formation and development of the theory and methodology of examination of property and equipment for military purposes and weapons (PEMPW) are only gaining momentum. In this area, research was carried out by a small number of scientists, among whom there are specialists with practical experience, employees of forensic research institutions of the Ministry of Justice of Ukraine and the Expert Service of the Ministry of Internal Affairs of Ukraine.

O.O. Buhaiova (2020) in a scientific work investigated the definition of such legal categories as "property of the Armed Forces of Ukraine", "military property", analyses scientific opinions on these definitions, raises the issue of inconsistency of terms and presents the development and explains the author's definition of the concept of "property of the Armed Forces of Ukraine". The work of R.P. Lavronov (2023) aimed at considering key aspects of the legal regime of military property in Ukraine, where, in particular, the conceptual apparatus related to the definition of military property and legislative acts regulating the legal

regime of military property are considered. In the work of I.I. Piskun & M.A. Sokolovsky (2023), the need for systematisation and ordering of military property noted, the authors recommend classifying it by purpose into two categories: military property of general purpose and military property of special purpose. According to the conclusion of these authors, additional research is necessary to resolve issues regarding the composition of military property, which is a key element for establishing the necessary mechanisms for legal regulation of relations regarding the use, possession and disposal of this property.

S.M. Dolynskyi (2023) raised the issue of distinguishing research objects by expert specialties 12.5, 12.2, 12.1, 10.10, 10.6. A.A. Marchuk & V.A. Tkachuk (2022) put forward for consideration the question of the relevance of training specialists in the field of valuation of military property. This need is due to the necessity of carrying out FCE according to direction 12.5, which includes the provision of conclusions of forensic examinations of military property or complex examinations (in cooperation with forensic ballistic experts). These conclusions are used as a source of evidence in criminal, economic, civil cases, as well as in cases of administrative violations.

M.V. Harbuz (2019) considered the problem of the imperfection of the methods of determining the residual value of the property of the Armed Forces of Ukraine and other military entities, in particular focuses attention on the lack of other developments that can be used by forensic experts during the assessment of PEMPW. O.Y. Kapinus (2023) emphasised the importance of strengthening control over military property assessment procedures, examines the algorithms for the assessment of this property and points out shortcomings in the legal regulation of this process. O. Furmanchuk (2023) noted that in general, the supervision of state property is carried out by various bodies, such as the supreme body of control over state finances, which is subordinate to the President of Ukraine, as well as state departments and subdivisions of ministries, which are subordinate to higher bodies of state control.

V.V. Yusupov (2021) examined the issues related to the specifics of the examination of military property in the conditions of Russian aggression, in particular the role of forensic examination in the investigation of criminal corruption offenses. S.M. Dolynskyi *et al.* (2022) considered the problems that arise when performing forensic examinations of military property. In the analysed scientific works, a number of important problematic issues in the examination of military property were considered, but, despite the completeness of the conducted researches, they did not consider the specifics of planning and implementation of FCE of military property in the context of the application of special knowledge, which require thorough consideration.

The purpose of the study was to systematise the available scientific research on the peculiarities of conducting forensic commodity expert examinations of PEMPW in order to provide a comprehensive perception of their real state, outline unresolved issues and determine the prospects for further research.

Materials and Methods

To ensure the independence, objectivity and completeness of commodity research it is necessary to be guided by the principle of complexity; the principle of problem interconnection carrying out commodity expert examinations of the Ministry of Education and Culture, the number of which has increased in the conditions of the Russian-Ukrainian war since the beginning of 2014; the principle of universality of the main methods of analysis and the combination of different methodological approaches to assessment; principle consistency of regulatory and methodical regulation of PEMPW evaluation issues.

The introduction of a new specialty did not solve the issues related to the evaluation of PEMPW. The only normative legal act that regulates the process of evaluation of PEMPW is the Methodology for determining the residual value of the property of the Armed Forces of Ukraine and other military formations (Resolution of the Cabinet of Ministers of Ukraine No. 759, 1998), however, due to the availability of the latest equipment and weapons, it has lost its relevance. It is worth noting that in the Register of Forensic Methods of the Ministry of Justice of Ukraine (Register of Forensic Examination Methods, 2024) there are no valid methods and methodical recommendations that could be used by forensic experts during the performance of STE in expert specialty 12.5 "Evaluation of property and equipment for military purposes and armaments" (Table 1).

Table 1. *Availability in the Register of Forensic Examination Methods of the Ministry of Justice of Ukraine by type "Commodity examination"*

Type and subtype of forensic examination	Index and type of expert specialty	The number of methods introduced in the Register	
		Total	Valid on 31.12.2023
Commodity expertise	12.1 "Determination of the value of machines, equipment, raw materials and consumer goods"	22	9
	12.1.1 "Research of gambling equipment"	No research	

Table 1. Continued

Type and subtype of forensic examination	Index and type of expert specialty	The number of methods introduced in the Register	
		Total	Valid on 31.12.2023
Transport and commodity expertise	12.2 "Determination of the value of wheeled vehicles and the amount of damage caused to the owner of the vehicle"	4	2
	12.3 "Evaluation of shipping facilities"	1	1
	12.4 "Evaluation of aircraft"	–	
Examination of military property	"Evaluation of military equipment and equipment"	–	

Source: *developed by authors based on Register of Forensic Examination Methods (2024)*

According to the official electronic database, which was created to inform subjects of forensic activity about the availability of methods for conducting forensic examinations, only 44% of the total number of available registered methods under the type "Commodity examination" are valid. Scientific and research institutions of forensic examinations that develop these methods belong to the Ministry of Justice of Ukraine. It is worth noting that the decision on state registration of 75% of current methods was made from 2009 to 2016, and 25% – in 2023. As a result of the analysis of the information indicated in Table 1, the problem of the lack of methodical support for the evaluation of PEMPW and the need for updating is clearly observed current methods.

The methodology that was used, when solving the task of this scientific work includes separate methods, which are a system of means and ways of revealing the regularities of establishing the development of planning mechanisms and carrying out commodity examinations of PEMPW. The following methods were used in the study: linguistic – for analysis terminology (analysis of the definition of such key categories as "military aid", "military property", "military goods", "dual-use goods", etc.); system-functional – for planning and carrying out commodity examinations of the Ministry of Education and Culture; dialectical – for the analysis of the practice of carrying out commodity examinations of the Ministry of Education and Culture; systematisation – for accumulation and generalisation of available information about the object FCE research, as well as the selection of criteria and means of identification; monographic – for specification of the expediency of updating the existing methodical support of FCE PEMPW and developing a new one; analysis and synthesis – for substantiating the conclusions formulated during the research and planning the prospects for further research; documentary – to establish the accuracy and completeness of the initial data contained in the documents provided by the initiator of the appointment of the FCE, in particular, indicating the type, species, model, characteristic features and dimensions, tactical and technical characteristics, categories of the quality (technical) state of the PEMPW.

Results and Discussion

The process of appointing and conducting FCE in the Poltava region shows the need for expert research, which was not relevant before. In particular, this can be said about research carried out within expert specialty 12.5 "Evaluation of property and equipment for military purposes and armaments". This type of examination solves tasks related to the assessment of the value of military property, determination of its type and purpose, characteristics according to the Ukrainian classification of goods of foreign economic activity, establishment of the country of origin, manufacturer and year of manufacture of the property (in cooperation with trasological studies), as well as detection changes in property quality indicators (in cooperation with specialists in the exploitation of similar property) and other aspects. However, solving these tasks is rather complicated, first of all (Dolynskyi *et al.*, 2022; Dolynskyi, 2023; Piskun & Sokolovsky, 2023):

- the lack of a unified terminological approach to the interpretation and clear demarcation of the concepts "military property", "property of the Armed Forces of Ukraine", "military goods", "dual-use goods" during the FCE;
- the absence of any scientific and practical publication that would contain rules, instructions, extracts from instructions, norms and other official documents and little algorithm carrying out a commodity study of evaluation of PEMPW;
- the technical complexity of PEMPW, the identification of which requires special knowledge from the technology of production, operation and maintenance;
- limited access to information regarding the type, species, model, characteristics, dimensions, tactical and technical characteristics that allow identification of PEMPW, both of Ukrainian production and of countries that provide humanitarian and international technical assistance to Ukraine;
- the lack of necessary documents that contain information about the object of research for its unique identification in connection with their destruction or loss through hostilities;
- the specifics of entering into agreements/sales contracts, which consists in the fact that the price per

unit of measurement of the product usually includes the price for additional services (transportation, assembly, installation, maintenance, etc.);

- the lack of access to price information of PEMPW imported to the territory of Ukraine in the customs regime of import;
- the absence of a legally justified mechanism for the interaction of expert institutions and entities that carry out the production and/or implementation of PEMPW on the issues of providing price information to relevant requests.

It is worth noting that, as part of supporting the defense capability of the Ukrainian people, since the beginning of martial law, on February 24, 2022, a large number of PEMPW was imported to the territory of Ukraine as part of the comprehensive partnership assistance of a wide range of democratic countries. The main types of military assistance provided to Ukraine by international partners include actual and necessary consultations, educating and training of military personnel; non-lethal military aid, such as medical supplies, personal protective equipment, communications, fuel, food, vehicles, and others; provision of weapons, including military equipment, various types of weapons and ammunition; as well as the provision of transport and communication services, intelligence and logistics, etc. (Prypolova, 2023). In turn, O.V. Kozlov (2017) considered the task and developed methods of forensic military examination based on the research of missile and artillery weapons.

International aid is provided mostly in the form of humanitarian and international technical assistance to the Armed Forces of Ukraine and other military formations for the timely additional provision of necessary vital material and technical means. In addition, Ukrainian business entities that have reoriented their production to the production of military products are not left out. In general, both international and Ukrainian partners supply a diverse range of military equipment (weapons, military equipment, missiles and ammunition, personal protective equipment, medical equipment, other materials and equipment).

It is worth noting that in accordance with the Resolution of the Cabinet of Ministers of Ukraine "On Amending the Resolution of the Cabinet of Ministers of Ukraine dated December 9, 2022 No. 1378" dated March 30, 2023 No. 290 (2022) the list of goods that can be used as civilian and military means imported into the customs territory of Ukraine during martial law without the need to obtain permission documents from the State Export Control Service of Ukraine has been expanded. These changes add to the list of dual-use items, including body armour, unmanned aerial vehicles, unmanned airships, defense and detection equipment, communications systems, television and night vision equipment, telemetry and telemetry control equipment, optical weapons sights, technologies for the development, production, repair of PEMPW, etc. However, during the use of such assistance in the field of security and defense, there are problems of legal regulation, namely the potential abuse and inefficiency of the use of military property, which significantly reduces the effectiveness of receiving such assistance, and accordingly, the risks of illegal appropriation and resale of military property and goods appear in the future military purpose. In the conditions of martial law, the problem of involving judicial experts to assess PEMPW in order to ensure a full, comprehensive and effective pre-trial investigation and preventing the loss of evidence in the pre-trial investigation on the grounds of criminal offenses.

The problems of uncertainty during the FCE regarding the assessment of PEMPW are predetermined lack of a clear interpretation of the terms in the normative legal acts of Ukraine. According to Scientific and methodical recommendations on preparation and appointment of forensic examinations and expert studies (Order of the Ministry of Justice of Ukraine No. 53/5, 1998) the list of objects of commodity expert examinations according to the types and subtypes of forensic examinations is defined:

- 12.1 "Determination of the cost of machines, equipment, raw materials and consumer goods" – goods for personal use, raw materials and equipment, and it is also determined that the object of research may be other goods;
- 12.5 "Evaluation of property and equipment for military purposes and armaments" – military property, military equipment and armaments.

The norms of Article 1 of the Law of Ukraine "On the Legal Regime of Property in the Armed Forces of Ukraine" (Law of Ukraine No. 1075-XIV, 1999) define the official interpretation of the term "military property", which means the state property complex belonging to institutions, organisations, military units and institutions of the Armed Forces of Ukraine. According to the provisions of the mentioned Law of Ukraine (Law of Ukraine No. 1075-XIV, 1999), military property includes buildings, houses, transmission devices, weapons, combat equipment, ammunition, technical, chemical, engineering, airfield, material, skipper, medical, veterinary, cultural and educational, household property, fuel and lubricants, communication property, food etc.

It should be noted that Article 1 of the Law of Ukraine "On State Control of International Transfers of Military and Dual-Use Goods" (Law of Ukraine No. 549-IV, 2003) defines the interpretation of the term "goods of military purpose as a whole or separately" as products of military use, such as special and military equipment, components for their production, weapons, ammunition, explosive materials, as well as equipment and materials used in the process of development, production and use of these products. The text of the Law of Ukraine "On State Control of International Transfers of Military and Dual-Use Goods" (Law of Ukraine No. 549-IV, 2003)

defines the term "dual-use goods" as specific types of equipment, products, materials, software and technologies, which are not specifically intended for military use. However, together with the civilian purpose, they can be used for military or terrorist purposes, or for the creation, production and use of weapons of mass destruction, goods for military use, or means of delivery of such weapons, including certain types of nuclear materials, chemical substances, biological, bacteriological and toxic substances.

Therefore, there is a need to distinguish the legally established concepts of "military property", "war materials" or "military products", which, in particular, the property that can be restricted in circulation or withdrawn from it belongs. Taking into account the by-laws and scientific publications of the authors V.Y. Kysil (2006), E.G. Boichenko (2015), O.O. Buhaiova (2020), the term "military property" has different terminological definitions, therefore it is advisable to distinguish the concept of "military property", i.e. "products of military purpose" and property that is military, taking into account only the fact that it is on the balance sheet of military units, institutions, organisations and institutions of the Armed Forces of Ukraine and, due to its consumer properties and purpose, can be used not only with military, but also for civilian purposes. V.S. Kozadaiev (2017) investigated that the elimination of contradictions in the designation of this concept should consist in the harmonisation of terminology at the legislative level, which will contribute to the effectiveness of legal regulation. P.M. Kondyk (2002), in addition to defining the concept of "military property", defined its types and characteristics, the powers of state structures to manage this property. V.S. Shcherbyna (2012) considered the peculiarities of the legal regime of military property, characterises its individual elements. One of the ways of distinguishing these concepts is consideration purpose of the property and its most effective use. Along with this, in this case, there is a need for identical presentation of information regarding property characteristics in different reference sources.

Article 3 of the Law of Ukraine "On the Legal Regime of Property in the Armed Forces of Ukraine" (Law of Ukraine No. 1075-XIV, 1999) regulates that PEMPW becomes military from the moment of its acceptance into the Armed Forces of Ukraine and official attachment to a specific military unit of the Armed Forces of Ukraine. In particular, it should be noted that a clear explanation is needed to resolve the issue of equipment, weapons and property belonging to the military, if it is at the stage of registration in the customs import regime, and there is a need to determine its classification characteristics in order to assign it to a certain grouping.

In expert practice, a single approach to solving typical tasks that are set before forensic experts should be fixed in the methods of conducting forensic examinations. To form an information database of available methods and methodological recommendations for conducting forensic examinations, which are recommended for use in expert practice and have passed certification in accordance with the Procedure for Attestation and State Registration of Methods of Conducting Forensic Examinations (Resolution of the Cabinet of Ministers of Ukraine No. 595, 2008) operates the Register of Forensic Examination Methods (2024). As of the beginning of 2024, in this register (Register of Forensic Examination Methods, 2024) there are no methods for conducting forensic examinations, and the type of expert specialty "Commodity examination" does not contain details at the level of subtype 12.5 "Evaluation of property and equipment for military purposes and weapons".

Methodological support for the implementation of STE in the specialty 12.5 "Evaluation of property and equipment for military purposes and armaments" should be aimed at creating a comprehensive unified approach to conducting expert studies to determine the value of PEMPW; ensuring methodical uniformity and systematisation of expert activity; optimisation of time spent and reduction of labour intensity during execution commodity studies; improving the effectiveness of research; guarantee necessary conditions to protect the expert's professional competence in the event of an appeal results of expert research. The methodology for carrying out FCE in specialty 12.5 "Evaluation of property and equipment for military purposes and armaments" should include certain elements (provisions) (Fig. 1).

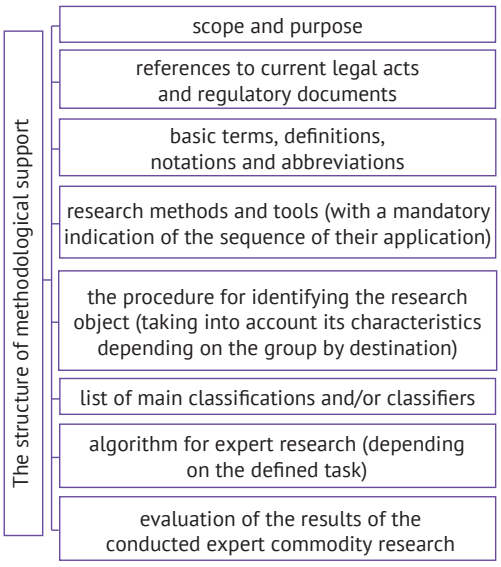

Figure 1. *Structure diagram of the methodological support of STE in the specialty 12.5 "Evaluation of property and equipment for military purposes and armaments" (authors' own development)*

Source: *developed by the authors*

As a result of the analysis of the tasks presented for the solution of the FCE of PEMPW, the purpose of the commodity research was to establish the market value or determine the amount of material losses due to damage or complete destruction of such property. Determining the value of property and property rights is regulated by the Law of Ukraine "On Valuation of Property, Property Rights and Professional Appraisal Activity in Ukraine" (Law of Ukraine No. 2658-III, 2001) and is carried out in accordance with the requirements of current normative legal acts on property valuation, such as national property valuation standards approved by the Cabinet of Ministers of Ukraine, as well as methods, methodological recommendations and other valid normative legal acts. These acts are developed taking into account the requirements of national standards and are confirmed by the Cabinet of Ministers of Ukraine or the State Property Fund of Ukraine. At the same time, the direct activity of forensic experts, including commodity experts, which is related to the evaluation of PEMPW, is carried out in the manner and under the conditions provided for by the Law of Ukraine "On Forensic Expertise" (Law of Ukraine No. 4038-XII, 1994), at the same time, the peculiarities determined by the Law of Ukraine "On Valuation of Property, Property Rights and Professional Valuation Activity in Ukraine" regarding methodical regulation of valuation of such property (Law of Ukraine No. 2658-III, 2001) are taken into account. The research part of the opinion of the forensic expert-commodity expert described in detail all the procedures related to the evaluation of PEMPW, established by the current normative legal acts on the evaluation of property (Law of Ukraine No. 2658-III, 2001; Resolution of the Cabinet of Ministers of Ukraine No. 1440, 2003). In addition, the forensic commodity expert must comply with the requirements of the national property valuation standards during the FCE, which is aimed at establishing the value of the property. The general requirements for the performance of tasks for determining the market and non-market types of the value of PEMPW, including the definition of the purpose and tasks of evaluation, type of value, methodical approaches and methods of evaluation, are regulated by National Standard No. 1 "General Principles of Valuation of Property and Property Rights" (Resolution of the Cabinet of Ministers of Ukraine No. 1440, 2003).

The planning and implementation of commodity expert examinations of PEMPW is based on a comprehensive understanding of the state of the object of evaluation not only at the time of the research, but also on a separate date from the current one, which is the result of unambiguous identification. Object identification in this case means establishing the identity between the object assessment that exists in reality and documentation for it. The complexity of the implementation of this stage of the expert product research consists in providing the forensic expert with documents that contain information about the type, species, model, characteristic features, dimensions, tactical and technical characteristics, conditions and term of operation, maintenance procedures, categories of quality (technical) the state of PEMPW, both of Ukrainian production and of countries that provide humanitarian and international technical assistance to Ukraine.

It should be noted that the initiators of the appointment of examinations often cannot provide the initial data necessary for conducting such studies, due to their complete or partial loss and/or destruction as a result of active military operations on the territory of Ukraine. It is important not to ignore the fact that record-keeping, documentary movement, receipt, storage, delivery to the unit from warehouses, recording of technical condition, organisation of technical maintenance and repair are complicated by actions necessary to eliminate the threat of danger to territorial integrity, as well as danger to the state independence of Ukraine as a whole, cessation of armed aggression and guarantee of national security.

In addition, the expert product research involved an examination of the damaged objects of the examination. At this stage, taking into account the tasks assigned to the expert, the damage caused by negative factors and the actual condition of the objects are fixed using organoleptic research methods, the degree of damage, the change in consumption properties and the possibility of their further use for the intended purpose are taken into account. A mandatory condition for conducting an inspection of the PEMPW is the involvement of a specialist with specialised knowledge in the field of military equipment and weapons. It's should be noted that the study of objects damaged by negative influences should take into account regime restrictions, provided access to them is provided, and be carried out in the shortest possible time to avoid changes in the object's condition.

V.M. Bondar (2016) investigated the sources of information and raw data necessary for carrying out FCE PEMPW, and also considered possible methodical approaches to determining the market and non-market value of these objects. The author also noted that during cost and comparative methodical approaches can be used to determine the cost of PEMPW. The income methodical approach cannot be applied, as it involves the assessment of the current value of future income, taking into account the principle of a direct relationship between the value of the assessed object and the income that will be received as a result of its intended use or possible resale.

The cost-methodical approach means determining the current cost of costs for replacement or reproduction of the STE object with subsequent adjustment to the amount of wear and tear (depreciation) (Resolution of the Cabinet of Ministers of Ukraine No. 1440, 2003). In practice for the Methodology for determining the

residual value of the property of the Armed Forces of Ukraine and other military formations (Resolution of the Cabinet of Ministers of Ukraine No. 759, 1998) is used to solve issues related to the assessment of the PEMPW, which provided for the use of a cost methodical approach. But the research was complicated by the fact that the specified Methodology (Resolution of the Cabinet of Ministers of Ukraine No. 759, 1998) was focused more on equipment and weapons, which stands on the balance of military formations, and in order to solve the assigned task, the expert needs to have at his disposal a whole series of initial data, which in the conditions of modern reality is practically cannot be provided. If the comparative approach is used, the situation does not improve, since there are no offers on the market for the sale of identical and/or similar property in public access; the selection of identical and/or similar property is complicated by its specificity and the need to take into account the terms of contracts (in particular, the terms of price formation), etc.

V.M. Bondar (2016) in his work emphasised the fact that the determination of the market value of PEMPW and the amount of material damage caused to the owner of the damaged (destroyed) property is possible with the use of combined, comparative and cost approaches in combination, according to the following algorithm of actions:

- with the application of a cost-methodical approach, the residual value of the PEMPW is determined, which involves taking into account the technical and commercial condition, the terms of operation, resources, and working hours as of the date of the assessment and the subsequent deduction of the amount of wear and tear;
- with the application of a comparative methodical approach, on the basis of initial data obtained from reliable sources, similar objects on foreign sales markets are selected.

After that, the average market value of the sale is calculated and a property offer is provided. Since the average market value of sales is a reflection of indirect factors, such as the technical condition, product appearance, resources and operational experience of the objects of comparison, their parameters are taken as average values. For further calculations, an appropriate adjustment is made between the object of research and the object of comparison.

In order to implement the specified methodical approaches for determining the value of PEMPW, it is necessary to have price information, taking into account the specific expert situation, determined by the research objects and the questions posed to the experts on the specific date of the assessment, taking into account the actual state of the appearance of the object and packaging, the presence or absence of damage and defects (provided the objects are provided for research), as well as information contained in the documents about the state of the objects during the purchase and sale of goods, or other situations that provide sufficient information about the research object (provided non-provision object for research).

Taking into account the provisions of National Standard No. 1 "General Principles of Valuation of Property and Property Rights" (Resolution of the Cabinet of Ministers of Ukraine No. 1440, 2003), which relate to the object of assessment, in particular PEMPW, and trends in the market of similar or similar property are also analysed, information on purchase and sale agreements of similar property, necessary for the application of a comparative methodical approach, and other important information. On the basis of this analysis, the formation of substantiated conclusions concerning the results of the conducted FCE is carried out, with the participation of a forensic expert-commodity expert.

In addition, in case of insufficient price information or its absence, in accordance with the provisions of paragraph 2.2 of the "Instructions on the appointment and conduct of forensic examinations and expert studies" (Order of the Ministry of Justice of Ukraine No. 53/5, 1998), the judicial the commodity expert must independently conduct a comprehensive commodity research and draw up a well-founded and objective written conclusion, which includes answers to the questions posed by the initiator of the FCE. Considering the specifics of the objects of research, in particular PEMPW, there is mostly no publicly available open price information on the Internet, which forces the forensic expert-commodity expert to turn to specialised enterprises of the relevant industries, which can provide the information necessary to determine the value of PEMPW. However, the available practical experience of carrying out STE shows that business entities that are owners of commercial information ignore such appeals or, in response to them, refer to the norms of the legislation of Ukraine (Law of Ukraine No. 436-IV, 2003), indicate that this information has potential commercial value and cannot be made available to third parties without legal grounds. The owner of the information is obliged to take appropriate measures to ensure the confidentiality of this information.

At the same time, the list and content of information that may constitute a commercial secret, as well as the procedure for their protection, are determined by its owner independently. In turn, it is worth noting that the information possessed by the specified business entities is extremely important for conducting the STE of the PEMPW, therefore it is necessary to regulate at the legislative level the mechanism of cooperation between expert institutions and economic organisations engaged in the manufacture or sale of goods for military purposes and dual-use goods.

It is worth noting that if there is no price information on the Internet it is possible to use the price data of the contract/agreement under which the delivery took place. However, the use of price data from contracts/

agreements requires a detailed study of the terms of the agreement for its compliance with the concept of market value, the inclusion of additional services (transportation, assembly, installation, maintenance, etc.) in the price per unit of product measurement and the implementation of the price update procedure in accordance with modern price level using adjustment indices (deflator indices) (Hokhberh, 2014). At the same time, the greatest difficulty lies in separating the cost of additional services from the price per unit of product measurement (due to the lack of clear calculations in the specification), in order to determine the objective market value.

Conclusions

According to the results of the analytical studies, the need to agree on the terminology related to the evaluation of PEMPW has been established, in particular, there is a need for a clear definition of terms and concepts that will not have different definitions. The work presents the main criteria and means of identifying PEMPW, which will allow the forensic expert to assign the research object to the appropriate classification group and determine the main characteristics that affect their value. In connection with the insufficient and ambiguous information about the PEMPW, it is advisable to collect and update the database regarding this property and create unhindered access to it. The authors justified the choice of a methodical approach to the assessment of PEMPW, which should be based on the principles of supply and demand, usefulness, substitution, the most effective use, taking into account the initial data, which contain complete, unambiguous and reliable information about the object of research. Operating with the practical experience of forensic experts-commodity experts who work in completely different conditions, often with research objects made of using the latest technologies, in conditions with limited access to information data and in an unsettled regulatory and legal field, it is worth noting the need to develop methodical support, which can be used by forensic experts-commodity experts when solving issues related to the evaluation of PEMPW when conducting commodity research in expert specialty 12.5 "Evaluation of property and equipment for military purposes and weapons".

The prospect of further research is the development of methodological recommendations for the conduct of FCE of PEMPW, which should include the following main elements (provisions): scope and purpose; basic terms and definitions of concepts, designations and abbreviations; references to means and methods of research with a mandatory indication of the sequence of their application; a description of the procedure for identifying the object of research with a mandatory indication of the means and criteria for identifying PEMPW; analysis of modern classifications and/or classifiers; algorithm of expert PEMPW; evaluation of the results of the conducted commodity research. Further research in the field of PEMPW evaluation will provide an opportunity to ensure the complexity, focus and comprehensiveness of the product research in order to achieve the logic and consistency of the expert's actions when solving specific expert tasks, which will contribute to the validity of his conclusions.

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Conflict of interest

None.

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Проблеми планування та здійснення товарознавчих експертиз майна і техніки військового призначення та озброєння

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Анотація. У період з 2014 по 2024 рік працівники установ судово-експертної діяльності підкреслювали важливість проведення незалежних, кваліфікованих та об'єктивних експертиз для забезпечення правосуддя. Це створювало потребу в проведенні судових товарознавчих експертиз майна та техніки військового призначення та озброєння. Метою дослідження був аналіз нормативно-правової та методичної бази здійснення судових товарознавчих експертиз майна і техніки військового призначення та озброєння, задля подальшої розробки єдиного підходу до проведення досліджень та гарантування систематичності експертної практики, підвищення достовірності отриманих результатів досліджень. У дослідженні використані такі методи: лінгвістичний, системно-функціональний, діалектичний, систематизації, монографічний, аналізу та синтезу. Результатом дослідження, який включав практичну складову судової товарознавчої експертизи було окреслення проблем планування та здійснення експертиз майна і техніки військового призначення та озброєння, які полягають у: відсутності єдиного термінологічного підходу до основних понять; технічній складності досліджуваних об'єктів; обмеженості доступу до інформації і документів, які містять характеристики об'єктів дослідження; необхідності врегулювання механізму взаємодії експертних установ і суб'єктів, що здійснюють виготовлення та/або реалізацію даних об'єктів; необхідності розробки науково-практичних видань. У роботі було виокремлено ідентифікаційні ознаки відповідного майна та техніки, які містять інформацію щодо виду, типу, моделі, розміру, тактико-технічних характеристик, категорії якісного (технічного) стану, які дозволять систематизувати роботу експерта у цьому напрямку. Наведено обґрунтування вибору методичного підходу до визначення ринкових та неринкових видів вартості, враховуючи наявність та повноту необхідних вихідних даних, зокрема аргументовано недоцільність застосування дохідного методичного підходу та рекомендовано використання витратного та/або порівняльного методичних підходів. Результати наукової роботи спрямовані на удосконалення якості виконання судової товарознавчої експертизи з питань оцінки майна та техніки військового призначення та озброєння і сприятимуть підвищенню обґрунтованості проведених товарознавчих досліджень. Результати дослідження можуть бути використані для подальшого розроблення методичного забезпечення, яке може бути використано судовими експертами для проведення досліджень за спеціальністю 12.5 «Оцінка майна і техніки військового призначення та озброєння»

Ключові слова: воєнна допомога; військове майно; товари подвійного використання; вартість; методичний підхід; оцінка майна

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Feedback provision of online clothing customisation with NFC labels

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Abstract. The widespread use of online clothing sales is hampered by underdeveloped consumer control methods. The introduction of electronic tags in the design of clothing can provide feedback between the consumer and the manufacturer. The purpose of the study was to create a model of online customisation of clothing with two feedback cycles based on the use of electronic tags and to prove its effectiveness. Research methods included modelling of the customisation process, methods of interviews with clothing manufacturers and questionnaires of potential consumers with further statistical processing of the results. The improved model of clothing customisation was developed and verified. The main blocks of the model are substantiated in the form of the elements "clothing database", "clothing attitude", "clothing adaptation", "clothing production", "clothing sales", "clothing consumer". At the same time, the key was to create a second feedback loop based on the use of electronic tags. Elements of customisation process are described. Model for determining the effectiveness of clothing customisation is developed. It was proved that the use of this model increases the efficiency of online customisation of clothing by 25-35%, increases the number of intentions to participate, purchase clothing and attract other participants by 5-13%. The introduction of electronic tags in the process of online clothing trade will increase efficiency, provide feedback, improve quality and competitiveness

Keywords: Internet trade; electronic tags; selling clothes; product-service system; garment consumer

Introduction

The massive introduction of computer and Internet technologies in the process of developing and selling clothes has determined a number of achievements and problems related to quality, efficiency, and competitiveness. The modern clothing market offers quite a large volume of products that are largely identical or similar. A certain obstacle to the introduction of Internet technologies in the production and sale of clothes is the presence of a pronounced feedback from the developer – producer – consumer of clothes.

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Steps in the direction of providing such a connection are the developed models of "product –service of clothing", in which services largely depend on consumption patterns formed in the process of communication between the manufacturer and the consumer (Piontek *et al.*, 2020). The internet customisation model described in the work of T.H. Nobile & L. Cantoni (2023) is more complex. At the same time, digital customisation is able to provide personalisation in the design and manufacture of clothes.

Brands are actively putting digital customisation models into practice. The number of scientific publications devoted to the problems of customisation in fashion is growing every year. One of the important problems in the production of modern clothing is ensuring its personalisation. A study by J. Qian & M. Zhao (2021) analysed methods of intelligent generation and means of virtual display of clothing design. The processes of actual implementation of these methods require further research. The first element of the Internet customisation system, according to most studies involves the formation of a database using innovative tools and existing achievements. The structural elements of constructions of various types of clothing for the purpose of their further customisation are largely considered in a number of publications (Slavinska *et al.*, 2021; 2022). The scientific work of J. Hwang & S.-Y. Youn (2023) investigated the process of product uncertainty during shopping of clothes in the Internet space. Consumers note the importance of communication with sellers, manufacturers, as well as product demonstration. The importance of providing a motivational factor, which is insufficiently reflected in existing models, is noted.

C. Lorenzo-Romero *et al.* (2023) described the process of co-creation in the development and consumption of clothing. Three different segments are proposed: "full co-creator", "company/brand-oriented co-creator" and "other people-oriented co-creator", which show three different ways of co-creating with a fashion firm. Such segments determine the direction of improvement of online clothing customisation systems. H.-L. Chan (2016) noted that one of the promising technologies in clothing supply management is the use of electronic labels. Implementation of similar systems is considered for logistics, as well as management of communication with clients. In particular, S.-H. Lee *et al.* (2021) considered the possibility of using electronic labels in an ecological aspect for operational control of the condition of clothing, which can potentially be used in the product-service system.

To a certain extent, electronic devices incorporated in the clothing can provide such feedback. Such devices have not yet been widely adopted. A contradiction arises between the possibility of modern electronic devices to create feedback for clothing consumers, the requirements for improving the Internet trade in clothing, and the insufficient implementation of new technologies in the real process of clothing customisation. The research hypothesis can be formulated in the fact that the use of electronic labels can significantly increase the efficiency of the online clothing customisation process.

The purpose of the study was to justify the feasibility of implementing feedback tools based on NFC labels.

Materials and Methods

The model of the customisation process includes a number of blocks that define the main processes and events. Block connections can be direct or have the form of loops that define feedback. In the process of the model building, a system of concepts was used based on the analysis of the functioning of the existing customisation system, the shortcomings and prospects for improvement were analysed based on the latest technical achievements that can improve the functioning of the system taking into account feedback. The basis for the research is the model of consumer satisfaction (Fig. 1).

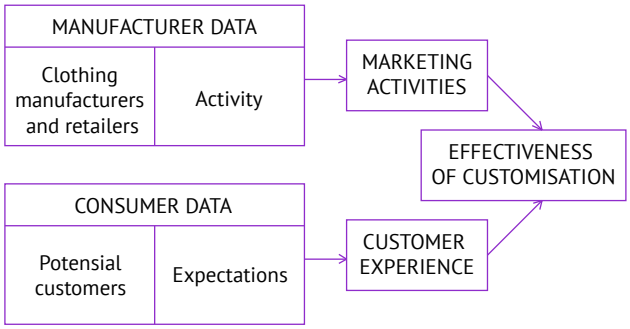

Figure 1. *Basic model of the effectiveness of the customisation*

Source: *based on M. Feori-Payne & E. McKinney (2022)*

In this model, the effectiveness of customisation is considered as a set of processes of waiting for customers based on their experience, capabilities, and experience of manufacturers and sellers of clothing with a special emphasis on online trade. Effectiveness is defined as the ratio of expectation and satisfaction when studying the processes of the intention to participate in customisation, the intention to purchase, and the intention to attract other consumers. Modeling the customisation process should include blocks related to garment database, garment relation, garment adaptation, garment production. Blocks must be introduced to provide convenience and satisfaction to consumers, as well as connections between all blocks, including feedback. In the future, the model developed and expanded using methods of analysis of existing blocks and connections,

synthesis of a new model using promising technical and organisational elements, as well as consideration and structuring of factors that affect the effectiveness of the customisation system.

During the research, the consumer audience was segmented, a questionnaire was conducted, the purpose of which was to identify the most important features of the customisation. In the process of processing the data, the results were analysed by factorial analysis and modelling. Identification of the management features of the digital organisation of economic processes is done by means of correlation analysis as well as process rating (Splender *et al.*, 2021). The process of surveying includes 349 consumers and surveying 89 manufactories. The survey process took place during personal interviews, personal questionnaires of consumers, questionnaires on the Internet and through social networks. Questions for consumers predicted definition of weighting factors of abilities to use customisation software. These abilities include: ability to replenish the database, ability to form an image, ability to adapt to individual parameters, ability to influence production, ability to monitor compliance. Questions to manufacturers were related to actual database of elements of clothing, customisation software, means of remote measurement, means of production, means of feedback at stage of implementation.

The questionnaire for consumers consisted of three parts. The purpose of the questionnaire was determined in the introduction, and the essence of customisation was briefly described. The requisite part included such characteristics of the respondent as age, gender, experience in buying clothes on the Internet in general, and participation in the independent design of clothes. In the process of determining the importance parameters, the scale with a range from 1 to 5 was used. After that, a statistical analysis was conducted to determine the average value of importance among all respondents. The Pearson correlation coefficients between different customisation factors were determined separately. The quality and reliability of the selected factors were assessed by determining Cronbach's Alpha for the selected set of parameters, as well as separately for each parameter in order to determine its importance for ensuring the effectiveness of the process.

To determine the effectiveness of creating a second feedback loop using electronic labels, a survey of potential clothing consumers was conducted. The survey was conducted using online personalisation techniques through cloud-based surveys involving respondents on social media and other possible means. A total of 349 respondents took part in the survey. Segmentation by experience of participation in the process of online personalisation of clothes allowed distinguishing the following groups: consumers without experience – 12%, beginner users – 24%, users with offline shopping experience – 37%, users with online shopping experience – 27%. The questions in the questionnaire related to consumer participation and were formed into five blocks that define the process of clothing customisation. These questions determined the real possibility of consumers participating in the stages with the involvement of modern technical and software tools available to them.

The study of the level of effectiveness of clothing customisation systems by manufacturers was carried out using interviews with managerial and technical specialists, manufacturers, and sellers of clothing. A total of 89 interviews were conducted. Segmentation of these participants identified the following groups: individual order – 27%, mass production – 34%, specialised customisation companies – 11%, internet commerce – 28%. The interview questions were determined by the same blocks that provide customisation. At the same time, emphasis was placed on methods of ensuring efficiency that can be used by manufacturers.

The main parameters of Internet marketing and customer experience in the process of forming a customisation strategy are given in the study of A. Wibowo *et al.* (2021). Similar studies are conducted using media methods and interviews with providers (Piontek *et al.*, 2020). The conceptual basis of the study offers three dimensions: awareness/association, perceived quality, and loyalty. The conceptual framework for dynamic clothing development (Feori-Payne & McKinney, 2022) highlights the importance of conducting in-depth interviews, testing with manufacturers and consumers. The study was conducted in accordance with the norms of The Declaration of Helsinki (2013).

Results

Analysis of the functioning of existing customisation systems demonstrates, a significant drawback of existing online customisation schemes is the lack or weakness of feedback from the client at the last stage of product consumption. It is proposed to introduce additional elements that can increase the efficiency of the process for the existing scheme of Internet customisation. It worth to describe the existing or necessary elements (Fig. 2).

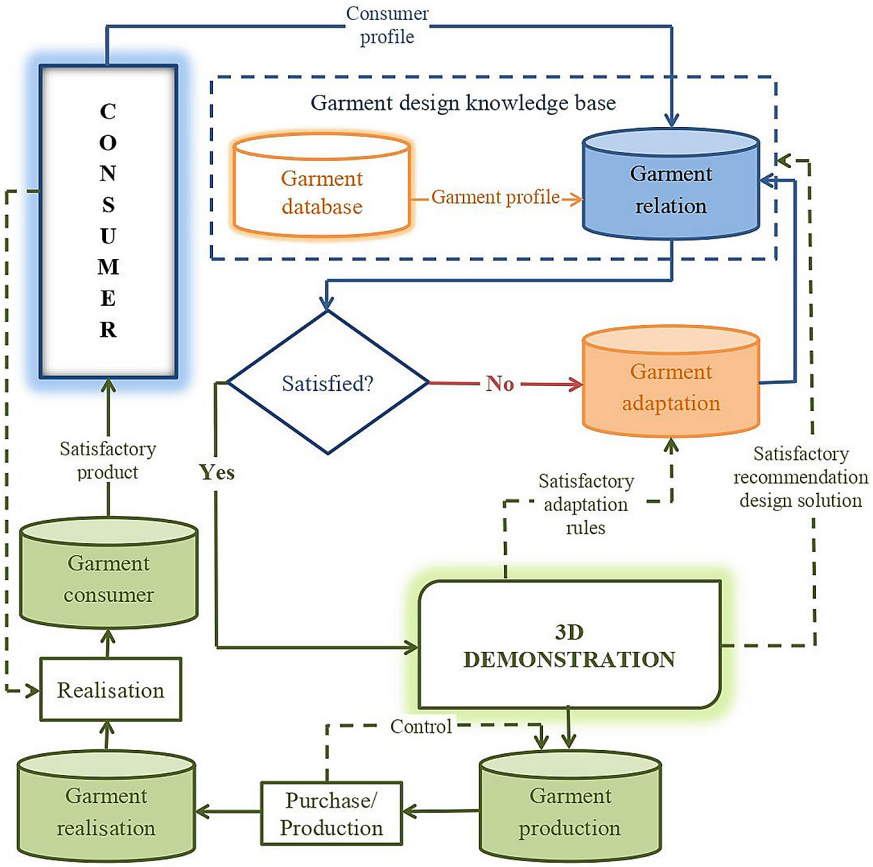

Figure 2. *A model of clothing customisation with double-feedback*
Source: *developed by the authors*

The consumer must have access to a database of clothing elements, which has a fairly large volume. At the same time, this volume should not require very high qualifications from consumers. Accordingly, the software must have an interactive block of communication with the consumer to establish a sufficiently stable relationship and have clear access for the consumer.

"Garment database" and "Garment relation" elements are basic for clothing customisation and must be provided with appropriate computer and software. Such elements do not provide feedback and a sufficient degree of proportionality when making clothes in the process of mutual design. Most of the existing customisation schemes involve the use of 3D scanning methods to provide real proportionality and a clear presentation of the created image of clothing on the figure. In this case, the "Garment adaptation" block is added to the system, which ensures that the clothes match the real figure.

This block involves the use of spatial measurement tools and private use or the creation of a network of service points with the possibility of 3D scanning of the human body. It determines the creation of the first feedback loop, which creates conditions for increasing quality and, accordingly, increasing the efficiency of customisation. At the same time, the overall process remains open, as the final stage of consumption remains without feedback.

The next block should be the "Garment production" block. It may not be interesting for the consumer, but it is an important part of ensuring the efficiency of the process. The "Garment realisation" block determines the delivery of the designed and manufactured product to the consumer and involves the use of well-known or advanced e-commerce tools. The usual scheme ends here. In the best-case scenario, customer feedback is provided in the form of a review on the website page.

The use of electronic tags in the design of clothing allows to store, compare, and restore all information

about the clothing produced in the customisation process. At the same time, the consumer gets the opportunity to create continuous online communication during control, operation, and further communication with the manufacturer in automatic mode. The use of electronic labels allows to create a "Garment consumer" block that determines the appearance of a second feedback ring. Such a ring, unlike the first one, completely closes the customisation of clothes, taking into account and ensuring the requirements and interests of the consumer.

Naturally, the interests of the consumer and the manufacturer should be aimed at one goal – improving the quality of service, which determines the increase in the efficiency of customisation. Further, all actions and research were carried out from two points of view. The first took into account the position of producers, and the second – the position of consumers. An updated structure of Internet customisation with the presence of electronic labels as a carrier of information necessary for feedback at the stage of clothing consumption was proposed for the study. The modern consumer is increasingly responding to individual clothing options. Practically every man's and woman's wardrobe has a shirt of the classic type, or almost close to this style. By applying the principles of customisation, your favourite shirt, like any other type of clothing in your wardrobe, can become personalised. From the fabric to the buttons, the style of the pockets, the collar, the cuffs, the colour of the stitches, and individual details to the smallest details – the entire look is personalised. Figure 3 shows the possible elements of customisation of the male magpie, which can be expanded taking into account innovative technologies (Polishchuk *et al.*, 2023) and technical production possibilities.

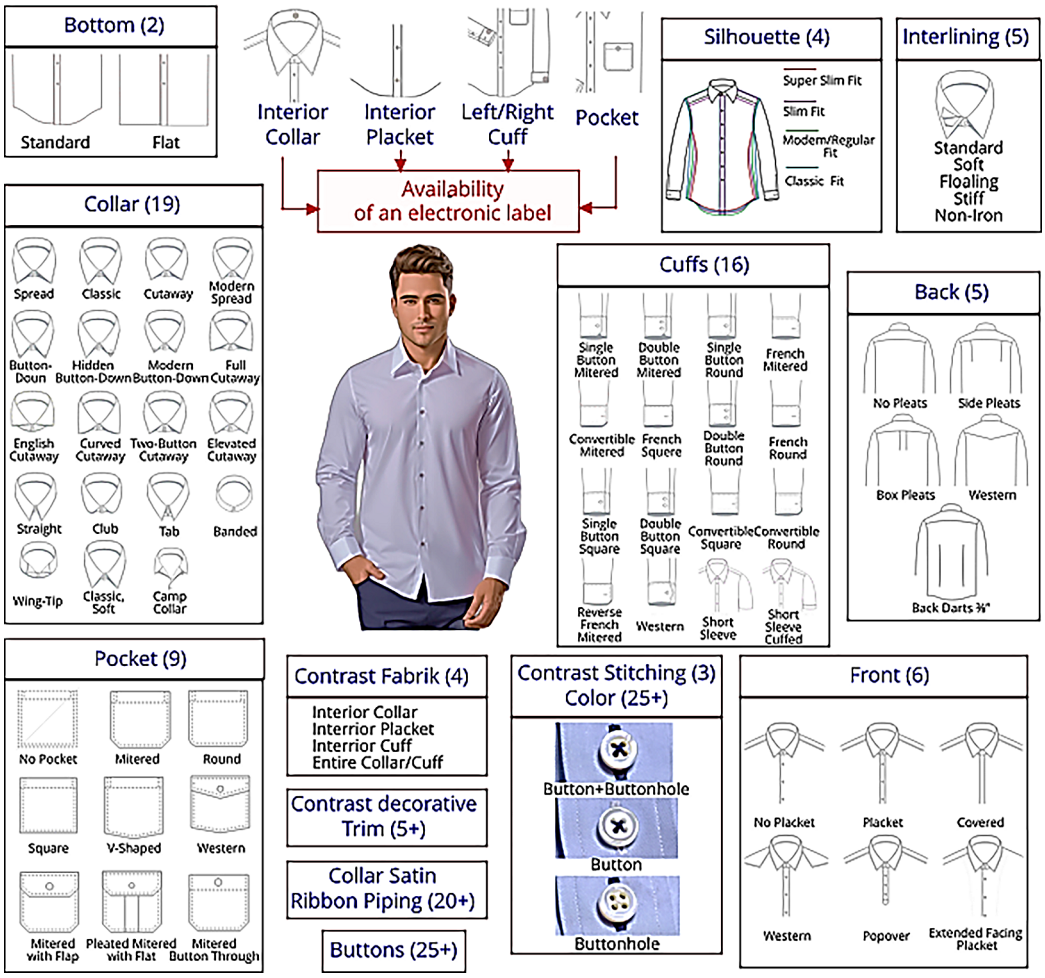

Figure 3. *Elements of customisation on the example of a men's shirt*

Source: *developed by the authors*

The detailing of the effectiveness of the elements of customisation of a men's shirt is presented in Table 1 from the position of the manufacturer and the position of the consumer.

Table 1. *Detailing the effectiveness of the elements of customisation of a men's shirt from the point of view of the producer and the consumer*

The effectiveness of customisation elements	
From the manufacturer's position	From the position of the consumer
The possibility of manufacturing the product according to individual sizes	
• Availability of a large number of standard sizes. • The possibility of making clothes according to individual measurements	• Conformity of the product to body dimensions. • Taking into account the features of the individual figure
Variants of materials by quality, colour, decoration, texture	
The possibility to present a catalog of materials with various sorting parameters (price, colour, pattern, raw material composition, seasonality)	Satisfying personal preferences for every aspect of life
Variants of buttons, variants for stitching, contrasting seams	
The possibility to present a catalog of buttons (threads) with various sorting parameters (price, colour, material, size)	Finishing the product with contrasting seams and stitches to emphasise originality and individuality, personalisation
Choice of silhouette (4 options)	
The possibility of manufacturing products of various styles	Satisfaction of personal preferences in the style, silhouette of the product
Design options: collar (19 options), interlining (5 options); cuff (16 options); pocket (9 options)	
The possibility to satisfy a wide range of consumers	• Correspondence of the collar to features of an individual figure. • Customer satisfaction with large/small wrist cuffs. • Correspondence of the cuff pocket to the designer's idea
Design: front (6 options); back (5 options); bottom (2 options)	
The possibility to satisfy a wide range of consumers in products of various designs	Compliance of the product with the required design, purpose and method of use (fuelled or not)
Availability of an electronic label	
• Establishing direct relations with consumers, understanding their preferences. • Informing consumers about sustainable development initiatives. • Tracking of goods after sale. • Increasing sales and stand out among others	• Access to product information, product origin, and care instruction. • Current information about the product, novelties. • Consumer registration and loyalty program. • Exclusive content is available only to owners of the brand's clothing
Availability of the function of developing one's own design	
Expansion and constant updating of customisation elements	Implementation of own design solutions, creation of a personalised product
Demonstration of a customised product	
The possibility to demonstrate a ready-made selection without the cost of its manufacture	The possibility to see the finished product before making a purchase in different options/angles

Source: *developed by the authors*

By analogy, any product that a company specialises in manufacturing is broken down into elements with possible options for further customisation. At this stage, the product is fully digital. A new, untested element here is the choice of an electronic tag, including its location, content and amount of information recorded on it. Electronic labels in this sense greatly enrich the process of collaborative design, provided that there is an online discussion of the information that can be recorded on them for further control and recovery during operation.

The results of the questionnaire and interviews made it possible to significantly improve the model proposed in Figure 1. The improved model, based on the research results, can be described by the diagram shown in Figure 4.

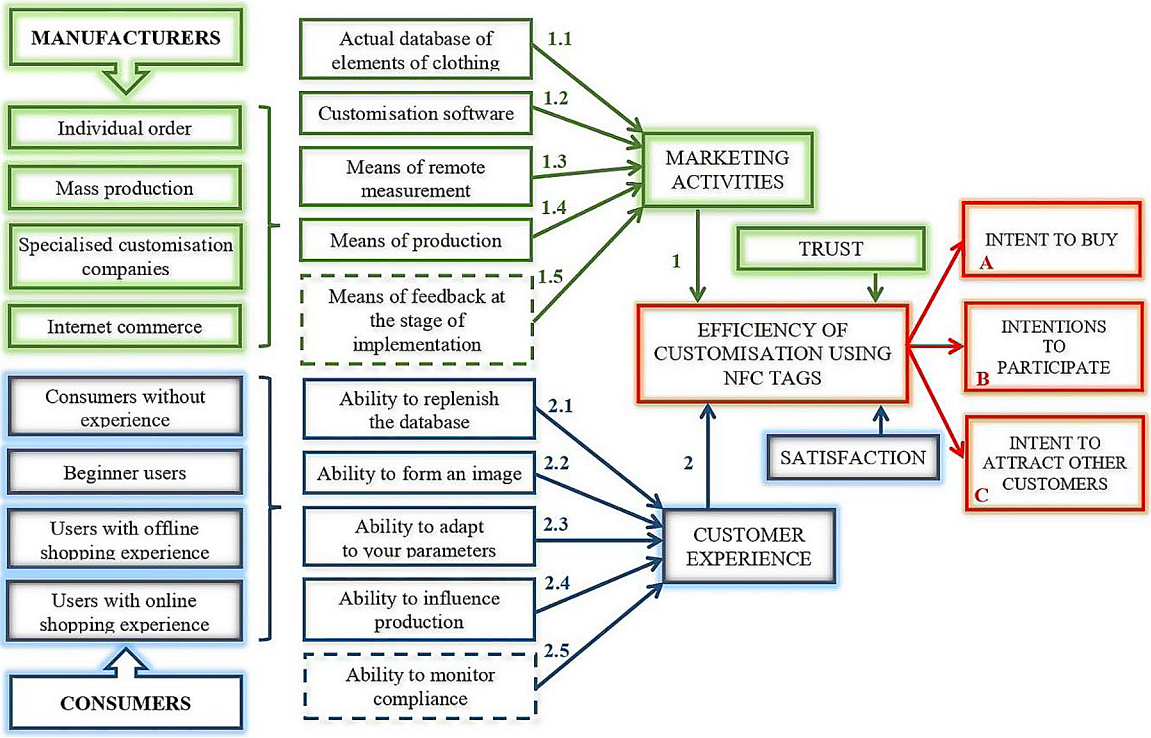

Figure 4. *Model for determining the effectiveness of clothing customisation*

Source: *developed by the authors*

The numbers 1.1-1.5 above arrows on the scheme shows the significance of the stages of customisation from the point of view of manufacturers, numbers 2.1-2.5 – the significance from the point of view of consumers. Numbers 1 and 2 are the effectiveness of the customisation process from the point of view of producers and consumers. Letters A, B, C meet the intention to participate, the intention to buy, and the intention to attract others. Prospective blocks for compliance control at the stage of consumption using electronic labels are highlighted with a dashed outline.

A general analysis of the significance of the factors that determine the importance of the blocks presented in the scheme in Figure 2 demonstrate a greater weighting for the stages related to the blocks aimed at controlling consumption. The importance of production processes is of less interest to consumers, while this stage is quite important for manufactories. The stages related to the selection of clothing items and ensuring proportionality is of high importance for both groups. At the same time, the final result, which ensures the consumer's control over the declared data, is the most important. This block determines the highest levels of correlation with all other processes.

It is worth discussing the results of the study with the help of Table 2 and Table 3. Cronbach's Alpha coefficient was calculated to assess the reliability of the survey and the most complete selection of customisation effectiveness criteria. The high values of this coefficient for producers (0.8491) and for consumers (0.8123) confirm a fairly high level and correct selection of criteria. This number can to some extent determine the level of effectiveness of customisation by the specified means. Analysis of Cronbach's Alpha coefficients for individual indicators indicates a significant impact of final control systems in the form of electronic labels on process efficiency. Thus, the exclusion of these tools leads to a decrease in Cronbach's Alpha coefficient and, accordingly, the effectiveness of customisation to 0.5981 for consumers and 0.6560 for manufacturers. The indicators of other stages are similar, but they do not have such a significant effect.

Table 2. *Efficiency coefficients of using electronic labels for feedback based on interviews with producers*

Parameter	Relevance	Cronbach's Alpha	Correlation parameter	Pearson's correlation coefficient	Cronbach's Alpha total
1.1	4.29	0.6994	1.2		
			1.3		
			1.4	0.5722	
			1.5	0.7570	

Table 2. Continued

Parameter	Relevance	Cronbach's Alpha	Correlation parameter	Pearson's correlation coefficient	Cronbach's Alpha total
1.2	4.21	0.6783	1.3	0.6945	0.8491
			1.4	0.5950	
			1.5	0.7614	
1.3	4.13	0.7121	1.4	0.6230	
			1.5	0.7881	
1.4	4.38	0.6714	1.5	0.8746	
1.5	4.61	0.6560	-	-	

Source: *developed by the authors*

The significance of the stage related to production can be discussed separately. This is the second most important indicator of efficiency for manufacturers (in its absence, efficiency decreases to 0.6714). At the same time, for consumers, the absence of a production stage, on the contrary, increases interest in the customisation process to 0.8644. This fact shows that the production process is not relevant when discussing with the consumer.

Table 3. *Efficiency coefficients of using electronic labels for feedback based on consumer surveys*

Parameter	Relevance	Cronbach's Alpha	Correlation parameter	Pearson's correlation coefficient	Cronbach's Alpha total
1.1	4.24	0.7773	1.2	0.6758	0.8123
			1.3	0.7123	
			1.4	0.5894	
			1.5	0.9030	
1.2	4.31	0.7496	1.3	0.7243	
			1.4	0.6022	
			1.5	0.8880	
1.3	4.44	0.6790	1.4	0.6237	
			1.5	0.9062	
1.4	3.08	0.8644	1.5	0.8918	
1.5	4.86	0.5981	-	-	

Source: *developed by the authors*

The results of the research indicate a significant, and to some extent determining, influence of the presence of an electronic label with the possibility of control at the stage of consumption. The results of the consumer survey regarding the intention to participate in the customisation process are discussed separately (Table 4).

Table 4. *The specific weight of the respondents, which determines the levels of participation in the customisation process*

Symbol	Intention	Without consumer control through electronic labels	With consumer control through electronic labels
A	Intentions to participate	0.89	0.92
B	Intent to buy	0.48	0.54
C	Intent to attract other customers	0.74	0.84

Source: *developed by the authors*

All intentions are increased with the use of electronic labels. This fact proves the expediency of introducing additional links into existing customisation systems, which can create additional feedback loops and significantly increase efficiency.

Discussion

Analysis of the existing publications and results shows that the obtained results demonstrate significant advantages and greater efficiency. The study of A. Wibowo *et al.* (2021) noted the role of social media in apparel distribution strategy. Attention is focused on the compatible role of online marketing tools and customer experience. The opposite movement described above leads to increased efficiency of the process. The need for constant communication in the fashion business is described in a study by L. Cantoni *et al.* (2020) but means of ensuring such communication have been proven fragmentarily. The resulting model provides such communication in a much larger volume.

The technical means of implementing electronic commerce provide communication with the client through the use of 3D technologies in order to obtain a real three-dimensional image of the consumer. The real body model is further used to visualise the image with clothing as described by S. Idrees *et al*. (2023). The results of these studies showed that the implementation of such tools has problems at the stage of consumer use of applications for virtual fitting because the qualifications of consumers are different. There are also problems with the confidentiality of the received information. The developed methods largely solve these problems.

T. Chen & Y. Lu (2022) described the process of designing clothes as a result of customisation, but it is not clear how to control the conformity of the final version of the product in the process of manufacture and sale. In the proposed model, these discrepancies are resolved by additional feedback provided by electronic tags. Z. Dai (2023) claimed that management in the customisation process should take into account all chains, including production. In contrast to his results, the developed model assumes control mechanisms of the final version of the real product are not proven.

The study of S. Guo & C.L. Istook (2022) described the interest of consumers in the process of online design of clothes, but the methods of monitoring the compliance of the final product with the desired result and the satisfaction of consumers with real clothes are not defined. These methods are provided in the developed model.

Provision of the Internet customisation process is described by X. Wang *et al*. (2022) in the form of a system of interconnected models, which include databases, communication models, and data generation models. First-level feedback is provided by virtual fitting effects. Such systems can be considered the closest to implementation. It is desirable to introduce second-level feedback models to them, taking into account positive or negative experience from implemented clothing models. This fact was taken into account during the development of the improved model, which made it possible to increase its efficiency.

A research paper of S. Abdissa *et al*. (2018) evaluated data management processes in the apparel manufacturing industry with database storage of a garment company. In this work, a linear model is proposed, which includes requirements, design, implementation, verification, and maintenance without explicitly expressed feedback. Such approaches should be considered as the first step towards a general product-service scheme management system. The model developed in this article involves a nonlinear approach with feedback, which significantly increases its adequacy.

The goal of the study of Z. Wang *et al*. (2022) was to ensure the gradual optimisation of the design solution through a series of human-machine interactions, i.e., the repeated execution of the cycle "design generation – virtual garment demonstration – consumer evaluation – adjustment" until the satisfaction of the end user. Such interactions really provide a certain feedback not only on a virtual, but also on a practical level. The new customisation model implements the following directions. Specific examples of the use of electronic tags in fashion clothing companies are given in the study by R. Leitz *et al*. (2018). M. Bertolini *et al*. (2017) conducted a number of test studies on the use of electronic labels in the process of clothing production. At the same time, this study is the first to use electronic labels for the purposes of online commerce.

The use of electronic labels in retail is described in a study by B. Ovezmyradov & H. Kurata (2022). Consumer reactions and parameters of brand costs in the direction of profitability were determined. The introduction of electronic labels into the process of online trade looks like a logical direction for further research. Digital technologies in the fashion industry are in some cases combine with the creation of smart clothes (Riabchykov *et al.*, 2022), while smart approaches are associated with the introduction of electronic labels (Shen *et al.*, 2019). The direction proposed in the study introduces the idea of smart clothes at the stage of implementation with the help of customisation processes.

In known studies, mainly RFID (Radio-frequency Identification) labels are proposed, which require special equipment for their programming and reading. M. Boada *et al*. (2022) noted that the use of cheap and affordable labels allows the use of a smartphone for producer-customer communication purposes. I. Ortiz-Gómez *et al*. (2023) claimed that the development of such NFC tags allows to significantly expanding the scope of their use. This study proved the possibility of using cheap NFC tags to ensure good results of online customisation. Possibilities of preserving the aesthetic properties of clothing during using of electronic tags and other electronic devices are discussed by Y. Liu *et al*. (2020). Design decisions regarding their placement in the stitching process or when using other methods are given in the current study.

N.G.K.K. Reddy & K. Rajeshwari (2017) offered a range of services related to the implementation of electronic labels in clothing. In particular, a system of interactive clothing with the possibility of unique identification is offered, which coincides with the tasks of customising clothes. Such interactive systems create benefits for both manufacturers and consumers; in particular, they can provide advice on the individual use of clothing, and its combination with other clothing elements, materials, and accessories. The propositions provided in the current study envisage the existence of interactive systems that create benefits for both producers and consumers; in particular, they can provide advice on the individual use of clothing, its

combination with other clothing elements, materials and accessories.

As a result of the discussion, a conclusion can be drawn about the relevance of introducing customisation into the process of Internet trade, which requires, in particular, the wide use of digital three-dimensional and other electronic means. The possibilities of solving the issue of control and feedback to the consumer are determined by the presence of electronic labels and their effectiveness.

Conclusions

The feasibility of introducing feedback means into online clothing customisation systems using NFC labels has been proven in this paper. Expanding the functionality of digital tools in the fashion industry creates new opportunities for online clothing customisation. An effective customisation model should include the following blocks and stages: the database block includes basic information about models and clothing elements; the garment relation block determines the direct creation of clothing based on the interactive interaction of the consumer with the software environment; the garment adaptation block defines the first circle of feedback and involves the use of 3D visualisation tools; the garment production block determines the possibility of producing clothes that were designed in interactive mode. This block is more relevant for manufactories. The garment realisation block involves the use of Internet trade tools. The garment consumer block proposed by us defines the possibility of controlling the consumer of clothes created in the customisation process. This unit is based on the use of electronic labels.

The study extended the model of Internet customisation with two feedback loops. The first round involves the coordination of co-dimensionality. Adding the possibility of feedback using electronic labels based on the results of consumer surveys increases the effectiveness of customisation. At the same time, Cronbach's Alpha according to the results of the consumer survey increases from 0.5981 to 0.8123. According to the results of the manufactories survey, this parameter increases from 0.6560 to 0.8491.

Intentions to take part in the customisation process along with intentions to purchase and attract other participants increase by 5-13%. These facts testify to the importance and relevance of the introduction of the second round of feedback using electronic labels in the Internet customisation system. Limitations of the performed work include the need to take into account the specifics of information on the properties of clothing that can be entered into electronic labels. In particular, personal information about consumers of clothing should be limited. Consumers must have experience in using such labels and in organising feedback in the online customisation process.

Opportunities and perspectives for further research can include NFC technologies, development of new types of NFC tags and labels that can be integrated directly into fabrics or accessories, garment personalisation. Further research is needed in the fields of exploring the ways of how consumers can personalise their garments using NFC. The possibility of marketing and business models determines consideration of perspective business models that may arise from clothing customisation through NFC.

Acknowledgements

None.

Conflict of Interest

None.

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Забезпечення зворотного зв'язку для онлайн-кастомізації одягу за допомогою NFC-міток

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Анотація. Широкому використанню онлайн-продажів одягу перешкоджає нерозвиненість методів споживчого контролю. Впровадження електронних міток в конструкцію одягу може забезпечити зворотній зв'язок між споживачем та виробником. Метою дослідження було створення моделі онлайн-кастомізації одягу з двома циклами зворотного зв'язку на основі використання електронних міток та доведення її ефективності. Методи дослідження включали моделювання процесу кастомізації, методи інтерв'ю з виробниками одягу та анкетування потенційних споживачів з подальшою статистичною обробкою результатів. Розроблено та верифіковано удосконалену модель кастомізації одягу. Обґрунтовано основні блоки моделі як елементи «база даних одягу», «ставлення до одягу», «адаптація одягу», «виробництво одягу», «збут одягу», «споживач одягу». При цьому, ключовим було створення другого контуру зворотного зв'язку на основі використання електронних міток. Описано елементи процесу кастомізації. Розроблено модель для визначення ефективності кастомізації одягу. Доведено, що використання цієї моделі підвищує ефективність онлайн-кастомізації одягу на 25-35 %, збільшує кількість намірів взяти участь, придбати одяг та залучити інших учасників на 5-13 %. Впровадження електронних міток в процес онлайн-торгівлі одягом дозволить підвищити ефективність, забезпечити зворотній зв'язок, покращити якість та конкурентоспроможність

Ключові слова: інтернет-торгівля; електронні мітки; продаж одягу; система «продукт-послуга»; споживач одягу

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Research on the habits, attitudes and motivations underlying craft food choice by consumers in Ukraine

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Abstract. There is a global demand for local craft food. Craft food production is promoted in most countries because it contributes to solving a number of socio-economic and environmental problems. The number of craft food producers in Ukraine is also growing, but the craft food market is still understudied. Therefore, the purpose of the research was to study through a survey the habits, attitudes and motivations that determine the choice of craft food products by consumers in Ukraine. The survey was conducted in two regional centers of Ukraine – Lutsk and Mykolaiv – among consumers of different age, gender, income levels and education levels. About 84.3% of the respondents are consumers of craft food. Respondents indicated that they buy craft food periodically and occasionally. Most consumers believe that craft food is tastier and of better quality than mass-produced food. Respondents noted that craft foods are more expensive than mass-produced foods, but 29% of respondents are willing to pay 10% extra for them. The most popular craft food products among Ukrainian consumers were identified, including baked goods, confectionery, meat and dairy products. Ukrainians buy craft food mainly directly from producers, in chain and specialised stores. Respondents indicated that they do not have enough information about craft food producers and their products. They would like to see more craft food advertising on online resources. Thus, the results of the survey made it possible to determine the habits and attitudes of Ukrainian consumers regarding craft food, as well as to investigate the motives leading to its purchase. The obtained results will be useful for producers of craft foods, as they will allow them to create a profile of the consumer of their products and to make the information about their products more effective

Keywords: local foods; craft producers; consumer preferences; craft food market; consumer survey

Introduction

In Ukraine, the small family business of production of craft foods, made according to special recipes and authentic or unique technologies, has become very popular. In particular, the production of craft foods such as bread, bakery products, confectionery, jams, beer, wine and other traditional spirits, meat products, dairy products, cheese is widespread. The development of such business is facilitated by a good raw material base and significant demand for such products. The same opinion is shared by the authors O. Komlichenko *et al.* (2023).

Traditionally, short food supply chains have been a popular form of food distribution channels in Ukraine.

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Those face-to-face channels consist of farm shops farmers' markets, roadside sales, and also craft stores. The popularity of short supply chains is growing as consumers demand fresh, nutritious and healthy foods from local farmers or craft food producers. Foods made with organic, plant-based ingredients from local farmers are especially valuable to consumers. Consumers are increasingly interested in knowing more about where their food comes from, who and how it is produced, and how it gets to their plate (Percival Carter & Welcomer, 2021). The authors S. Lingham *et al.* (2022) pointed that craft food often has higher production costs, so it needs to stand out from mass-produced food, then the purchaser will be willing to pay more for craft food. As noted by C.T. Cirne *et al.* (2019), consumers are willing to pay more for craft foods, because they believe these foods taste better, are healthier, and help support small, family-owned businesses. J. Cadby (2021) found that to achieve a high level of quality, craft food producers often use a direct trade model to source higher quality ingredients directly from the origin. To promote their products in the marketplace, craft producers should use contemporary marketing techniques to reach customers who are making decisions based on information from websites and social media (Quinn & Seaman, 2019). It is important to brand a craft food product with an emphasis on the name, symbols, origin (place of production, geographical name), special characteristics in order to distinguish it from similar competing products, which will make it easier to promote the product and increase its recognition among consumers (Danko & Kolodiazhna, 2023).

The term "craft" is becoming increasingly popular, and food with this label can be found in supermarkets and restaurants. In this way, as S. Rivaroli *et al.* (2020) pointed out, food producers are trying to ride the wave of the "craft" trend to attract more consumers. However, consumers need to be careful because products labeled as "hand-crafted" are often nothing more than "crafty marketing", a deceptive marketing practice used by industrial food and beverage companies to introduce "craft-like" brands. The problem is that there is no clear definition, especially in existing low and regulations, of what a craft product is. Consumers of craft food need to be sure that the products they buy are made according to local culinary traditions and that they have an authentic taste that distinguishes them from mass-produced foods. Craft food producers send various signals to consumers that their product is not mass-produced. In order to solve this problem, the legislation of some EU countries (Italy, Spain, Belgium) includes an explanation of which food or beverage can be considered as craft. In particular, the criteria for defining a food product or beverage as craft are the ingredients used, the production process and the scale of production. Ukraine is also taking the first steps in this direction, in particular, the law on craft producers of strong alcohol has been adopted. According to the Law of Ukraine No. 3193-IX (2023), a small producer of distillates is a producer who manufactures distillates on equipment with the capacity of no more than 20,000 decaliters per year (in terms of 100% alcohol) and alcoholic beverages using distillates of its own production no more than 10,000 decaliters per year. Other legislative changes have been developed that will contribute to the development of craft food and beverage production in Ukraine (Kalinichenko, 2022). In order to further increase the number of craft producers, the government should support craft food producers by taking initiatives to promote the consumption of such foods, encourage the production of craft food at the place of origin of raw materials and stimulate small-scale farmers.

Craft food production is associated with a number of socio-economic benefits, including the valorisation of local resources, agricultural diversification, local economic development, especially in rural areas, skilled employment. The production of craft foods also has a positive effect on the development of gastronomic tourism in Ukraine.

The scientists E. Percival Carter & C. Welcomer (2021) noted that, small-scale farmers and craft food producers are creative in their approach to product recipes and design and positioning decisions. They can quickly generate a new idea, develop a new product, produce a prototype, and test the new product in the local market. This is because small producers know well both the production process and the preferences of local consumers. However, small craft producers may face financial problems caused by incorrect costing and pricing of products, poor record keeping, and owners who consider profit as their income instead of paying themselves a salary and investing profits in the business.

Consumers' food choices are the result of a complex set of interrelated subjective and environmental factors that include many conscious aspects and subconscious motivations. Therefore, it is important to analyse the target group in order to create a consumer profile and to identify the attributes of the food that are important to consumers and the factors that guide consumers when choosing food products. Some of the universal product attributes include safety, readiness, affordability, environmental friendliness, aesthetics, usefulness, uniqueness, and sensory appeal. Factors that motivate consumers to purchase foods include the product's effect on health and mood, cooking time, sensory properties, naturalness of ingredients, price, ethical and religious factors. For consumers of craft foods, food waste management is also a very important factor (De Boni *et al.*, 2019). Therefore, studies to determine the motivation of Ukrainian consumers to buy craft food products and to determine their perception of this group of food products are important.

The purpose of this research was to study the attitudes of consumers towards craft food and to determine

their vision of the development of the craft food market in Ukraine.

Materials and Methods

Research conducted through target-group surveys in different segments of the craft market makes it possible to determine what motivates consumers to prefer craft products, what criteria they use to choose them, and what the trends are in this market.

The survey was conducted in May, 2024 in two cities of Ukraine: Lutsk (Volyn region), Mykolaiv (Mykolaiv region). The consumer survey was conducted by interviewers at the entrance of supermarkets. Participation was voluntary and anonymous. Data were collected using a self-administered questionnaire designed in Google Forms. Consumers were able to download Google Forms by scanning the QR code provided by interviewers. Respondents were instructed by interviewers on how to complete the survey and how long it could take.

In the conditions of martial law in Ukraine, as a result of internal and external migration of the population and the presence of the males in the armed forces, it is difficult to accurately determine the size of the population of cities, the sex-age structure of the population and other characteristics of the population. Therefore, based on data from open sources of information, the following assumptions were made when calculating the sample size: the population of Lutsk is 217000 people (214,000 people in 2021 (Timonina, 2021)); the population of Mykolaiv is 430,000 people (471,000 people in 2021 (Timonina, 2021)). The size of the sample of consumers in the cities was calculated according to the method with a confidence probability of P = 0.95 and an error of ±7%, resulting in a sample size of 200 people for each city (Marmoza, 2009). Hence, in the survey, 400 consumers were interviewed, including 200 people in each city. Respondent demographics are shown in Table 1.

Consumers were selected using a quota sampling method, with age and gender as quota control variables (Table 1). Due to the impossibility of determining the sex-age structure of the population under martial law, the following assumptions were made:

1) in the structure of the population of both cities, the percentage of females and males is 60% and 40%, respectively (in 2021, the population of Lutsk consisted of 44.8% male and 55.2% female; in 2021, the population of Mykolaiv consisted of 45.4% male and 54.6% female (Timonina, 2021));

2) in both cities, all age groups are equally represented (20% each).

The sample was also included consumers with varying levels of income and education. It was taken into account that in Ukraine more than 70% of the population has higher education (Strategy of development..., 2020). Accordingly, the percentage of consumers surveyed with higher education was 74-75% (Table 1).

Table 1. *Demographic characteristics of respondents included in the study, expressed as a percentage (N = 400)*

Location	Age (years)	%	Gender	%	Income level	%	Education level	%
Lutsk	18-25 26-35 36-45 46-55 > 56	20 20 20 20 20	Male Female	40 60	High Medium Low	11 59 30	Higher Professional Secondary	75 7 18
Mykolaiv	18-25 26-35 36-45 46-55 > 56	20 20 20 20 20	Male Female	40 60	High Medium Low	16 44 40	Higher Professional Secondary	74 6 20
Total (Lutsk and Mykolaiv)	18-25 26-35 36-45 46-55 > 56	20 20 20 20 20	Male Female	40 60	High Medium Low	13 51 36	Higher Professional Secondary	75 6 19

Source: *developed by the authors*

The percentage of respondents with professional and secondary education, as well as the distribution of respondents by income level, was determined on the basis of the results of the survey. The questionnaire was designed to understand consumer habits, attitudes and motivations toward craft foods. The questionnaire contained 19 questions of four types (Table 2): open-ended, dichotomic Yes/No, check-one-that-applies (COTA), and check-all-that-apply (CATA). The questionnaire was structured in four parts as follows: characteristics of craft food (questions Q1-Q3); consumer habits, attitudes and motivations toward craft foods (Q4-Q11); obtaining information about craft food (Q12-Q14); demographic characteristics of respondents (Q15-Q19). Income level was defined as follows: low level – monthly income is equal to or less than two minimum monthly salaries in Ukraine (16000 UAH); medium level – monthly income of UAH 16000-32000; high level – monthly income over UAH 32000. The word cloud was created using Word It Out. A word cloud is a visual representation of the words that appear more frequently in the respondents' answers.

Table 2. *Survey questionnaire*

The first part	The third part
Q1. Do you know what craft food is?[b] Q2. What words can you use to describe craft food?[a] (2-4 words) Q3. What is the difference between a craft food and a mass-produced food?[a] (2-4 words/phrases that characterise the difference)	Q12. Do you recommend craft food to relatives/friends/colleagues?[b] Q13. Do you have enough information about craft food and producers in Ukraine?[b] Q14. How would you like to receive information about craft food?[d]
The second part	**The fourth part**
Q4. Do you buy craft food?[b] Q5. How often do you consume craft food?[c] Q6. What craft food do you buy?[d] Q7. Where do you buy craft food?[d] Q8. Why do you like/dislike craft food?[a] (2-4 words/phrases) Q9. What is the most important factor(s) you consider when choosing craft food?[d] Q10. Are you willing to pay more for craft food?[c] Q11. Is the assortment of craft food sufficient in your region?[b]	Q15. How old are you?[c] Q16. What is your gender?[c] Q17. What is your level of education?[c] Q18. How would you rate your current monthly income?[c] Q19. What is your city of residence in Ukraine?[c]

Note: *[a]Open-ended question; [b]Yes/No question; [c]COTA; [d]CATA*
Source: *developed by the authors*

All data from the completed consumer surveys have been stratified by location, gender, age range, income and education levels. Absolute frequencies and percentages were used to describe the quantitative survey data (Garcia-Alvarez *et al.*, 2014). Survey results were displayed using Excel 2016 software. The study was conducted in compliance with the norms of The Declaration of Helsinki (2013).

Results and Discussion

Craft products in Ukraine are experiencing a significant rise in popularity, reflecting a growing consumer demand for high-quality, artisanal goods. These products, often produced by small-scale, local manufacturers, are made using traditional methods and natural ingredients, which contribute to their unique flavours and authenticity. From handcrafted cheeses and sausages to locally produced honey and baked goods, craft items offer a taste of regional heritage and craftsmanship. Many consumers are drawn to these products not only for their quality but also for the story behind their production and the connection to local culture. As a result, craft products are becoming an essential part of Ukraine's evolving food and drink scene, highlighting the rich diversity of its culinary traditions.

Table 3 shows the results of a survey on consumer awareness of craft food. All respondents in both cities, males and females, aged 18 to 55, know what craft food is. Males and females over the age of 56 are less familiar with the term "craft food". Moreover, in both cities the percentage of females over the age of 56 who know about craft food is higher than that of males. This may be due to the fact that females are more familiar with the range of food products on the market, as they tend to buy them for the family. It should also be noted that the percentage of Mykolaiv residents over the age of 56 who are familiar with craft food products is slightly lower than in Lutsk. Thus, 97.5% of male residents of Lutsk and 96.2% of male residents of Mykolaiv know what craft food is. The percentage of females who are unfamiliar with craft food is very low in both cities.

Table 3. *Percentage of respondents who know what craft food is (the results of answering the question Q1)*

Age (years)	Percentage (%) of respondents who know what craft food is			
	Male		Female	
	Lutsk	Mykolaiv	Lutsk	Mykolaiv
18-25	100.0	100.0	100.0	100.0
26-35	100.0	100.0	100.0	100.0
36-45	100.0	100.0	100.0	100.0
46-55	100.0	100.0	100.0	100.0
> 56	87.5	81.3	91.7	87.5
All ages	97.5	96.2	98.3	97.5

Source: *developed by the authors*

The survey aimed to identify the words used by each group of consumers to describe craft food products (question Q2). The total number of non-repeated words was 47.5 words were discarded because they didn't fit the topic of the study. Two responses from respondents did not contain any words. Three responses included the names of craft products (cheese, bread, beer, ice cream, spirits), which were also disregarded. Females were more likely than males to use a variety of words to describe craft foods. Table 4 illustrates

the words that respondents used to describe craft food products, and only words that appeared in the responses of more than 5% of respondents are included. The most commonly used words to describe craft food were tasty, fresh, small-batch, natural, domestic and handcrafted. Females most often described craft food with the words tasty, fresh, and small-batch. Males most often described craft food with the words tasty, fresh, and natural.

Table 4. *Words used by consumers to describe craft foods (the results of answering the question Q2)*

Words used by consumers to describe craft foods	Percentage (%) of respondents who used the following words			Words used by consumers to describe craft foods	Percentage (%) of respondents who used the following words		
	Male	Female	M & F		Male	Female	M & F
Authorial	8.1	2.9	5.0	Innovative	10.6	4.6	7.0
Costly	13.8	17.5	16.0	Local	38.8	20.8	28.0
Delicate	9.4	6.3	7.5	Natural	45.0	38.3	41.0
Domestic	35.0	38.3	37.0	Original	15.0	3.3	8.0
Elite	6.3	5.0	5.5	Small-batch	40.6	42.1	41.5
Family	28.8	32.5	31.0	Special	18.1	7.1	11.5
Fresh	53.8	42.5	47.0	Tasty	61.3	57.5	59.0
Handcrafted	48.8	27.5	36.0	Traditional	40.0	35.8	37.5
Healthy	12.5	6.7	9.0	Unique	10.6	7.9	9.0
High-quality	40.0	45.0	43.0	Useful	13.1	21.3	18.0

Note: *M & F – all respondents*
Source: *developed by the authors*

Consumers used a variety of words and phrases to describe the difference between craft foods and mass-produced foods (question Q3). The words that appeared in the responses of more than 5% of the respondents are shown in Table 5. In addition, 2 responses contained words unrelated to the topic of the survey, and 3 responses contained only symbols. According to the respondents, the main characteristics that distinguish craft foods from mass-produced foods are better taste and higher quality of craft foods. However, according to consumers of both genders, craft food is more expensive than mass-produced food. Craft food also differs from mass-produced food because it is made in small batches, is more natural, and is made according to original recipes, as noted by 42.5%, 39.0%, and 18.5% of respondents, respectively. The percentage of male respondents who used the phrase "craft food has an original recipe" was significantly lower than the percentage of female respondents. Perhaps this is because women in Ukraine are more familiar with cooking methods and recipes. In response to the Q4 question, about 84.3% of all respondents indicated that they are purchasers of craft foods. In addition, 89.5% of respondents in Lutsk and 79.0% of respondents in Mykolaiv buy craft foods. Among those who buy craft foods in Lutsk, about 63.1% are females and 36.9% are males. And among those who buy craft foods in Mykolaiv, about 62.0% are females and 38.0% are males. Thus, the ratio of male to female buyers of craft foods in the two cities is similar. Table 6 shows the distribution of craft food buyers among respondents by age category.

Table 5. *Words and phrases used by consumers to describe the difference between a craft food and mass-produced foods (the results of answering the question Q3)*

Words used by consumers*	Percentage (%) of respondents who used the following words			Words used by consumers*	Percentage (%) of respondents who used the following words		
	Male	Female	M & F		Male	Female	M & F
Craft food tastes better	85.0	81.7	83.0	Craft food is small-batch product	40.0	44.2	42.5
Craft food has high quality	75.0	80.0	78.0	Craft food is more natural	38.8	39.2	39.0
Craft food has higher price	59.4	64.6	62.5	Craft food has an original recipe	5.6	27.1	18.5

Note: *M & F – all respondents; *words and phrases used by consumers to describe the difference between a craft food and mass-produced foods*
Source: *developed by the authors*

Table 6. *Percentage craft food buyers (the results of answering the question Q4)*

Age (years)	Percentage (%) of craft food buyers			
	Male		Female	
	Lutsk	Mykolaiv	Lutsk	Mykolaiv
18-25	50.0	56.3	83.3	54.2
26-35	93.8	68.8	100.0	87.5
36-45	100.0	100.0	100.0	100.0
46-55	100.0	100.0	100.0	95.8
> 56	68.8	50.0	87.5	70.8

Source: *developed by the authors*

Regardless of the education level, the vast majority of respondents purchase craft food products (Fig. 1a). The percentage of medium- and low-income buyers who purchase craft foods is also high (Fig. 1b).

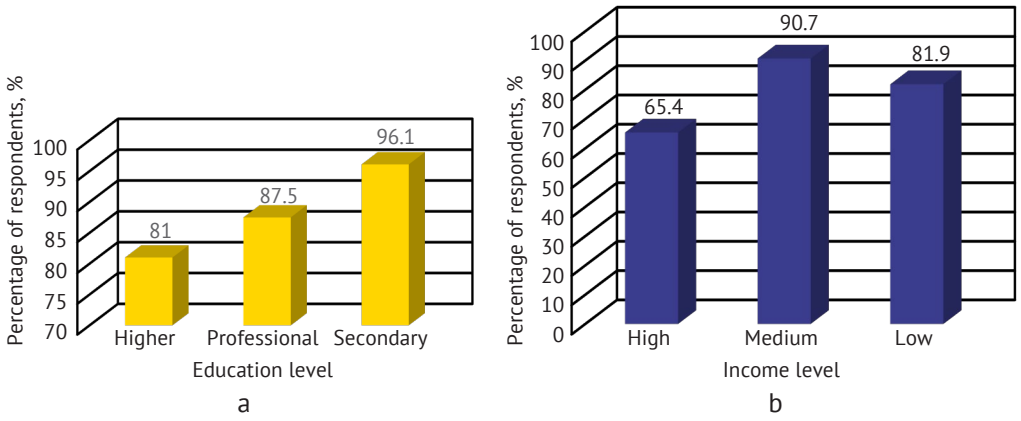

Figure 1. *Percentage of craft food buyers with different levels of education (a) and income (b)*
Source: *developed by the authors*

The number of respondents who periodically consume craft foods is 41.0% (Table 7), and among them females and males – 45.8% and 34.0%, respectively. In Lutsk, more residents periodically consume craft food, than in Mykolaiv. In both cities, the percentage of respondents who regularly consume craft foods is low. The largest percentage of respondents indicated that they occasionally consume craft foods. Never consumed craft foods about 7.0% of respondents, and most of them are males and residents of Mykolaiv.

Table 7. *Frequency of craft food consumption (the results of answering the question Q5)*

Frequency of craft food consumption	Percentage (%) of respondents				
	in two cities combined			in each city separately	
	M & F	Male	Female	M & F*	M & F**
Regularly	8.0	6.0	9.2	8.0	8.0
Periodically	41.0	34.0	45.8	46.0	36.0
Occasionally	44.0	50.0	40.0	43.0	45.0
Never	7.0	10.0	5.0	3.0	11.0

Note: *M & F – all respondents; *all respondents from Lutsk; **all respondents from Mykolaiv*
Source: *developed by the authors*

Among the variety of craft foods on the Ukrainian market, consumers buy mainly baked goods (56.0%), confectionery (52.0%), meat products (48.0%) and dairy products (42.0%), semi-finished products (24.0%) and alcohol (21.0%). Meat products (56.3%), baked goods (48.1%), confectionery (46.3%) and alcohol (38.1%) are most popular among males. Females prefer craft baked goods (61.3%), confectionery (55.8%), dairy products (48.8%) and meat products (42.5%) (Fig. 2).

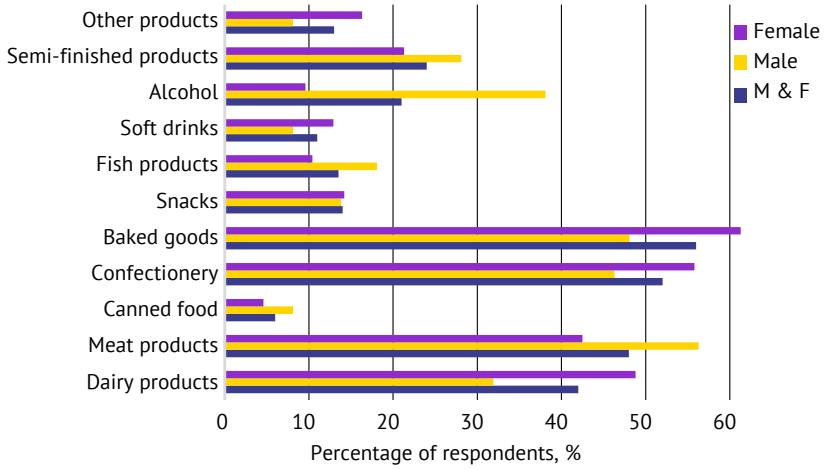

Figure 2. *Craft food preferred by consumers (the results of answering the question Q6)*
Note: *M & F – all respondents*
Source: *developed by the authors*

Consumers aged 18-25 mostly buy craft foods directly from producers (31.3%), in specialised stores (31.3%), and in chain stores (33.8%) (Fig. 3). Respondents aged 26-35 prefer to purchase craft foods directly from producers (40.0%) and in chain stores (40.0%), and a significant percentage of consumers in this age group purchase foods online (31.3%). For consumers aged 36-45, the main place to buy craft foods is from the craft producer (46.3%). This age group is also characterised by buying food online (37.5%), in specialised and chain stores (32.5% each), and at the market (31.3%). Respondents in the 46-55 age group indicated that they prefer to buy craft foods directly from producers (50.0%), but they also buy food from chain stores (43.8%) and specialised stores (37.5%). Consumers aged > 56 years mainly buy craft foods at fairs or markets (75.0%) and in chain stores (56.0%) (Fig. 3).

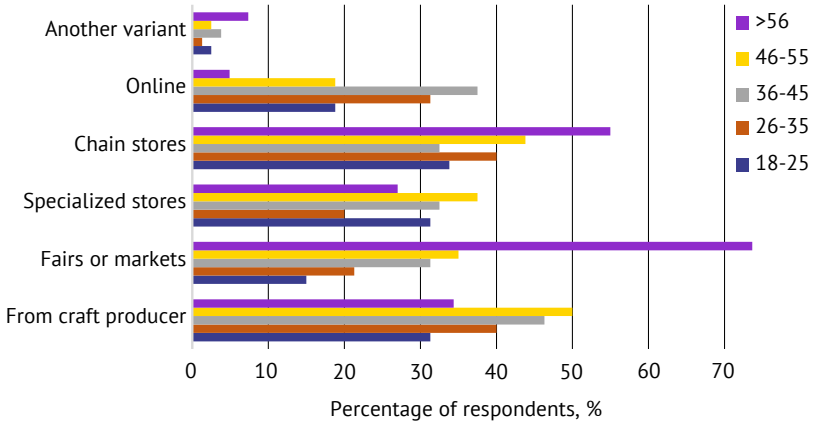

Figure 3. *Places where customers buy craft foods according to their age (the results of answering the question Q7)*
Source: *developed by the authors*

Figure 4 shows a word cloud created from the list of words most frequently used by respondents to characterise their commitment to craft food. The size of a word indicates how important it is and how often it appears in respondents' answers. The larger the font size of the word, the more often respondents used it to answer question Q8. Quality, delicious and natural were the most common words used to describe the commitment to craft food. Expensive was the most common word used by respondents to describe their dislike of craft food. When choosing craft food, surveyed consumers pay the most attention to its taste, ingredients and appearance. In addition, the most important factor for males is taste and for females it is food ingredients. The price of craft food is an important factor for low-income people. Food ingredients are the most important factor for people with high and medium income levels. When choosing products, 31.0% of consumers consider the producer. Males pay more attention to what is new on the market than women

(Table 8). Among all respondents, about one-third of respondents are willing to pay up to 10% extra for craft foods, and about one-quarter of consumers are willing to pay 11-20% more (Table 9). About 11.7% of consumers are willing to pay any price for quality craft foods, and most of these people are high-income consumers. It should also be noted that a quarter of consumers aged 18-25 are also willing to pay any price for craft foods. Only 17.0% of respondents are unwilling to pay more for craft foods, and the largest number of these people are consumers over the age of 56. Consumers who are uncertain about their willingness to pay more are most likely to be in the 26-35 age group and among low-income people. Low-income consumers are also unwilling to pay 21-30% extra for craft foods, but 15.4% of high-income consumers are willing.

Figure 4. *Word cloud characterising respondents' commitment to craft food (the results of answering the question Q8)*

Source: *developed by the authors*

Table 8. *Factors to consider when choosing a craft food (the results of answering the question Q9)*

Factors to consider when choosing a craft food	Percentage (%) of respondents					
	M & F	Male	Female	Income level		
				High	Medium	Low
New craft product	25.5	38.1	17.1	32.7	28.9	18.1
Appearance	45.3	51.9	40.8	30.8	42.2	54.9
Craft food producer	31.0	30.0	31.7	30.8	33.3	27.8
Taste	77.0	76.3	77.5	73.1	71.1	86.8
Ingredients	71.5	56.3	81.7	84.6	73.5	63.9
Price	36.5	48.1	28.8	11.5	24.5	62.5
Other factors	7.0	10.0	5.0	11.5	6.9	5.6

Note: *M & F – all respondents*

Source: *developed by the authors*

Table 9. *Consumer willingness to pay more for craft foods (the results of answering the question Q10)*

Characteristic of respondent group	Percentage (%) of respondents					
	Willing to pay			Any price for high quality	Unwilling to pay more	Uncertain I'm ready to pay more
	up to 10% extra	up to 11-20% extra	up to 21-30% extra			
Age (years)						
18-25	25.0	20.0	1.2	25.0	11.3	17.5
26-35	30.0	20.0	5.0	10.0	10.0	25.0
36-45	33.8	25.0	3.7	16.3	8.7	12.5
46-55	31.3	43.7	7.5	5.0	5.0	7.5
> 56	25.0	10.0	2.5	2.5	50.0	10.0
Income level						
High	19.2	5.8	15.4	57.7	0.0	1.9
Medium	30.9	27.0	3.9	17.6	6.9	13.7
Low	21.5	15.3	0.0	8.3	21.5	33.4
M & F	29.0	23.8	4.0	11.7	17.0	14.5

Note: *M & F – all respondents*

Source: *developed by the authors*

More than half of the respondents in both cities noted that the assortment of craft foods in their region is insufficient (Table 10). In addition, the percentage of such respondents is higher in Lutsk than in Mykolaiv. In both cities, males are more likely than females to be dissatisfied with the assortment of craft foods in their region.

Table 10. *Consumer satisfaction with local assortment of craft foods (the results of answering the question Q11)*

Answer to question Q11	Percentage (%) of respondents						
	M & F	M & F*	M & F**	Lutsk		Mykolaiv	
				Male	Female	Male	Female
Yes	43.8	39.0	48.5	36.3	40.8	38.8	55.0
No	56.2	61.0	51.5	63.7	59.2	61.2	45.0

Note: *M & F – all respondents; *all respondents from Lutsk; **all respondents from Mykolaiv*
Source: *developed by the authors*

Some 81.8% of consumers recommend craft food to relatives, friends and colleagues (Fig. 5). Moreover, more females (87.1%) than males (73.8%) make such recommendations.

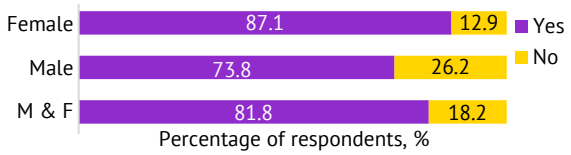

Figure 5. *The results of answering the question Q12 (Do you recommend craft food to relatives/friends/colleagues?)*
Source: *developed by the authors*

The majority of respondents indicated that they do not have enough information about craft foods and their producers in their region (Fig. 6). In addition, more females than males reported this. Only 34.0% of respondents in Lutsk and 44.0% of respondents in Mykolaiv stated that they have enough information about craft producers and their products. In order to draw attention to their products and to differentiate them from mass-produced foods, craft food producers try to send information to consumers and use the labels such as "artisan", "small-batch", "handcrafted" (Leissle, 2017). As noted by L. McKitterick *et al.* (2016), craft enterprises also disseminate information about the traditional food and food culture of regions, which enhances the reputation of the regions. A. Bouma *et al.* (2014) found that small craft food producers try to do everything possible to popularise their products, even if they have the financial problems that arise, especially at the beginning of their activity.

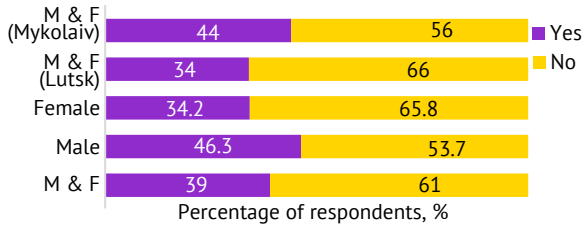

Figure 6. *The results of answering the question Q13 (Do you have enough information about craft food and producers in Ukraine?)*
Source: *developed by the authors*

Consumers with higher education would like to receive information about craft foods from online resources for craft producers (58.7%), popular online resources (57.7%), and web chats or life chats (35.0%) (Fig. 7). Consumers with professional education prefer to receive information from the same sources as consumers with higher education. However, they believe that popular online sources are the most appropriate (75.0%). Consumers with a secondary education would also like to get information about craft foods from producers to come from online resources for craft producers (67.1%), popular online resources (67.1%), and web chat or live chat (53.9%). Consumers with different levels of education would least like to receive information about craft products from print media (9.0%).

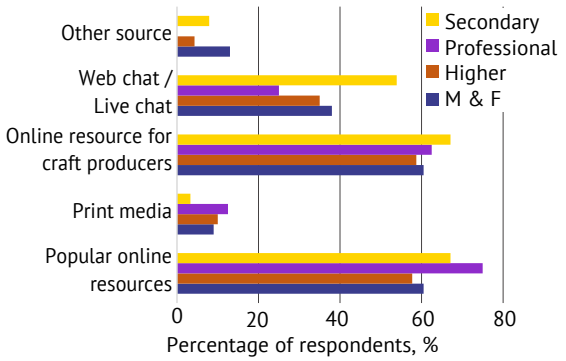

Figure 7. *Preferred sources of information about craft foods for consumers with different levels of education (the results of answering the question Q14)*
Source: *developed by the authors*

Figure 8 shows the preferred sources of information about craft foods for consumers of different ages. Respondents of all ages prefer to get food information from online resources. Consumers aged 18-35 are the biggest supporters of such information resources. In addition, approximately 85.0% of respondents aged 18-25 selected popular online resources as the best source of information about craft foods, and approximately 87.5% of respondents aged 26-35 considered an online resource for craft producers to be such a source. A significant proportion (20.0%) of consumers aged over the age of 60 would like to receive information from print media. At the same time, consumers in this age group are more likely to get information from popular online

resources (43.8%) and online resources for craft producers (42.5%). In the 36-45 age group, the most common ways to get information are through a craft online resource (62.5%) and popular online resources (58.8%). In the 46-55 age group, preferences were almost evenly split between an online resource for craft food producers (56.3%), popular online resources (50.0%), and online chats (50.0%).

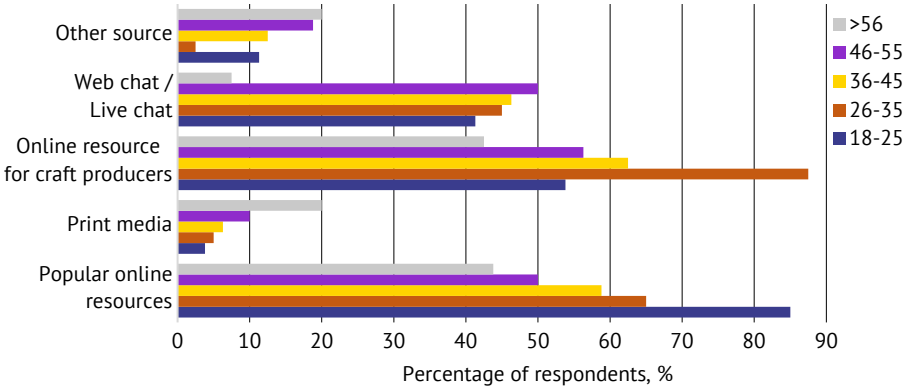

Figure 8. *Preferred sources of information about craft foods for consumers of different ages (the results of answering the question Q14)*

Source: *developed by the authors*

Over 84.3% of survey respondents declared that they are purchasers of craft foods, including about 41.0% who do so periodically. These results are very similar to previous research by D. Thilmany *et al.* (2010) in other countries, which found that the vast majority of respondents (85.0%) buy locally grown fresh produce. Another study by M. Dunne *et al.* (2017) showed that 64.4% of respondents purchase craft foods, including 33.9% who do so weekly and 48.2% who do so intermittently throughout the year.

The research showed that respondents with lower levels of education are more likely to consume craft foods than those with professional or higher education. Consumers with higher income levels are less likely to purchase craft foods. This correlates with previous research by A. Annunziata *et al.* (2019), which stated that high levels of education and high level of income have a negative impact on local food consumption.

Understanding food choice motives is necessary to improve consumers' dietary health and well-being. Food choice is a complex function of food sensory characteristics combined with the influence of non-sensory factors, including price, consumers' expectations, likes and dislikes, and habits. R. Brečić *et al.* (2017) emphasised that consumers are generally very concerned about intrinsic food characteristics, as taste and natural content, they are also rather sensitive to the price of the food as the most important extrinsic attribute. According to the survey results, consumers of both mass-produced and craft foods are primarily concerned with sensory attributes (taste, appearance), ingredients, and price when choosing foods. They also associate craft foods with products that contain natural ingredients, and are tasty, fresh, and domestic. According to respondents, quality is one of the most important attributes of craft food. K. Grunert (2005) found that when asking consumers what they regard as food products of good quality, the answers always include characteristics such as: taste (and other sensory characteristics), health, process characteristics such as organic production, natural production, GMO-free, fat content, packaging. Findings of this study are similar to previous research that provides strong evidence that consumers associate local food with attributes such as: freshness, high quality, nutritional value, safety, evocation of domestic flavours, naturalness (Kovács *et al.*, 2022). Most of these local food attributes are universal product attributes (Dhargalkar *et al.*, 2016). E. Carrillo *et al.* (2011) also suggested that sensory properties and naturalness of ingredients are the factors that motivate consumers to purchase foods. As indicated by C. Gómez-Corona *et al.* (2016), the main motivation for consuming craft foods or beverages may also be the search for authenticity, the desire for new taste experiences. Hence, craft food can be seen as an alternative to mass-produced food because of the trust in its high quality.

Respondents believe that craft food are more expensive than mass-produced foods. However, consumers can find craft foods in the marketplace that are sold at very different market prices. The studies summarised by S. Rivaroli *et al.* (2021) suggested that the price attribute is consistently associated with the perceptions of food quality and that consumers judge the quality of craft food by price, associating higher price with higher food quality. Hence, there has been consumer interest in local craft food, but food price remains an issue for now, especially for low-income consumers. In some cases, consumers are willing to pay a premium for local food over non-local food, and even higher than for organic food (Enthoven & Van den Broeck, 2021). A survey

of respondents indicated that approximately 29% of consumers are willing to pay 10% more for craft foods.

According to the results of the survey, the following craft products are most in demand among consumers: baked goods, confectionery, meat products and dairy products. Results of alternative studies by D. Znotina & M. Igavens (2017) indicated that the most popular craft food products among buyers are poultry meat products, teas, natural juices, biscuits, yogurt, cheese, lard.

The conventional model of food supply to consumers includes chains of the national and international supermarkets and hypermarkets. An alternative model includes mostly local and small distribution channels such as farmers' markets and regular or occasional local fairs, open air-markets, cooperatives, specialised stores, buying directly from producers (Kawecka & Gębarowski, 2015). Other places where craft foods are sold include roadside sales, harvest festivals, and restaurants that specialise in local products (Pokorná *et al., 2015*). The survey results show that consumers buy craft food both through both traditional and local distribution channels. Over 30% of consumers prefer to buy food products directly from small, local producers. Rational, symbolic and cultural motivations that motivate consumers to purchase local food products in local retail channels versus supermarkets can be divided into main categories: health (healthy food without hormones, herbicides, and pesticides), environmental motivation (organic food), and economic motivation (supporting the local economy), emotional and spiritual role of food products in consumers' lives (supporting unique local traditions and values, embodying one's heritage) (Spielmann & Bernelin, 2015). As a result, local food production and distribution brings producers and consumers closer together. As noted by A. Tregear (2005), this contributed to the development of sustainable local food supply chains.

Modern consumers can also find needed food products from all over the world. Alternative food distribution channels using modern forms of communication are Internet shops, online sales portals, which help more direct and easier to deliver food to the final consumer than traditional channels (Kawecka & Gębarowski, 2015). Online shopping creates the ability to buy local food without leaving home and avoiding the crowds, which is a huge benefit for many consumers (Gumirakiza & VanZee, 2017). The results of the conducted research indicate that consumers of craft products in Ukraine also use modern forms of buying food via the Internet, especially in the age group of 26-45, more than 30% of such consumers.

A lack of reliable information or incomplete disclosure about the attributes of a food product has the potential to destroy trust between consumers and producers, whereas providing trustworthy information about food can greatly increase consumer confidence (Lam *et al.*, 2020). As noted by E. Lioutas (2014), consumers seek food information by using one or more of the available out-of-store (published material, media, experts, institutional bodies, and social milieu and media) or in-store (store personnel, food labels) information sources. Surveyed craft food consumers prefer such sources of information about the food products such as online resources for craft producers, popular online resources, and web chats or life chats.

The results of the study allow craft food producers to better understand the preferences of consumers of different ages, genders, education levels, and incomes, as well as to understand their motivations for choosing craft food products. Based on the research results, producers can create a profile of the craft food consumer. Information on the regularity of consumer purchases of craft foods and where they are purchased will also be useful to producers. An effective advertising campaign is important to increase the number of buyers. The results of the study allow producers to decide where to place information about their products so that their advertising is accessible to consumers and effective.

Conclusions

In Ukraine, there is an increase in interest in craft food. This is due to a global trend toward the consumption of local and traditional foods from small, local producers. Consumers perceive craft foods as higher quality and tastier than mass-produced foods. However, there is very little study devoted to the Ukrainian craft food market.

The survey conducted among consumers of two regional centers of Ukraine, Lutsk and Mykolaiv, confirms that Ukraine is not isolated from global trends in the field of food consumption. Consumers (more than 97.0%) are well aware of what local craft food is. 84.3% of respondents in both cities buy craft food, with females buying it more often than males. Perhaps this is due to the fact that in Ukraine, females traditionally buy food for the family. It should be noted that consumers with a higher level of education and a higher level of income are less likely to purchase craft foods compared to consumers with lower levels of education and income. Most consumers buy craft foods periodically (41.0%) and occasionally (44.0%).

Consumers characterise craft foods as tasty, fresh, small-batch, natural, domestic, handcrafted, natural, traditional, high-quality and local. They believe that craft foods have better taste and quality than mass-produced foods, but at a higher price. These beliefs create a mostly positive consumer attitude toward craft foods and motivate consumers to buy them. The higher price is a deterrent to the purchase of craft foods by low-income consumers. However, about 29.0% of consumers are willing to pay 10% more for craft foods than for mass-produced foods.

The most popular food products in the craft food segment are baked goods, confectionery, meat products and dairy products. When choosing a food product,

consumers mainly take into account its taste, appearance and content of ingredients. 56.2% of respondents do not consider the range of craft foods in their city to be sufficient.

Consumers buy craft food products, mostly from producers or in chain stores. In addition, a significant proportion of consumers, especially those over the age of 56, buy craft food products at markets and fairs, as well as in specialised stores. These are the formed habits of Ukrainian consumers regarding the places of purchase of food products. It is also becoming more common to purchase craft food products through online resources. Consumers actively recommend craft foods to others based on their experience of consuming them. This is a positive factor for the development of the craft food market, as information about this food segment spreads among consumers. On the other hand, consumers indicated that they do not have enough information about craft foods and their producers. Sources of such information, according to consumers, can include popular online resources, producers' online resources and web chats.

The survey made it possible to find out the attitude of the residents of two cities of Ukraine to craft food and to determine the motives that guide them in choosing such food. The main one is the confidence that local craft food is of higher quality, tastier and more natural. Further research should be aimed at identifying the main problems faced by producers of craft foods in Ukraine during their production and sale to consumers.

Acknowledgements

None.

Conflict of Interest

None.

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Дослідження звичок, ставлення та мотивацій, що лежать в основі вибору крафтової їжі споживачами в Україні

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Анотація. У світі наявний зростаючий попит на місцеву крафтову їжу. Виробництво крафтових продуктів харчування активно підтримується в багатьох країнах, оскільки це сприяє вирішенню низки соціально-економічних та екологічних проблем. Кількість виробників крафтових продуктів в Україні також зростає, але ринок крафтової їжі залишається недостатньо дослідженим. Тому метою дослідження було вивчення через опитування звичок, ставлення та мотивацій, які визначають вибір крафтових продуктів споживачами в Україні. Опитування проводилося в двох обласних центрах України – Луцьку та Миколаєві – серед споживачів різного віку, статі, рівня доходів та освіти. Близько 84,3 % опитаних є споживачами крафтової їжі. Респонденти зазначили, що купують крафтову їжу періодично і час від часу. Більшість споживачів вважають, що крафтова їжа смачніша та кращої якості, ніж масово вироблена їжа. Респонденти відзначили, що крафтові продукти дорожчі за масові, але 29 % респондентів готові платити за них на 10 % більше. Були визначені найпопулярніші крафтові продукти серед українських споживачів, серед яких випічка, кондитерські вироби, м'ясні та молочні продукти. Українці купують крафтову їжу переважно безпосередньо у виробників, у мережевих та спеціалізованих магазинах. Респонденти зазначили, що їм не вистачає інформації про виробників крафтової їжі та їхні продукти. Вони хотіли б бачити більше реклами крафтової їжі на інтернет-ресурсах. Таким чином, результати опитування дозволили визначити звички та ставлення українських споживачів до крафтової їжі, а також дослідити мотиви, що спонукають до її придбання. Отримані результати будуть корисними для виробників крафтових продуктів, оскільки вони дозволять створити профіль споживача їхніх продуктів і зробити інформацію про свої продукти більш ефективною

Ключові слова: місцеві продукти харчування; крафтові виробники; споживчі переваги; ринок крафтової їжі; опитування споживачів

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Commodity aspects of forming a modern range of interior nanotextiles

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Abstract. The use of modern nanotechnologies in the manufacture of interior textile materials allows expanding and diversifying the range of products, providing completely new functional properties, as well as obtaining unique beneficial effects on these materials and products: aesthetic, antimicrobial, dirt-repellent, therapeutic, and at the same time satisfying the specific needs of consumers. The purpose of the article was to study and substantiate the main directions of formation of the modern range and properties of interior nanotextiles for various purposes. The study used statistical, analytical methods, and the method of system analysis. The analysis of literature sources has shown that in 2010-2024, Ukrainian and foreign scientists studied in detail the economic and technological feasibility of the widespread use of textile nanotechnologies to expand and optimise the range of nanotextiles, including interior ones. Guided by this approach, the article presented an analysis of literature sources for the last 2019-2024 years, which considered the main directions of development and achievements of nanotechnology in textile production to expand the range and properties of interior nanotextiles in Ukraine and the world. On this basis, theoretical provisions for the further development of nanotechnology and the market of interior nanotextiles were formulated and substantiated. The article identified promising areas of use of interior nanotextiles for curtains and draperies, linen, furniture, decor and floor coverings. The advantages and disadvantages of these types of nanotextiles in comparison with traditional materials are identified. The necessity and expediency of expanding the production of various nanoemulsions, nanodispersions and nanopreparations in Ukraine is substantiated in order to provide interior textiles with useful properties, improving their quality and environmental safety. The main focus is on providing textile interior nanomaterials and products with polyfunctional unique properties. In practice, the conducted research can serve to select priority areas of research in the manufacture of interior nanotextiles for various purposes

Keywords: nanotechnology; interior; nanoprocessing; nanopreparations; consumer properties; environmental safety; hygiene

Introduction

In 2024, it is important to consider the problems of introducing modern nanotechnologies into the practice of Ukrainian textile production in order to create a fundamentally new unique range of nanotextiles for various purposes (interior, medical, clothing, technical, special). Modern innovative nano-, bio-, chemical

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and information technologies are widely used in the textile production of textile materials and products. All this has led to the expansion and increase of the existing range of textile clothing, interior and other textile materials and the emergence of new types of textiles on the world markets. In order to assess the state and generalise the problem of forming the range and properties of interior nanotextiles, it is advisable to provide an abstract of the publications of Ukrainian and foreign authors, including our own publications, considered in this paper.

In her research, L.V. Kyrylenko (2019) analysed scientific papers on the development of nanotechnology and the production of nanomaterials in Ukraine. The author provided an assessment of the legislative acts of Ukraine aimed at solving these problems. The author reveals the impact of the growth of nanotechnology on the development of other industries. The expediency and importance of state support for the development of modern priority nanotechnologies in Ukraine are substantiated. The main problems of further development of the market of modern textile nanomaterials in Ukraine are identified.

The paper by M.A. Shah *et al.* (2022) provided an overview of the latest achievements in the field of nanotechnology and the production of nanotextiles for various purposes with new unique properties. First of all, it is noted that it is possible to obtain new modern properties using nanotechnology on textile nanomaterials for various purposes, including interior, namely: water-repellent properties; antibacterial properties; UV protection properties; low shrinkage properties; dirt-repellent properties; fire-resistant properties.

The work of D. Pargai (2021) described the types of smart dyes, such as photochromic, thermochromic, electrochromic, solvatochromic, used in the textile industry. The characteristics and properties of these types of dyes are given, and the most common areas of application of textile materials dyed with them are indicated. It has been found that textiles dyed with photochromic dyes of different fibre composition have high protective properties against UV radiation and are widely used for sewing window curtains, producing protective camouflage clothing and other products. The properties of dyes on textile materials with antibacterial and UV-protective properties, as well as dyes with high protection against mosquitoes and insects on dyed textile materials, were investigated.

The authors O.N. Aguda & A. Lateef (2022) analysed scientific research on the modification of the surface of textile materials with nanostructures to ensure the antimicrobial properties of nanotextiles for various purposes. The role of nanoparticles in the functionalisation of textiles as a means of combating resistant strains of microorganisms is investigated. The authors note that since bed linen, medical textiles, and clothing come into contact with microbes, nanotechnology has made it possible to produce antibacterial nanotextiles. The article presents research on the effect of zinc oxide, titanium dioxide, copper (II) oxide and silver nanoparticles on the antibacterial properties of cotton, wool, silk fabrics and some synthetic fibres. Positive results were obtained in the production of innovative functional nanotextiles with antimicrobial properties.

Scientists A. Komolafe *et al.* (2021) noted that the integration of electronics into traditional textile materials creates innovative electronic textiles (e-textiles). Electronic textiles are textiles that contain special electronic functions of biometric sensors, wireless communication, power transmission, and connection of sensors and other devices within the textile material. The scope of electronic textiles is diverse. Electronic textiles are used in the production of medical textiles for monitoring human health and interior textiles for decorating living spaces. Electronic textiles are especially widely used in the production of protective clothing for military purposes, etc. The paper describes in detail the types of e-textiles, the most popular areas of their application, properties and technologies for the manufacture of e-textiles for various purposes.

Scientists A. Singh & J. Sheikh (2022) have successfully synthesised a multifunctional reactive dye for dyeing polyamide fabric (nylon) to give it enhanced properties. The authors have dyed and treated polyamide fabric with a multifunctional reactive dye that has a repellent function and a protective function against UV radiation. The resulting textile materials have unique properties, namely the ability to protect people from mosquito bites, since the dyed fabric contains a repellent dye that acts on insects when in contact with the surface. The durability of the dyeing and the resulting effects on the fabric to various wear factors was investigated. The studied fabrics can be used in the production of protective clothing for various purposes, curtains, tents, technical fabrics.

R.A. El-Abassy *et al.* (2019) studied the problem of improving the microclimate of the interior of premises in medical institutions. It has been established that with the right choice of interior nanotextiles (floor coverings, curtain materials, bed linen), it is possible to improve the microclimate of hospital premises, where it is especially important. It is noted that interior textile nanomaterials contribute to the destruction of bacteria, mould, fungi, and prevent their development. Thus, the use of interior nanotextiles with antibacterial properties helps maintain a healthy microclimate in hospitals.

The work of E. Decker (2023) noted that the textile industry is undergoing a profound shift towards sustainable development, driven by demand and the urgent need to address environmental issues. The authors emphasise that information on the assessment of the impact of nanotechnologies, nanomaterials and nanoparticles on the safety of nanotextiles for various purposes, including interior nanotextiles, in scientific

sources is fragmentary and requires a more qualified interpretation. It is noted that in 2024, the research of new nanotechnologies for the production of nanotextiles, nanofibres, nanopreparations and nanoemulsions, nanoapretents, nanodyes for textile purposes is significantly ahead of research on their negative impact on the human body and environmental pollution. Therefore, nanotextiles for various purposes, including interior textiles, should be marketed only after assessing their safety. It is emphasised that it is important and expedient to continue to conduct comprehensive commodity research on the properties, quality and safety of nanotextiles for various purposes, fibre composition and production methods.

In this study, it is advisable to assess the problems associated with the formation of the range of interior nanotextiles, their classification and environmental safety assessment. The aim of the study was to substantiate the directions of development of the latest (improved) range of interior textile nanomaterials for various purposes obtained by various types of nanoprocessing.

Materials and Methods

This study was conducted in 2023-2024 by researchers from Lviv University of Trade and Economics and Lutsk National Technical University. The expediency of addressing these issues is due to the lack of modern commodity analysis of these problems in educational, periodical and scientific publications of Ukraine; the need to increase the export potential of the Ukrainian textile and light industry to implement the Association Agreement with the EU; and the need to bring Ukrainian enterprises out of the protracted economic crisis they are in as of 2024.

Practical aspects of the formation of a modern range of interior nanotextiles were studied using analytical and statistical methods. Analytical methods were used when considering the term 'nanotextiles' using the ISO 18184:2019 (2019) standard, when analysing scientific publications, analysing the economic indicators of nanotextiles use, which were determined on the basis of the report of the Textile Manufacturers Association (Nanotextiles market report overview, 2023). The paper also used the official report of Archroma (2022), which has developed and implemented the Perapret® AIR liq technology for purifying indoor air with interior nanotextiles using nanosized TiO_2 particles. Statistical methods were used to process official statistical data, in particular, to analyse the largest producers of nanotextiles and to identify trends in their development. In addition, statistical analysis was used to assess the dynamics of the introduction of nanotechnology in the production of textile materials, and to forecast future trends in supply and demand for nanotextiles. Systematic analysis was used to comprehensively assess the impact of nanotechnology on the properties of textile materials, thus verifying the statements about the positive impact of nanotechnology on the formation of a set of consumer properties of nanotextiles. The key indicators studied were antimicrobial activity, water repellency, self-cleaning ability and resistance to contamination.

A diverse selection of sources was a key prerequisite for a qualitative analysis of the issue. This study was conducted based on the analysis and systematisation of data from regulatory documents (ISO standards) and reports from textile manufacturers (Nanotextiles market report overview, 2023). The secondary data for the study of this topic are scientific publications from open sources for the period 2010-2024, which contain the results of research on the use of nanotextiles in the world. A cross-comparative and chronological search was used to select scientific sources. For the analysis, it was selected articles that consider both commodity and economic aspects of nanotextiles, focusing on a review of scientific papers on determining the mechanisms for the formation of an improved set of consumer properties of nanotextiles, analysis of textile processing technologies (modification with nanoparticles of Ag, Se, ZnO, TiO_2, SiO_2, CuO and Fe_3O_4 to obtain antifungal properties on these textile materials, treatment with nanoemulsions, use of graphene and silver nanoparticles for the treatment of textile fibres), efficiency and usability of the resulting nanotextiles during operation.

Results and Discussion

As the analysis of Ukrainian and foreign literature shows, in the practice of foreign textile production, nanotechnology is primarily used to provide new (improved) specific properties to interior nanotextiles. In textile commodity science, nanotextiles are structured into six main groups, as shown in Figure 1.

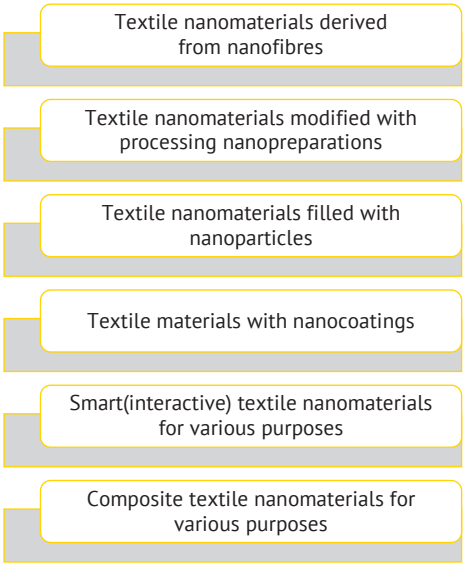

Figure 1. *Types of nanotextiles*
Source: *developed by the authors*

The most popular textile nanomaterials and products on the nanotextile market are: textile nanomaterials for various purposes (interior, medical, sports, military); nanowear for sports purposes; nanowear for military purposes; nanowear for medical purposes; nanotextiles for technical purposes. The leading countries in the production of nanotextiles for various purposes are: USA, Japan, China. The largest leading companies operating in the nanotextile market are: Nano Textile, Colmar, Shanghai Huzheng Nano Technology, eSpin Technologies, FTEnE, Parker Hannifin, Schoeller Technologies, Odegon Technologies, Aspen Aerogel (Research and market, 2024).

Based on the analysis of the achievements of modern nanotechnologies in the production of interior nanotextiles, a table was compiled with a list of new unique properties that interior textiles acquire when produced using the latest nanotechnologies (Table 1).

Table 1. *Interior nanotextiles with new properties obtained using nanotechnology*

No.	Interior textile group	Specific properties
1	Bed and table nanolinen	Biostability, hydrophilicity, dirt resistance, dirt repellency
2	Curtain and blind textile nanomaterials	Lightfastness of dyes, fire resistance, dirt repellency, ability to purify indoor air
3	Textile nanomaterials and products for floor and wall coverings	Biostability, fire resistance, hydrophobicity, oleophobicity self-cleaning ability, ability to purify indoor air
4	Furniture and decorative nanomaterials and products	Biostability, fire resistance, hydrophobicity, oleophobicity, self-cleaning ability

Source: *developed by the authors*

The table shows that the use of nanotechnologies for the production of different groups of interior textiles allows to obtain a fundamentally new range of interior textile nanomaterials and products with improved unique properties (dirt-repellent, fire-resistant, biostable, hydrophobic, oleophobic, self-protecting and indoor climate improvement). It is worth giving an example of the most promising types of nanomodifications used to obtain new (improved) properties on interior textile nanomaterials for various purposes. The main types of nanoparticles used in the textile industry in the production of interior nanotextiles and their properties are shown in Table 2.

Table 2. *Properties of nanoparticles used to modify interior textile materials*

No.	Properties	Nanoparticles
1	Antibacterial, antifungal properties	Ag, chitosan. SiO_2, TiO_2, ZnO, CuO Se, Fe_3O_4
2	Protective properties against ultraviolet radiation	TiO_2, ZnO
3	Self-cleaning, dirt and water repellency	Fluoroacrylate, SiO_2, TiO_2, carbon nanotubes
4	Water absorption	TiO_2
5	Fire resistance	Carbon nanotubes, nanoclay
6	Increase in strength	Al_2O_3, SiO_2, carbon nanotubes, ZnO, polybutylacrylate
7	Electrical conductivity, antistatic, remote heating	Fe, soot, carbon nanotubes, Cu, polypyrrole, polyaniline
8	Release of active substances, medicines or aromas	Nanoclay, SiO_2
9	Chemical, biological protective properties, self-sterilising function	TiO_2, MgO
10	Antiviral properties	Graphene and silver composite
11	Ability to purify the air	TiO_2

Source: *developed by the authors based on L. Almeida & D. Ramos (2017), K.S. Lyubka et al. (2019), O.N. Aguda & A. Lateef (2022)*

Nanoparticles of various substances in the form of nanoemulsions and nanodispersions are used in the final processing of interior textile materials. The data in Table 1 and Table 2 show that the introduction of nanotechnology into textile production allows for the creation of new and improvement of existing types of textile nanomaterials and products for interiors. Innovative nanotextiles for interiors contribute to a significant increase in human comfort and provide effective protection against various negative impacts (atmospheric, mechanical, biological).

It is worth focusing on a more detailed consideration of the range of interior nanotextiles in foreign textile production practice, while determining the possibility of using foreign experience in the practice of the Ukrainian textile industry. It is worth emphasising

that nanotechnology is increasingly being used to protect interior nanotextiles (especially cellulose and keratin-based materials) from the effects of harmful pathogenic and fibre-destroying microorganisms. Since microbiological degradation is a significant factor in the wear and tear of interior textiles, it is important to note that the problem of effective protection of various types of interior nanotextiles using nanotechnology is not yet well understood and scientifically substantiated.

It should also be emphasised that in the practice of Ukrainian finishing textile production, a limited range of biocidal nanopreparations of selective action, nanoemulsions, nanodispersions is used for antimicrobial treatment of interior textiles of various purposes, which suppress the development of the most harmful types of microorganisms for human health and environmental pollution. In this regard, there is a need to study the interaction of interior nanomaterials with certain types of harmful microorganisms, especially on those types of interior textiles that are most vulnerable to their impact.

Analysis of the work of L. Almeida & D. Ramos (2017) shows that it is necessary to pay attention to the use of nanopreparations to provide interior nanotextiles for various purposes with polyfunctional properties (several beneficial effects) – appropriate biostability, hydrophobicity, oleophobicity, self-cleaning from contaminants. It is reasonable and justified to use biocidal dyes for this purpose, which provide textile materials and interior products with the simultaneous effect of antimicrobial resistance and colouring of these materials.

Scientists I.S. Halyk & V.D. Semak (2014) substantiated the feasibility of using nanotechnologies in the colouring of eco-textiles for various purposes and in the final processing of clothing and interior textile materials. First of all, this concerns the use of nanotechnology to significantly increase the weather resistance and biostability of textile materials for various purposes, fibre composition and structure.

In her work, H.O. Pushkar (2013) studied the problem of developing a new promising environmentally friendly range of interior textile materials in order to improve their consumer properties by using modern types of environmentally friendly raw materials, various types of natural (vegetable) and synthetic dyes, as well as promising types of dirt-repellent and fire-retardant treatments for the main processing. Based on the results of theoretical and experimental studies, practical recommendations have been developed for the targeted creation of a new environmentally friendly range of interior textiles with specified consumer properties.

The possibility of introducing modern innovative nanotechnologies into the research and practice of production of goods in the light industry of Ukraine was determined by T.V. Kutsenko (2017). The author also described the characteristics of the range of textile nanomaterials for various purposes with protective functions. The questions presented in Figure 2 require a comprehensive commodity research in this regard.

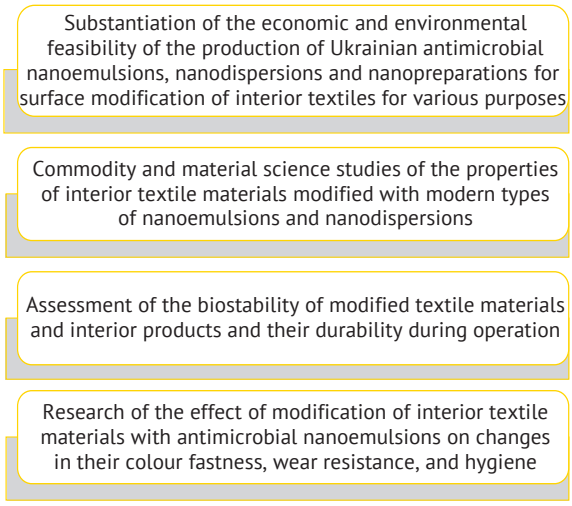

Figure 2. *Directions of interior textile materials research*
Source: *developed by the authors*

It is worth mentioning that it is appropriate and justified to use the latest nanotechnologies to make interior textile materials and products fire-resistant and less prone to ignition. This primarily applies to interior textiles for curtains and draperies, floor and wall coverings, as well as textile materials for furniture upholstery and wall drapery. V.A. Barbur & A. Heintz (2019) state that the following can be used for this purpose: low-flammability nanofibres, yarns and films of various chemical structures; various flame retardant nanoemulsions, nanodispersions and various nanopreparations.

Nanocoatings using nanoclay and carbon nanotubes are widely used to provide interior textiles with fire-resistant properties. The most promising brands of flame retardant nanopreparations that provide interior products with a given fire resistance are described in A.K.R. Chowdhury (2020). The book discusses the fundamentals of fire resistance and flammability of textile materials of different fibre composition and explores different types of flame retardants, including natural flame retardants, halogen, phosphorus and nanotechnology-based flame retardants. The research is aimed at developing fire-resistant and safe textile materials for a wide variety of uses, including clothing, protective clothing, floor coverings, upholstery, drapery.

It is worth mentioning that interior nanotextiles play an important role in improving the microclimate in residential, administrative and public spaces. This applies to chemical, biological, mechanical and other types of indoor microclimate pollution, which should be minimised and cleaned by decorating these premises with different types of interior nanotextiles. In particular, the study by H.O. Pushkar (2013) found that nanoemulsions, nanodispersions and nanopreparations

used to modify interior textile materials and products should be able to neutralise microclimate pollution in these rooms and purify their air.

According to foreign experience, nanoscale TiO_2 particles are used to treat interior textile materials (cotton, polyester, polyamide, viscose and their mixtures). This treatment has been developed and studied by Archroma material scientists for interior textile nanomaterials and products made from them (curtains, textile wall and floor coverings, upholstery and covers for home furniture) (Archroma..., 2022). Studies have shown that colouring based on nanoscale TiO_2 particles is activated by daylight or artificial light and thus provides air microclimate purification in residential and public spaces.

It is worth mentioning that in 2024, nanotechnology will be widely used to provide interior textile materials and products with higher and more durable effects of hydro- and oleophobicity, dirt repellency and self-cleaning. According to the analysis of literature sources, it is in this area that nanotechnology in textile production has the greatest success. In their research, M.A. Shah *et al.* (2022) comprehensively consider the use of nanomaterials in the textile industry: the economic efficiency of their use, improving the functional properties of textiles, the comfort of products, and the issue of potential nanotoxicity of textiles, taking into account the leaching of nanomaterials into the environment. Ukrainian scientists I.S. Halyk & V.D. Semak (2014) found in their research that it is due to nanotechnology that traditional interior materials can acquire such properties as water and oil resistance, reduced flammability, resistance to pollution, softness, antistatic and antibacterial characteristics, heat resistance and the ability to retain their shape. One of the best-known nanotechnologies for finishing is Teflon, which provides materials with water-, oil- and dirt-repellent properties. For this purpose, nanoemulsions of fluorocarbon polymers are used. Interior textile nanomaterials and products with such nanocoatings are resistant to repeated washing, have high form stability and excellent aesthetic appearance, which is confirmed by the studies of K.S. Lyubka *et al.* (2019) and H.O. Pushkar *et al.* (2020). Md. Syduzzaman *et al.* (2023) also studied superhydrophobic textile materials with self-cleaning ability, in particular, their work presents the results of studies of textiles on the surface of which silica is applied with subsequent hydrophobic modification of polydimethylsiloxane. The researchers found that this treatment significantly improves wear resistance, water repellency and self-cleaning properties of the material.

The influence of nanoparticles on the antimicrobial properties of textiles is widely studied in textile materials science. In particular, O.N. Aguda & A. Lateef (2022) in their work studied in detail and thoroughly the role of nanoparticles in the functionalisation of textiles as agents to combat microorganisms, analysed scientific reports on their antiviral, antifungal and antibacterial effects. The authors also discussed the problems and prospects of nanotextiles for biomedical applications.

The work of V.A. Barbur & A. Heintz (2019) noted that the American company Battelle has developed coated textiles with conductive properties using carbon nanotubes (CNT-Carbon Nanotubes), which eliminates many of the problems associated with metal yarns or embedded wire systems in textile material. Such a textile nanocoating has high electrical conductivity, flexibility, lightness and can be applied to the textile material in a thin layer, which contributes to the high drape properties and performance characteristics of the textile nanomaterial itself. The resulting nanocoated textiles (CNTs) are used in the production of furniture and household goods. Heated textile materials can be used in mattress covers, for upholstery of sofas and armchairs, in the production of blankets and pillows and other interior textile products. With these textile nanomaterials, furniture can be heated, allowing people to feel comfortable at low room temperatures while reducing overall energy costs. Battelle has also developed nanofabrics with sensors. The sensors embedded in the fabrics can be used to detect and assess humidity levels, and can also measure movement, weight, orientation, light levels, or vital signs of human health. The information received from the sensors can be transmitted to the point of use via a conductive coating. This technology thus opens up a range of potential intelligent applications in the production of nanotextile floor and wall coverings, most notably carpets that can glow in the dark to show the way to emergency exits or bathrooms, or wall coverings for bathrooms and laundry rooms where there is excessive humidity. T. Ali *et al.* (2023) noted that nanotextiles are very popular as of 2023 because they are multifunctional, offer UV blocking, are flame retardant, have antimicrobial properties, and are capable of tissue regeneration without compromising comfort.

Ukrainian scientists O.V. Pakholiuk *et al.* (2021) studied the effect of colour fastness of cellulose-containing fabrics that can be used as interior textiles on repeated washing. The study established the influence of cold and classical dyeing technologies using different types of active dyes at different concentrations in the dye. The authors of O.V. Pakholiuk *et al.* (2020) noted that it is important to create a separate segment of the nanotextile and clothing market for different purposes.

According to the analysis of the state of the foreign interior nanotextile market, in particular, the results of research by M.A. Shah *et al.* (2022) and the official Nanotextiles market report overview (2023), the world practice has already outlined the areas of use of interior nanotextiles and nanomaterials for their manufacture. In particular, this applies to such types of interior nanotextiles as furniture and decorative materials and products made of them, carpet floor coverings, curtain and drapery textile materials and products, as well as bed and table linen. C. Som *et al.* (2011) noted that

engineered nanomaterials can open the way to the use of textile products in construction, medicine, automotive, environmental and safety technologies. S. Mura *et al.* (2015) demonstrated the synthesis of silica nanoparticles without the use of toxic organic compounds.

However, given all the advantages of nanotextiles, scientists highlight the issue of environmental friendliness and safety of its use. In particular, M.A. Shah *et al.* (2022) critically assess the use of nanotextiles, pointing out the need for in-depth scientific research on the potential toxicity of leached nanomaterials from textiles. D. Brouwer (2010) found in his study that the share of atmospheric pollution by carbon compounds from textile and clothing production is about 10% of total emissions, and textile dyeing contributes to water pollution by 17-20%, the use of nanomaterials for dyeing contributes to the accumulation of nanomaterials in water bodies. Information on the range and properties of interior nanotextiles for various purposes presented in the literature remains incomplete.

It should be mentioned that the Ukrainian textile industry has not yet resolved a number of important issues related to the formation of the range, properties, quality level and environmental safety of various types of interior nanotextiles. The key problems include:

- incapability to determine the economic, environmental and technological feasibility of producing certain types of interior textiles in Ukraine and the need to import these goods;
- insufficient research on the impact of nanoparticles, nanotechnologies and interior nanomaterials on human health and the environment;
- lack of standards for interior nanotextiles, as well as norms, methods and criteria for assessing their quality;
- lack of information on potential research on the range and properties of interior nanotextiles, which makes it difficult to determine the main directions of such research;
- there is no information on the results of the commodity (including environmental) examination of the range and properties of interior nanotextiles for various purposes.

The outlined problems highlight a number of commodity and material science issues related to the production, formation of the range and properties of interior nanotextiles that require priority research. Most of the issues discussed in the article are of a staging nature and do not claim to be exhaustive.

Conclusions

Based on the analysis of literature data and the results of own research, the main directions of formation of the range and properties of interior nanotextiles for various purposes are substantiated. The areas of the most promising and effective application of interior nanotextiles for furniture and decoration, curtains and drapes, linen and floor covering purposes are substantiated. The article identified the strengths and weaknesses of different groups of interior nanotextiles in comparison with their traditional analogues.

The possibility of applying foreign experience for the production of interior nanotextiles at Ukrainian textile enterprises has been determined. At the same time, the priority should be given to those nanotechnologies that can provide interior nanotextiles with various multifunctional, unique properties. The necessity and expediency of expanding the range of Ukrainian-made nanopreparations to provide interior textile materials and products with a wide range of various useful properties to improve their environmental safety and quality was also substantiated. As a result of the study, it was determined that it is advisable to use nanopreparations for the treatment of interior textile materials and products to provide interior nanotextiles with properties that minimise or neutralise air pollution and contribute to the improvement of the microclimate in residential and public spaces. The study also found that the use of nanotechnology in textile production makes it possible to create new and improve existing types of textile nanomaterials and products for interiors. Innovative nanotextiles for interiors increase human comfort and provide effective protection against various negative impacts, such as atmospheric, mechanical and biological factors.

The issues raised should be covered and professionally interpreted in new generation textbooks on textile nanomaterials and nanomaterials science, the publication of which is currently particularly necessary and relevant. In the periodicals of the relevant specialised universities, it is necessary to create separate thematic sections for professional coverage of issues related to the formation of the range, properties, quality and safety of nanotextiles for various purposes. Prospects for further research are consideration and discussion of these problems at regional inter-university scientific and practical conferences, as they are relevant and need to be addressed quickly in the Ukrainian textile industry and trade.

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Conflict of Interest

None.

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Товарознавчі аспекти формування сучасного асортименту інтер'єрного нанотекстилю

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Анотація. Застосування сучасних нанотехнологій у виготовленні текстильних матеріалів для інтер'єру дозволяє розширити та урізноманітнити асортимент продукції, надати абсолютно нові функціональні властивості, а також отримати на цих матеріалах та виробах унікальні корисні ефекти: естетичні, антимікробні, брудовідштовхувальні, лікувальні, і разом з тим задовольнити конкретні потреби споживачів. Метою статті було дослідити та обґрунтувати основні напрямки формування сучасного асортименту та властивостей інтер'єрного нанотекстилю різного цільового призначення. У дослідженні було використано статистичний, аналітичний методи, метод системного аналізу. Аналіз літературних джерел показав, що за 2010-2024 роки, українськими та зарубіжними науковцями детально досліджувалася економічна і технологічна доцільність широкого використання текстильних нанотехнологій для розширення та оптимізації асортименту нанотекстилю, включаючи інтер'єрного призначення. Керуючись цим підходом, в статті наведено аналіз літературних джерел за останні 2019-2024 роки, в яких було розглянуто основні напрямки розвитку та досягнень нанотехнологій в текстильному виробництві для розширення асортименту і властивостей нанотекстилю інтер'єрного призначення в Україні та світі. На цій основі було сформульовано та обґрунтовано теоретичні положення подальшого розвитку нанотехнологій і ринку нанотекстилю інтер'єрного призначення. Визначено перспективні напрямки використання інтер'єрного нанотекстилю для портьєр, штор, білизни, меблів, декору та покриттів для підлоги. Виявлено переваги і недоліки цих видів нанотекстилю порівняно з традиційними матеріалами. Обґрунтовано необхідність та доцільність розширення виробництва різних наноемульсій, нанодисперсій та нанопрепаратів в Україні, щоб надати текстильним виробам для інтер'єрів корисні властивості, підвищивши їх якість та екологічну безпечність. Акцентовано основну увагу на наданні текстильним інтер'єрним наноматеріалам і виробам поліфункціональних унікальних властивостей. На практиці, проведені дослідження можуть слугувати у виборі пріоритетних напрямків досліджень у виготовлені інтер'єрного нанотекстилю різного цільового призначення

Ключові слова: нанотехнології; інтер'єр; нанооброблення; нанопрепарати; споживні властивості; екологічна безпечність; гігієнічність

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Technical regulation of hygienic properties of infant clothing

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Abstract. Hygienic properties for children's clothing are a significant factor in quality and safety and require careful study and control. However, the technical regulation of safety and hygiene standards for children's clothing remains a significant challenge in the global market. The mechanism for ensuring the safety of children's clothing requires new solutions from governments. Key aspects of protecting children's health in clothing manufacturing include controlling the quality of raw materials, monitoring production processes, and regulating the use of chemical bleaches and dyes. The aim of this work was to examine the hygienic properties of infant clothing entering the Ukrainian market. The assessment of hygienic authorities was carried out using standard methods, including atomic absorption and chromatographic methods. Odorimetric studies revealed that the sample of the "Sova Kids" body suit does not meet the regulatory standards for odour intensity. The results of the study on hygienic properties showed that all samples meet the established requirements, but the "Sova Kids" body suit exhibited the best hygroscopicity. Chemical analysis for heavy metals revealed that in Sample No. 2, the "SMIL" body suit, the copper content exceeds both international and Ukrainian standards by 0.6 μg/kg. A very high concentration of dichlorodiphenyl trichloromethylmethane (DDT) was found in all three samples of infant clothing. These values are 12 to 17 times higher than the established Ukrainian and international standards (permissible limit: up to 0.5 μg/kg). Meanwhile, Sample No. 3 does not include any labeling data or manufacturer information. The results of this study hold practical significance for retail chains selling infant clothing and can be utilised by wholesale and retail entrepreneurs, as well as clothing manufacturers. They also serve as a basis for regulatory authorities, especially certification bodies, to implement stricter measures"

Keywords: environmental safety; heavy metals; pesticides; assessment of substance content; hygroscopicity

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Introduction

Infants and toddlers represent a unique group of textile users. The distinct nature of this group lies in the fact that the requirements for their clothing are not determined by the consumers themselves, but by adults – such as parents or nannies – who observe the children's reactions to clothing and personal hygiene items. Long-term experience shows that the most suitable fabrics for children's underwear and clothing are those made from cellulose-based fibers. Globally, there is also a growing trend towards using fabrics and knitwear that contain linen and cotton fibers.

Focusing on these issues is linked to the frequent use of chemical, especially synthetic, fibers and threads in the production of fabrics for children's clothing and personal hygiene products. Some manufacturers prioritise commercial interests over children's needs and hygiene standards. Therefore, ensuring the quality of children's products is a pressing issue that requires a systematic solution. The safety of clothing, particularly in terms of hygienic and environmental properties, is an ongoing global concern being studied by scientists not only in Ukraine but around the world. For instance, V. Afanasyeva & Z. Karpenko (2020) dedicated her research to addressing the regulatory and technical challenges surrounding children's clothing.

In a study by O.V. Domanova (2019), the issues of labeling Ukrainian-made children's clothing were examined. Similarly, O. Zavorotna & L. Halavska (2022) conducted experimental research on the consumer properties of children's clothing in her works. P. Dewangan & R. Kumar (2023) also focused his scientific research on the standarts for children's clothing. They underscore the critical importance of safety regulations for children's wear in India, given the anticipated growth in the market. Despite the absence of specific regulations, the study reveals the potential risks associated with children's clothing, emphasising the need for comprehensive safety standards. D. Sanjeevana & R. Thenmozhi (2022) explored methods to improve the wear resistance and hygiene of children's clothing by using fabrics with enhanced functional properties. The work D. Santiago *et al.* (2024) studied the dependence of the functional properties of children's clothing on the composition of the fabric. In review article F. Burks *et al.* (2021), the potential negative effects of improper textiles for children's wear, fabric dyestuffs, and common textile wet processing were covered. Y. Sorumlu *et al.* (2022) dedicated their work to the issues of safe use of fittings for children's clothing

In 2013, State sanitary standards and regulations (2012) came into force in Ukraine, based on research conducted at the L.I. Medved Institute of Ecohygiene and Toxicology, the Research Institute of Transport Medicine, and various regional sanitary and epidemiological stations as part of the harmonisation of Ukrainian standards with those of the International Association for Research and Testing in the Field of Textile and Leather Ecology (Oeko-Tex Standard 100, 1992). Children's clothing must not cause skin irritation, allergic reactions, or long-term harmful effects (such as carcinogenic, mutagenic, or teratogenic activity), nor should it disrupt the skin's natural flora. In other words, textile materials and products must be safe for health, comfortable, and accompanied by a positive conclusion from the state sanitary and epidemiological inspection. This is particularly important due to children's heightened sensitivity to external factors caused by the dynamic conditions in which children's products are used. The hygienic and safety standards for children's clothing must meet the highest requirements and be recognised by all sectors (production, distribution, and ecology) as the first level of structural approach, especially with Ukraine integrating into the European Union.

The aim of study was to analyse the hygienic properties of children's clothing to ensure they meet modern safety standards.

Materials and Methods

An analysis of the children's clothing market in Ukraine identified key trends and growth prospects in individual segments, revealing that the market has been steadily expanding since 2018, despite the accerelated cyclicity of economic crises. For the study of hygienic properties of children's clothing sold in Odesa, three retail chains were selected: "Antoshka" ("Betis"), "SMIL", and "Sova Kids" (the latter representing a more affordable option). The characteristics of the research samples are summarised in Table 1 and presented as follows: Sample No. 1: TM "Betis"; Sample No. 2: TM "SMIL"; Sample No. 3: TM "Sova Kids".

Table 1. *Research objects*

Sample number	Product name	Regulatory document	Producer	Sample image
1	Bodysuit "Princess" TM "Betis"	DSTU GOST 31407:2014 (2014)	TM "Betis" 57500, Mykolaiv region, Ochakov, Ukraine	

Table 1. Continued

2	Red bodysuit TM "SMIL"	DSTU GOST 31410:2014	UNL LLC "Baltskaya Road 5", Odessa, Ukraine	
3	Bodysuit TM "Sova Kids"	Not indicated	Not indicated	

Source: *developed by the authors*

Experimental studies were conducted using standard methods. The mass fraction of fibers was determined in accordance with DSTU 4057-2001 (2001), while the combustion characteristic was assessed using the combustion method. Hygroscopicity was determined according to DSTU GOST 3816:2009 (ISO 811) (2009), each elementary fabric sample, measuring 50x200 mm, was placed in a separate cup for weighing and then transferred to a desiccator with an air humidity of 97-99%. After 4 hours, the samples were weighed, dried at a temperature of 105-109°C, and weighed again. Hygroscopicity (*H*), expressed as a percentage, was determined using the following formula:

$$H = \frac{(mh-md)}{md} * 100, \quad (1)$$

where m_h – mass of the hydrated aliquot, g; m_d – mass of the aliquot after drying to the constant mass, g.

Fabric water absorption is defined by the amount of water that the fabric can absorb within a specified time period. Water absorption (Wa) is calculated by the formula, %:

$$W_a = \frac{g_{ad}-g_h}{g_{ad}} \times 100, \quad (2)$$

where W_a – water absorption; g_{ad} – mass of the air-dried fabric; g_h – mass of the hydrated fabric.

To determine water absorption, a fabric sample measuring 4x4 cm is submerged in a vessel with distilled water for 10 minutes. The samples are then removed and pressed for 30 seconds. For this, the wet fabric is placed between three sheets of filter paper, covered with three additional sheets, and a load of 10 g/cm² is applied. Odorimetric studies include:

- assessment of the external condition of the products (packaging integrity, product aesthetics, compliance with intended use and age group);
- evaluation of the quality and intensity of the odour.

The determination of the quality and intensity of product odour is conducted with the involvement of volunteers (at least 6), all of whom must have no impairments in their olfactory organs or nasal cavity. The study is performed in a well-lit, well-ventilated room. When evaluating odour quality, attention is given to the presence or absence of any foreign, unpleasant, or unusual smells for the product in question. The intensity of the odour is assessed using a five-point scale (Wright, 1966) as shown in Table 2.

Table 2. *Odour intensity of textile, leather, and fur materials*

Quantitative assessment in points	Characteristics
0	Absent; not detected by any of the volunteers
1	Barely noticeable; detectable only by the most sensitive individuals
2	Weak; noticeable and can be identified if volunteers specifically focus on detecting it
3	Expressive; easily perceptible, even without specific attention from volunteers
4	Strong; readily attracts attention
5	Unbearable; makes prolonged indoor presence intolerable
The intensity of odour in textile, leather, and fur materials and products for children should not exceed 1 point, while for adults, it should not exceed 2 points	

Source: *based on State sanitary standards and regulations (2012)*

To determine the content of heavy metals in textile materials, a comparison solution containing known quantities of elements was prepared in 100 cm³ volumes. This was analysed in accordance with DSTU GOST 22001:2008 (2008) using a ZEEN-IT 650p atomic absorption spectrometer (Germany). Both the comparison solutions and the test samples are introduced into the atomiser of the spectrometer, and the analytical signal values are recorded. The total metal content (μg/g) is then calculated using the following formula:

$$X = \frac{C1*V1}{m1*1000}, \quad (3)$$

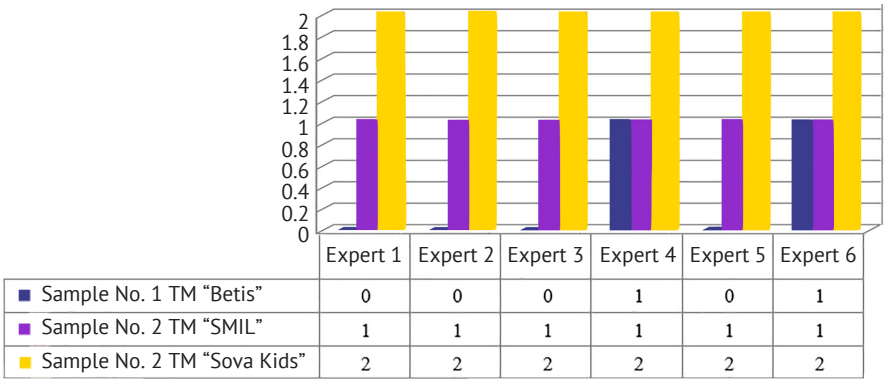
where, *C1* – mass concentration of the element being analysed in the solution, μg/cm³; V_1 – solution volume, cm³; m_1 – mass of the aliquot, g.

Pesticide content was determined using chromatographic methods. For the analysis of pesticides in textile materials, an electron capture detector was employed, with a temperature ramp rate of 1.2°C/min.

Results and Discussion

In the manufacture of clothing for newborns, cotton fabrics such as calico, flannel, and bombazine are commonly used. These fabrics are known for their diverse weaving structures, processing types, appearances, and properties. They offer high hygienic standards, durability, softness, and a pleasant feel, alongside an attractive appearance. Chemical analysis revealed that all three samples are made of 100% natural cotton. Additionally, Sample No. 3 contained a small amount of wool, with a fiber composition of 80% cotton and 20% wool.

Among the hygienic indicators, the odour of the product is also significant. The results for odour intensity are presented in Figure 1 and are normalised according to State Sanitary Rules and Regulations (based on the 5-point scale established by R.H. Wright (1966)).



	Expert 1	Expert 2	Expert 3	Expert 4	Expert 5	Expert 6
Sample No. 1 TM "Betis"	0	0	0	1	0	1
Sample No. 2 TM "SMIL"	1	1	1	1	1	1
Sample No. 2 TM "Sova Kids"	2	2	2	2	2	2

Figure 1. *Assessment of odour intensity (point)*

Source: *developed by the authors*

According to the results of the odour intensity assessment, it was found that the sample with the least noticeable odour was Sample No. 1 (TM "Betis"), with an average score of 0.33. Sample No. 2 (TM "SMIL") ranked second, with an average score of 1. However, Sample No. 3 exceeded the permissible odour intensity, receiving a score of 2 from all experts. This violates the State sanitary standards and regulations (2012), which stipulate that odour intensity should not exceed 1 point.

For the manufacture of clothing for infants, it is necessary to select the material based not only on the indicators given in the regulatory documentation, but also to take into account the specifics of age-related use. Since not all standardised indicators of the current legislation reflect the operating conditions, it was advisable to determine the ability of materials to absorb water for this product range. Hygroscopicity of knitted fabrics is characterised by its ability to adsorb and desorb hygroscopic and capillary moisture when environmental conditions change. This indicator is of great importance for the clothing of infants. It is also known that the indicators of hygroscopicity and water absorption depend on the fibrous composition of the product, the structure of knitwear and the operating conditions of the product. The results of determining hygroscopicity and water absorption are clearly shown in Figure 2.

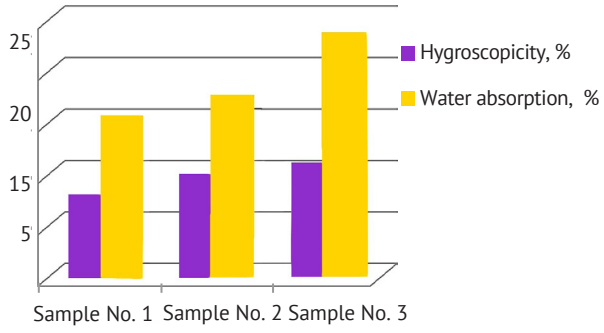


Figure 2. *Assessment of the quality of children's clothing by hygiene indicators*

Source: *developed by the authors*

Based on the results of evaluating clothing for "hygroscopicity" and "water absorption", Sample No. 3 demonstrated the best hygroscopicity. This can be attributed to the high surface density of the knitted fabric and the presence of wool fibers in its composition, which have higher hygroscopic properties compared to fabrics made solely from cotton. Ecological indicators of children's clothing also depend on the type and quantity of insecticides and fungicides used in agriculture, as only natural raw materials are intended for the production of children's fabrics. Special attention must be given to the content of heavy metals, which can enter textile materials through the use of dyes and vary depending on technological processes. The most hazardous heavy metals include cadmium, bismuth, cobalt, manganese, copper, zinc, nickel, tin, mercury, and lead. High concentrations of these metals can significantly impact the health of children, particularly infants, causing various biological effects such as allergens and skin irritants, with varying durations and detection times. Therefore, determining the presence or absence of heavy metals in fabric compositions is crucial. Tests were conducted at the Odessa branch of the Institute of Biology of the Southern Seas, National Academy of Sciences of Ukraine. The results of the heavy metal content analysis are presented in Table 3.

Table 3. *Heavy metal content in baby clothing*

Samples	Content of metals detected, µg/kg							
	Co cobalt	Cr chromium	Cu copper	Ni nickel	Pb lead	Cd cadmium	As arsenic	Hg mercury
DSTU requirements	2.0	1.0	5.0	1.0	0.2	0.1	0.2	0.02
OEKO-Tex requirements	1.0	1.0	5.0	1.0	0.2	0.1	0.2	0.02
Sample No. 1	< 0.05	0.521	< 0.1	< 0.1	< 0.05	< 0.05	< 0.05	< 0.010
Sample No. 2	< 0.05	0.400	5.6	< 0.1	< 0.05	< 0.05	< 0.05	< 0.010
Sample No. 3	< 0.05	0.310	0.4	< 0.1	< 0.05	< 0.05	< 0.05	< 0.010

Source: *developed by the authors*

Data from Table 3 show that all elements detected in the knitwear composition are within permissible limits, except for copper. In Sample No. 2, the copper content exceeds both international and Ukrainian standards by 0.6 µg/kg. This elevated level may be attributed to the use of copper-based dyes, as Sample No. 2 features a bright red colour, in contrast to the less coloured Sample No. 1 and Sample No. 3. Sample No. 1, being a bleached canvas, shows the lowest copper content but the highest chlorine content (0.521 µg/kg). This higher chlorine level is likely due to the use of hypochlorite solutions in the bleaching process; however, the chlorine content remains within acceptable limits. Sample No. 3, which is not bleached and contains minimal dye, visually exhibits the least amount of both chlorine and copper, as reflected in its product design. It is well-known that to prevent microorganisms, moths, and rodents, fungicides and insecticides are frequently applied to raw materials and products with natural origins during storage and transportation. Additionally, in traditional land cultivation, insecticides and fertilisers are used to enhance yield. Approximately 10% of all pesticides used globally are associated with cotton cultivation, and residues of these pesticides remain in the fabric after processing. Pesticides can be a source of skin diseases and allergic reactions, particularly for infants whose skin is highly sensitive to external stimuli. Table 4 presents the results of the analysis of pesticide content in the fabrics.

Table 4. *Pesticide content in children's clothing*

Indicator name	OEKO-Tex -100	DSTU 4239:2003	Sample No. 1	Sample No. 2	Sample No. 3
DDT	up to 0.5	up to 0.5	12.67	12.76	16.94
DDE	up to 0.5	up to 0.5	0.00	0.00	0.00
DDD	up to 0.5	up to 0.5	0.00	0.00	0.00
Aldrin	up to 0.1	up to 0.1	0.00	0.00	0.00
Lindane	up to 0.5	up to 0.5	3.44	2.21	0.63
Heptachlor	up to 0.25	up to 0.25	0.00	0.00	0.00
Dieldrin	up to 0.1	up to 0.1	0.00	0.00	0.00

Source: *developed by the authors*

Studies on the composition of knitwear revealed very high concentrations of DDT (dichlorodiphenyltrichloroethane) in all three samples. Notably, Sample No. 2, which is marketed as eco-friendly and bears eco-labeling and safety certificates, showed a particularly high concentration of DDT. Specifically, the DDT content in Sample No. 1 from TM "Betis" was 12.67 μg/kg, while in Sample No. 2 from TM "SMIL" it was 12.76 μg/kg – both of which are approximately 12 times higher than the established norms. Sample No. 3 from TM "Sova Kids" had a DDT content of 16.94 μg/kg, exceeding both Ukrainian and international requirements by 16 times, with the permissible amount being up to 0.5 μg/kg. Additionally, non-compliance with regulatory requirements was observed for lindane content in all three samples, which also exceeded permissible norms: 3.44 μg/kg, 2.21 μg/kg, and 0.63 μg/kg, respectively, against the permissible limit of no more than 0.5 μg/kg.

Similar studies are presented in the work of M. Zhaldak *et al.* (2023), which analysed the database of current regulatory documents governing the quality and safety indicators of clothing for children and newborns. Clothing for newborns sold by the Epi-Center K retail chain (Ukraine) was examined, and it was determined that while the studied samples meet the safety requirements of regulatory documents, they do not comply with labeling standards. In the article by O. Zavorotna & L. Halavska (2022), modern knitwear materials used in the production of children's clothing are analysed. The study established a correlation between the material's component composition and the structural and technological design of children's garments. Modern decoration techniques and their safety are also discussed.

The authors L.Ye. Halavska & O.V. Gnatiuk (2019) focused on the influence of raw materials on the quality characteristics of children's clothing in their research. They propose eco-friendly linen as a material with superior hygienic properties. S. Mikhaylov & V. Mikhaylov (2010) studied the mass fraction of the components of synthetic detergents for children's clothing in textile materials after washing. M. Turdiyev & D. Yuldasheva (2021) conducted research on the effects of raw materials on the hygienic properties of children's clothing. Their experimental data showed that breathability and hygroscopicity are directly influenced by the fabric's quantitative composition, which in turn affects the thermal protection properties of the clothing. S. Sun *et al.* (2023) focused on eco-friendly clothing, referred to as "green design", in their study. The authors presented a comparative assessment of children's clothing made from traditional materials versus those of organic origin. Their experiments confirmed the absence of heavy metals and pesticides in the organic fabrics. Additionally, the study examined the environmental impact of clothing after disposal. C. Gomes *et al.* (2024) noted that the textile industry is one of the sectors with the greatest impact on the environment.

The researcher H. Chen *et al.* (2022) studied the concentration of heavy metals in children's clothing produced in four Asian regions. The research revealed particularly high levels of nickel and chromium, especially in products from Chinese manufacturers. The study also evaluated the exposure doses of heavy metals on infants' skin. M. Rahman *et al.* (2019) also highlighted the presence of heavy metals in fabric compositions, particularly in children's clothing. As an alternative, they proposed the use of a cationic fixative, which reduces the toxicity of clothing by eliminating electrolytes. The researchers also advocated for reducing wastewater production. Fundamental research conducted by P. Nyamukamba *et al.* (2020) revealed that the quality and safety of children's clothing in South African regions do not meet regulatory standards. The study found toxic substances in most samples (27 out of 34), particularly high concentrations of formaldehyde and elevated levels of all regulated heavy metals, except arsenic.

The authors J. Rovira & J.L. Domingo (2019) focused their research on identifying harmful chemicals in materials used for manufacturing children's clothing, and experimentally demonstrated the toxic-allergic effects of these components. High levels of flame retardants, quinoline, formaldehyde, and benzothiazoles were detected. Similar studies were conducted by M. Herrero *et al.* (2023), where 120 samples of children's clothing (for ages under 3) and maternity clothing were tested in Spain. The authors investigated the potential dermal health effects on children. During the research, high concentrations of heavy metals, including aluminum, zinc, and titanium, were detected.

Conclusions

The evaluation of the labeling on children's clothing for infants available on the Ukrainian market revealed several issues. Specifically, Sample No. 3 from TM "Sova Kids" lacks essential marking information. This sample only displays the trademark and does not provide mandatory details such as the manufacturer's name, country of origin, or component composition. Furthermore, based on odorimetric analysis, this sample also fails to meet the requirements outlined in State Sanitary Rules and Regulations. According to the results of the water absorption and hygroscopicity tests, all samples met the established requirements. However, Sample No. 3 from TM "Sova Kids" exhibited the highest hygroscopicity. This is attributed to the presence of up to 20% wool fibers in its composition, which contributes to its superior moisture-absorbing properties.

According to the results of the safety studies, it was found that all three samples did not meet the established Ukrainian and international standards for pesticide content. However, the levels of heavy metals in the

infant clothing samples were within the permissible limits. In summary, there is a pressing issue concerning the control of dangerous and low-quality infant clothing entering the Ukrainian market. Notably, the presence of eco-labeling and hygiene reports on clothing does not align with the high concentrations of pesticides detected. This research underscores the critical need to examine the hygienic properties of infant clothing more rigorously and highlights the necessity for constructive actions by state and regulatory authorities.

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None.

Conflict of Interest

None.

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Технічне регулювання гігієнічних властивостей дитячого одягу

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Анотація. Гігієнічні властивості дитячого одягу є важливим фактором якості та безпечності і потребують ретельного вивчення та контролю. Однак технічне регулювання стандартів безпеки та гігієни дитячого одягу залишається значним викликом на світовому ринку. Механізм забезпечення безпечності дитячого одягу вимагає від урядів нових рішень. Ключовими аспектами захисту здоров'я дітей при виробництві одягу є контроль якості сировини, моніторинг виробничих процесів та регулювання використання хімічних відбілювачів і барвників. Метою цієї роботи було дослідити гігієнічні властивості дитячого одягу, що надходить на український ринок. Оцінка гігієнічних показників проводилася за допомогою стандартних методів, включаючи атомно-абсорбційний та хроматографічний методи. Одориметричні дослідження показали, що зразок боді «Sova Kids» не відповідає нормативним показникам за інтенсивністю запаху. Результати дослідження гігієнічних властивостей показали, що всі зразки відповідають встановленим вимогам, але найкращу гігроскопічність продемонстрував боді «Sova Kids». Хімічний аналіз на вміст важких металів показав, що у зразку № 2, боді «SMIL», вміст міді перевищує як міжнародні, так і українські стандарти на 0,6 мкг/кг. У всіх трьох зразках дитячого одягу було виявлено дуже високу концентрацію дихлордифенілтрихлорметилметану (ДДТ). Ці показники в 12-17 разів перевищують встановлені українські та міжнародні норми (допустима межа – до 0,5 мкг/кг). При цьому зразок № 3 не містить жодних маркувальних даних або інформації про виробника. Результати дослідження мають практичне значення для торговельних мереж, що реалізують дитячий одяг, і можуть бути використані підприємцями оптової та роздрібної торгівлі, а також виробниками одягу. Вони також слугують основою для регуляторних органів, особливо органів сертифікації, для впровадження більш суворих заходів

Ключові слова: екологічна безпека; важкі метали; пестициди; оцінка вмісту речовин; гігроскопічність

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Abrasion resistance of titanium-based biofunctionalised oxide ceramic coatings

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Abstract. The requirements of modern production for details are very high. Particular attention is paid to the friction resistance parts that work in the friction mechanism. Titanium alloys are characterised by low wear resistance and have the ability to stick to the surface of the body of greater hardness. Therefore, applying wear-resistant coatings to the surface of titanium alloys is relevant. The purpose of this work was to increase the operational properties of titanium alloys by creating protective coatings on their surface. The work investigated the wear resistance of plasma electrolyte oxidised coatings on titanium alloy. Experimental studies revealed that the coatings have different oxides (stoichiometric and non-stoichiometric) in their structure. Non-stoichiometric oxides are characterised by low physical and mechanical properties and settle in the pores after primary wear. In the process of wear, a non-stoichiometric oxide serves as a lubricant. This has a positive effect on their tribological properties. It has been established that applying a coating to the surface of a titanium alloy increases the abrasion resistance by 10 times. The interface between the metal base and the coating is uneven, which is achieved due to the melting of the surface of the titanium alloy during PEO. This feature demonstrates the high adhesion properties of coatings formed by the PEO method to the titanium base. The paper established the dependence of the size and shape of the pores on the working modes. It was found that the size of the pores on the surface of the coating is 10...70 μm, and high internal porosity of the coating material was established. It was found that porous coatings melt internally, so the porosity is open, not through. The studied property of the coatings can help in implantology, since the connection of muscle tissue with the implant occurs without the formation of a capsule

Keywords: phosphates; friction; plasma electrolytic oxidation; durability; wear; porosity

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Introduction

Changing the surface composition is one of the most promising methods of increasing the resistance to surface activation and mechanical properties of light alloys. A. Kurup *et al.* (2021) explained in their work the acceleration of the osseointegration process of titanium alloys that have a coating with complex morphology. The authors investigated the coating by the plasma electrolytic oxidation method. The uniqueness of this method lies in the ability to change the properties of the surface by changing the working modes of the synthesis. Researchers K. Babaei *et al.* (2020) investigated the effect of carbon allotropes in the form of carbon nanotubes, graphite, diamond, and graphene in an electrolyte solution. Increased corrosion and wear resistance of coatings synthesised on the basis of aluminium has been established. G. Mortazavi *et al.* (2019) showed, how the value of the current affects the porosity of the coating. The authors indicated that a higher current makes it possible to obtain a coating with a higher amount of porosity and a higher roughness. This is achieved due to a large number of spark discharges that occur on the surface. This is achieved due to a large number of spark discharges that occur on the surface. High temperature leads to the formation of both stable rutile and metastable anatase. Increasing the current density makes it possible to obtain a coating with stable amorphous dense anatase. It was established that the thickness of the oxide ceramic coatings on the titanium alloy increases due to the increase in the current density.

The authors M. Riabchykov *et al.* (2023b) aimed to create a coating on a titanium alloy for biomedical purposes. Therefore, coating materials should be very porous. Researchers H. Fakhr Nabavi & M. Aliofkhazraei (2019) showed in their research that coatings with high porosity and roughness applied to titanium alloy by the PEO method make it biocompatible with the living organism. The authors achieve an increase in the biocompatibility of coatings by adjusting the phases of rutile and anatase in the coating material. M. Riabchykov *et al.* (2023a) in their work indicated the higher porosity of materials, when using nanocomponents that would be added to them. Therefore, adding nanoparticles of biocomponents to the alkaline electrolyte is completely justified.

The scientists P. Bocchetta *et al.* (2021) described the problems of using titanium alloys Ti-6Al-4V in implantology due to the presence of toxic components such as Al and V. It is known that after oxidation, layers with high porosity are formed on titanium alloys. With the PEO method can control the amount of titanium oxide phases and their modification. Yu. Yuferov & K. Borodyanskyi (2024) explained the importance of Ca/P content in PEO coatings. The introduction of Ca and P particles in the form of ammonium dihydrogen phosphate into the electrolyte was investigated. The morphology, chemical and phase composition of the coatings are characterised by high biocompatibility. Therefore, adding biocomponents to the coating can increase their biocompatibility. N. Imbirovych *et al.* (2023) found that the introduction of diatomite and hydroxyapatite into a ceramic coating on a titanium alloy makes it rougher. These properties have a positive effect on the excellent implantation and growth of the implant with muscle tissue.

In 2024, the field of implantology has developed greatly, but there are still some problems. In practice, it is very important, which implant system the doctor uses, as well as its design. N. Usmaniya *et al.* (2024) described in their work that with poor-quality processing of titanium alloy and an undeveloped design, its atoms migrate into the surrounding bone tissue, causing its fibrous degeneration (damage to bone tissue). Later, it became clear that in such cases, the implants are rejected quite quickly. This direction of research refers to the problem of increasing the biocompatibility of surfaces, therefore, innovative metal processing was applied, such as plasma electrolytic oxidation (PEO).

The purpose of this work was to develop biocompatible coatings by the method of plasma-electrolytic oxidation in alkaline silicate-phosphate electrolytes with the addition of hydroxyapatite and diatomite. As a result of adjusting the ratio of current density and concentration of electrolyte components, it will be possible to obtain coatings with high physical and mechanical properties and with a highly developed surface.

Materials and Methods

The process of plasma-electrolytic oxidation was carried out in the anode-cathode mode with different modes of operation. When the sample is oxidised, the voltage at the anode gradually changes. The time, when the first spark starts depends on the composition of the electrolyte and the current to be set.

As a result, a discharge occurs between the sample and the electrolyte, and hydrogen begins to be released at the anode. The breakdown of the primary film on the sample under study leads to the formation of discharge channels in which high-temperature plasma-electrolyte reactions occur. Titanium interacts with oxygen, forming gaseous and solid/liquid phases Ti, TiO, TiO_2. During plasma-chemical reactions in an alkaline medium (electrolyte), narrow channels with increased ionic conductivity are formed on certain areas of the sample surface. Such areas become foci of local damage to the alloy, namely the barrier oxide film that forms on the surface of the metal under natural conditions. A spark on the surface of a titanium alloy is shown in Figure 1. This result indicates a discontinuity of the semiconductor field.

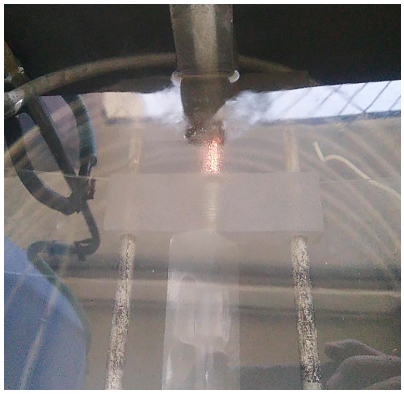


Figure 1. *Synthesis of an oxide ceramic coating in a spark discharge plasma on a titanium alloy sample*
Source: *developed by the authors*

Working electrolytes were solutions based on distilled water containing potassium hydroxide, calcium, liquid glass, sodium pyrophosphate and polyphosphate, diatomite and hydroxyapatite with a concentration of components from 3 to 20 g/l. The ratio of cathodic to anodic current density was for the first sample Ia/Ic = 1A/dm^2. The oxidation time was 30 min. The investigated effects of the composition of the electrolyte were recently changed according to the conditions of the experiment. After the synthesis, the samples were washed and dried.

Experiments on friction with a reversibly forward movement on titanium alloy samples were carried out at the installation. The principle of operation of the installation involved reversible friction of the sample by its reciprocating movement in relation to the counterbody. A flat sample is fixed on the slider of the crank mechanism. The sample was loaded of force from 0.2 to 1.5 kg through a vertical rod. The contact surface area of the sample was 0.8 cm^2. The counterbody material is alloy 2024 with an Al_2O_3 coating 150 thick and a microhardness of 1500 MPa, formed in an electrolytic plasma. The kind of friction was dry.

The surface after synthesis of plasma electrolytic oxidation coatings was observed using a Tagarno Prestige FHD Controller XPlus microscope (Denmark) connected to a computer. The magnification was more than 600 times, with high frame rate and high image resolution, with manual and autofocus magnification and with an automated zoom scale.

Results and Discussion

The coating formation process occurs within an electric field that supplies energy for plasma-chemical reactions on the working electrode. When the anode potential exceeds the Faraday zone, the dielectric or semiconductor film on the anode undergoes breakdown. This breakdown results from electron injection from the valence band into the conduction band. Within the breakdown channel, a significant temperature increase occurs, leading to electrolyte ionisation and plasma formation, where plasma-chemical reactions drive oxide synthesis.

Notably, the introduction of diatomite helps stabilise the synthesis process, as the voltage remains nearly constant due to the higher silicate content in the solution, which enhances electrolyte conductivity. Increased electrical conductivity in the electrolyte reduces the required synthesis voltage. Nevertheless, the voltage generated at the anode and the resulting current density are adequate to form craters surrounding the pores. These properties increase the biocompatibility of the coating (Imbirovych *et al.*, 2023).

Due to its non-toxic properties, excellent biocompatibility and strength properties, titanium alloys are suitable for use in implantology. L. Chen *et al.* (2018) investigated the wear of titanium alloys and explained their limitations in friction units, as they have the ability to stick to the body, so "scratches" appear during the friction process, which limits their use in friction units. In Figure 2, it can see "streams" of metals remaining after contact with the counterbody in the friction process.

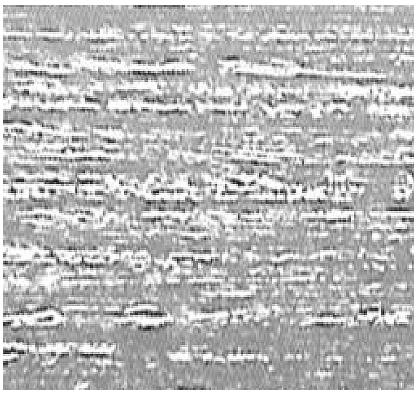


Figure 2. *Titanium alloy after wear resistance tests*
Source: *developed by the authors*

This effect is negative of mechanical nodes, therefore the formation of a strong surface of the structural state, which is characterised by high hardness, is relevant. L.M. Elias *et al.* (2006) developed titanium alloys with Nb and investigated their mechanical properties. It was found that the mechanical properties of these alloys are suitable for the use in implantology. M. Geetha *et al.* (2009) discussed the demand for titanium alloys in implantology. Their good combination of strength and density promotes biocompatibility. Thus, modification of the state of the surface with bioelements to increase roughness has a positive effect and leads to rapid growth of human tissue with an implant. X. Lu *et al.* (2015) proposed the idea of introducing reactive particles into the coating by adding them to the

electrolyte. This made it possible to seal the porosity of coatings and expand the possibilities of creating compositions by the PEO method. J. Qin *et al.* (2022) investigated the effect of graphene nanoparticles on the mechanical properties and porosity of PEO coatings on magnesium alloys. They found an increase in hardness, wear resistance, and porosity by adding nanoparticles to the magnesium-based coating.

Based on the results of the research conducted by scientists, a coating with hydroxyapatite and diatomite particles was developed (Fig. 3). The obtaining coating is characterised by a large number of pores on the surface. It should be noted that the pores form craters above themselves, which form the roughness of the surface (Fig. 3, a). These pores are of different sizes and shapes (Fig. 3, b). The pores can be examined in more detail at higher magnification (Fig. 3, c and d). Pores in the coating are formed due to a spark discharge. In the future, the coating grows and the pores overlap each other. This leads to closed porosity. This effect is very positive for the rapid introduction of muscle tissue into the implant. Therefore, implants with a similar surface are not rejected by the living organism. This leads to high biocompatibility of the implant material.

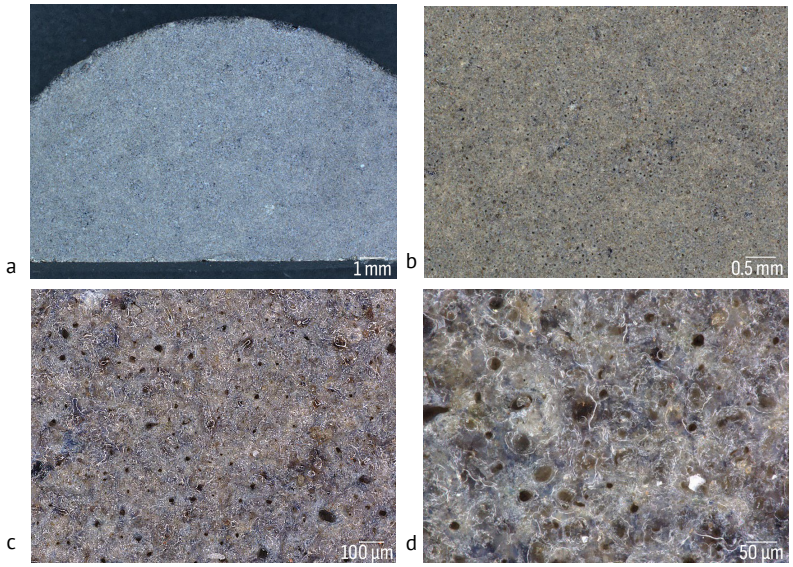


Figure 3. *Oxide ceramic coatings synthesised by PEO on a titanium base at different magnifications*
Note: *a, b, c, d – pores on the surface of the coating at different magnifications*
Source: *developed by the authors*

After the synthesised coating, a brittle oxide may appear on their surface, which easily falls off. At minimal loads, the oxide crumbles easily and closes the pores. In addition, this non-stoichiometric oxide behaves as a lubricant under friction conditions in the future. Therefore, an oxide with low mechanical properties has a positive effect on wear resistance.

In the future, studies of the wear resistance of the obtained coatings were carried out. Figure 4 shows the surfaces of the coatings, which were formed as a result of the synthesis of the titanium alloy, before and after friction. From the conducted research and visual inspection of the surface, it becomes clear that the roughness of the surface, which is determined by the craters of the pores, has a positive effect on the wear resistance of the surface of the coating material. By appearance, it can observe a change in the surface before and after friction. Smoothing the surface after wear leads to a reduction in its thickness and removal of the roughness that was formed as a result of the PEO process. From the conducted research, it follows that starting from the first stages of the friction process, smoothing occurs, during which the upper, non-stoichiometric oxide layer (anatase), which clogs the pores on the surface, is quickly erased. At the next stage, the friction coating becomes smooth, and wear practically stops. Lower is a study of the wear resistance of the coating obtained on a titanium alloy at different distances between the cathode and anode into the electrolyte without diatomite (modes 1 and 2 in Table 1) and with it (mode 3 in Table 1).

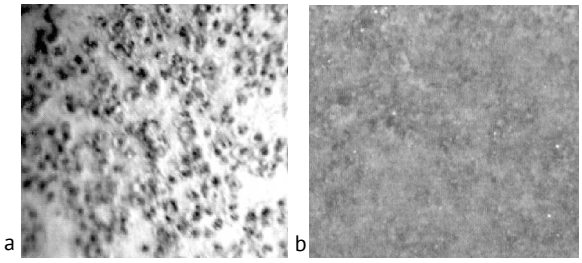


Figure 4. *External pores on the coating after oxidation of the titanium alloy by the PEO method (a); coating after friction tests (b) (x150)*
Source: *developed by the authors*

Figure 5 shows the samples that were synthesised in order to establish their wear resistance. As a result of tests of samples from the studied synthesised alloy of Grade 5, traces of wear were obtained. As a result of testing the samples, the wear intensity of the coating surface under the given conditions was established.

Figure 5. *Traces of coating wear after friction tests*
Source: *developed by the authors*

The obtained results show the intensity of wear of coatings during the first 500 m for the synthesised surface with phosphates and calcium of about 0.12...0.1 μm/m. The addition of diatomite to the electrolyte (mode 3) characterises the lowest wear of the coating in this area and further. For systems with phosphates and calcium, from a distance of 500 m to 1000 m, the wear of coatings increases almost twice. This result demonstrates a greater lapping distance compared to the coating that was synthesised in the electrolyte using diatomite. As a result of the experiment, it was found that the wear of the coating synthesised in an electrolyte with sodium pyrophosphate (electrolyte No. 1) is somewhat higher compared to the coating synthesised in an electrolyte without phosphate components (electrolyte No. 2) (Table 1).

Table 1. *Wear intensity of titanium-based coatings in different working environments*

No. composition	Electrolyte composition	Intensity of PEO-coating wear *I*, μm /m			
		L, m 500	L, m 1000	L, m 1500	L, m 2500
1	0.5 g/l KOH+0.5 g/l l.g.+0.5 g/l $Ca(OH)_2$+0.5 g/l $Na_4P_2O_7$	0.12	0.25	0.2	0.19
2	3 g/l KOH+2 g/l l.g.+3 g/l $Ca(OH)_2$	0.1	0.18	0.175	0.17
3	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	0.092	0.09	0.052	0.03

Source: *developed by the authors*

The lowest value of the friction intensity during the grinding process is characteristic of the coating synthesised by electrolysis with diatomite, and is equal to 0.03 μm/m at the largest distance traveled, which is 2500 m. In the course of the experiment, it was established that as a result of surface treatment of Grade 5 titanium alloy, coatings are synthesised that are characterised by high wear resistance, which was evaluated by dry friction (Table 1). Thus, at the first stage of abrasion (Fig. 6) v_f is the largest for oxide ceramics synthesised according to mode 1. Therefore, secondary structures on the counterbody develop faster here. According to the obtained results of wear of bio-coatings, it was established that after 1000 m of the covered path, the coating wears off and the rate of wear of the coating decreases sharply. Thus, coatings synthesised in an electrolyte No. 1 wear out at an average rate 0.076 μm/m, the coatings synthesised in an electrolyte with a composition of No. 2 are worn by 0.17 μm after a 2500 m path, and therefore the speed wear of such coatings is 0.068 μm/m. The lowest rate of wear is characteristic of coatings synthesised in the electrolyte according to modes No. 3 since the rate of wear of coatings is 0.012 μm/m (Fig. 6). At the next stage of friction, the intensity of wear increases for the two systems. The coating, oxidised in an electrolyte with a higher content of components and additionally with diatomite wears out with less intensity.

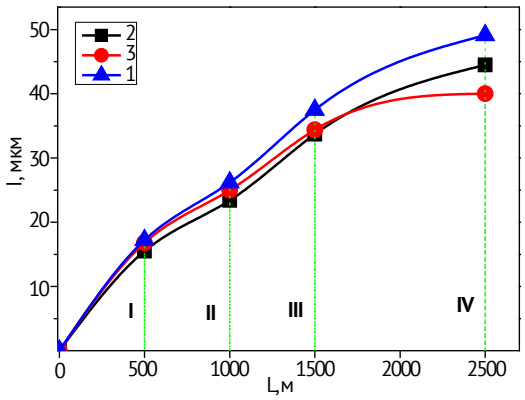


Figure 6. *The wear intensity I of the coating on the titanium alloy from the travelled distance L*
Source: *developed by the authors*

In the third and fourth stages, the intensity of wear decreases for these systems. However, the lowest value of wear intensity is for the coating, which was synthesised according to mode No. 2, which does not contain sulfates and bio-additives. After rubbing the surface to the counterbody, the angle of inclination of all the curves shown in Figure 5 decreases. For the sample, which was oxidised in an electrolyte containing KOH, liquid glass, and diatomite, after grinding, a smear is formed that contains a horizontal section, which indicates the high wear resistance of such a coating. The intensity in this area is 0.001. The rate of

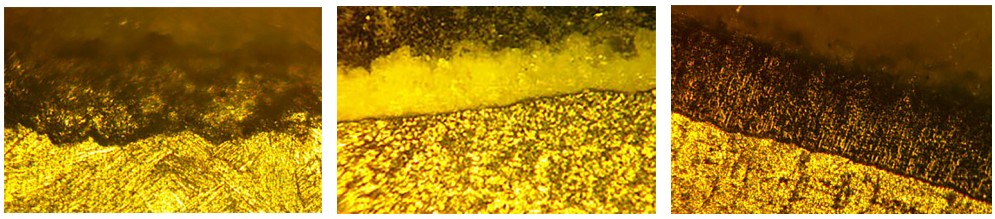
wear of biocoatings after each stage of the distance is presented in Table 2. Experimental results show that after 500 m of travel, the coating containing datomite in its layer has the lowest wear rate. From the obtained results, it can be seen that the lapping for the coating, which was synthesised in an environment without sodium diatomite and pyrophosphate, ended already at the first stage, after which the rate of wear begins. After 2.5 km of the covered path, the rate of wear of the coating is the highest for the sample that was processed under mode No. 3. As can be seen from the conducted studies, v_f decreases by an order of magnitude after 1 km of travel, which is associated with the completion of the process of rubbing the coatings with the counterbody. The greatest rubbing is characteristic of coatings that were synthesised in an environment with diatomite. This is explained by the highest roughness of such coatings.

Table 2. *Wear rate of titanium-based coatings in different working environments*

No. composition	Electrolyte composition	The rate of wear of biocoating $v \cdot 10^{-3}$, g/m			
		L, m 500	L, m 1000	L, m 1500	L, m 2500
1	0.5 g/l KOH+0.5 g/l l.g.+0,5 g/l $Ca(OH)_2$+0.5 g/l $Na_4P_2O_7$	0.24	0.26	0.1	0.02
2	3 g/l KOH+2 g/l l.g.+3 g/l $Ca(OH)_2$	0.2	0.16	0.01	0.001
3	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	0.18	0.9	0.076	0.044

Source: *developed by the authors*

S. Aliasghari *et al.* (2014) investigated that the obtained coatings have a thickness of 40...50 μm, and their structure consists of titanium oxides, which are characterised by stoichiometric and non-stoichiometric composition. Rutile is the most stable form of titanium oxide. V. Korzhyk *et al.* (2024) in their work determined the dependence of the mechanical properties of the coating on the structural state of the metal base. The appearance of cracks in the coating was established and the location of the elements in the coating was explained. Research coatings synthesised on titanium alloy in various modes are presented in Figure 7.



a b c

Figure 7. *The microstructure of the coating synthesised in an alkaline electrolyte for 60 min.*

Note: *a – in an electrolyte without diatomite and with hydroxyapatite at Ia/Ic = 1.5 (x250); b – in an electrolyte without diatomite and hydroxyapatite at Ia/Ic = 1 (after etching) (x250); c – in an electrolyte with diatomite and hydroxyapatite at Ia/Ic = 1 (x200)*

Source: *developed by the authors*

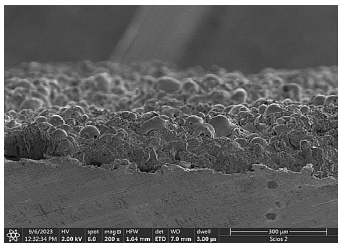
It can be seen from the given photos that the border between the coating and the metal is uneven, which is explained by the mechanism of its production. Figure 7, b shows a PEO coating on a titanium alloy after etching. The obtained microstructures make it possible to determine that the obtained coating is ceramic and does not have a crystalline structure. It can be noted that the coatings synthesised in different electrolytes have different thicknesses. In Figure 7, a, metallic particles of the substrate were found in the coating. This may cause it to stick to another surface during friction. The introduction of diatomite and hydroxyapatite into the coating by adding these components to the electrolyte makes it possible to obtain a coating of greater thickness and a laminar structure (Fig. 7, c).

In practice, it is very important which implant system the doctor uses, as well as its design. Poor titanium alloy processing and inadequate design can lead to atom migration into the surrounding bone tissue, resulting in its fibrous degeneration (damage to bone tissue) (Kaur & Singh, 2019). To eliminate the possibility of aluminum and vanadium elements entering the surface, H. Fakhr Nabavi *et al.* (2017) developed a two-layer coating on a titanium alloy. The authors studied the influence of the morphology of the first layer on the morphology of the second layer. Scientists conducted research on the synthesis of titanium alloys in an alkaline electrolyte with phosphates. It was established that the application of the second layer reduces the corrosion resistance of the surface. The dependence of the porosity of the second layer on the

first was revealed. Coatings obtained on titanium alloy by the PEO method are not through-through, so they exclude the possibility of the corrosive environment getting on the metal base.

Therefore, surface morphology is of great importance in the direction of biocompatibility of the surface material. For a more complete analysis of the internal construction coating, a fractographic analysis was conducted (Fig. 8). Photo shows that there are craters at the site of pore formation, which are clearly visible in Figure 8, a. Study of the fractograms, which are presented in Figure 8, b, show the presence of pores inside the coating. These pores are melted down and have different shapes and size. Also, they often merge with each other. As a result, the pores form longer shapes. In the field of implantology, the shape of such pores is acceptable.

a



b

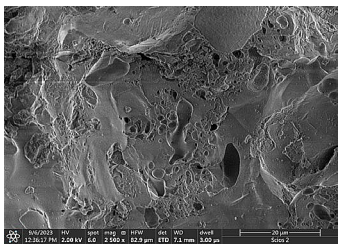


Figure 8. *Fractogram of a sample of titanium alloy with PEO coating*

Note: *a, b – coatings are synthesised in an environment with hydroxyapatite and diatomite*

Source: *developed by the authors*

The results obtained confirm the studies conducted by J. Jakubowicz (2020) indicated that surface treatment accelerates osseointegration. According to this study, it can be established that the pores inside the coating are fused and are not through. The internal chaotic porosity of the coating material leads to rapid growth of the implant with the living organism and its strong contact. Such a result of the implant introduction allows to assert the good quality of growth, when the postoperative capsule is removed. Also, this result reduces the percentage of rejection of the implant by the body.

Conclusions

In this work, it was established that the structure of the coating is characterised by a lamellar and a highly porous structure. The highly porous internal structure of the coating makes the material lighter and promotes better contact of the surface of the synthesised titanium alloy with the muscle tissue.

The study of the structural state of the coating material makes it possible to confirm the high adhesive properties of the coating with the metal. After all, the uneven border between the base and the PEO coating confirms the melting process of the metal surface in the process of plasma electrolytic oxidation. Energy parameters directly affect the value of the crater height, and therefore the surface roughness. Thus, with higher ratios of current densities, surface roughness increases. Adding diatomite particles to the electrolyte increases their roughness.

The increase in wear resistance due to the presence of a PEO coating on a titanium alloy can be explained by the presence of an unstable brittle non-stoichiometric oxide on its surface, which in the process of friction clogs surface pores, acting as a lubricant, as a result of which surface wear during reverse forward movement practically stops and increases 10 times. The coefficient of friction for coatings obtained in an electrolyte with phosphates is not much higher. Importantly, these coatings did not contain a flat area after the friction experiment. It was established that all coatings synthesised on titanium alloy increase their tribological properties.

The influence of the studied amount of hydroxyapatite and diatomite on the porosity of the PEO coating and the established ratio of Ca/P in the coating is promising. This result affects the biocompatibility of the material being synthesised. Therefore, studies of the influence of work modes on the elemental composition and porosity of PEO coatings are relevant. These studies will be investigated in subsequent works. Studying this correlation will give the opportunity to develop a synthesis regime with high biocompatibility of the coating material.

Acknowledgements

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Conflict of Interest

None.

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Стійкість до стирання біофункціональних оксидних керамічних покриттів на основі титану

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Анотація. Вимоги сучасного виробництва до деталей є надзвичайно високими. Особливу увагу приділяють частинам, що працюють у механізмах тертя. Титанові сплави характеризуються низькою зносостійкістю та здатністю прилипати до поверхонь із більшою твердістю. Тому нанесення зносостійких покриттів на поверхню титанових сплавів є актуальним завданням. Метою даної роботи було підвищення експлуатаційних властивостей титанових сплавів шляхом створення захисних покриттів на їхній поверхні. У роботі досліджувалася зносостійкість покриттів, отриманих методом плазмового електролітного оксидування (ПЕО), на титанових сплавах. Експериментальні дослідження показали, що покриття мають у своїй структурі різні оксиди (стехіометричні та нестехіометричні). Нестехіометричні оксиди характеризуються низькими фізико-механічними властивостями та накопичуються в порах після первинного зношування. У процесі зношування нестехіометричний оксид виконує функцію мастила, що позитивно впливає на їхні трибологічні властивості. Встановлено, що нанесення покриття на поверхню титанових сплавів збільшує зносостійкість у 10 разів. Межа між металевою основою та покриттям є нерівномірною, що забезпечується плавленням поверхні титанових сплавів під час ПЕО. Ця особливість демонструє високі адгезійні властивості покриттів, сформованих методом ПЕО, до титанової основи. У роботі встановлено залежність розмірів і форми пор від режимів обробки. Виявлено, що розмір пор на поверхні покриття становить 10…70 мкм, а матеріал покриття характеризується високою внутрішньою пористістю. Встановлено, що пористі покриття плавляться всередині, тому пористість є відкритою, але не наскрізною. Досліджена властивість покриттів має значення для імплантології, оскільки забезпечує з'єднання м'язової тканини з імплантом без утворення капсули

Ключові слова: фосфати; тертя; плазмове електролітне оксидування; довговічність; зношування; пористість

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Development of glutinous biocomposite materials filled with coffee grounds

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Abstract. The intensive development of biocomposite materials is associated with the use of waste from agricultural production or the food industry as raw materials. Such raw materials are renewability and eco-friendly, but require special processing for preparation for use as a filler and development of methods of forming biocomposite products, which determines the high relevance of research in this direction. The aim of the work was to study the intensity of the influence of the mechanical and thermal fields on the mechanical properties and nature of the structuring of glutinous biocomposite materials with a high content of coffee grounds (190-200 wt. parts). The forming technology of biocomposite materials consisted in heat treatment of the composition. Next stages are pressing and holding of composition at a temperature of 150°C under a pressure of 8-11 MPa. The work used the methods of determining a compressive strength and an impact toughness. The method of infrared spectroscopy was also used to study structuring processes. It was established that the use of coffee grounds in the quantity of 200 wt. parts provides an increase in compressive strength up to 75.8 MPa under the condition of forming a biocomposite material with a density of 1.17 g/cm3. An increase in the resistance of biocomposites to dynamic loads occurs in the case of the introduction of a filler in the amount of 190 wt. parts using a preliminary

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pressing at a specific load of 8 MPa. The practical significance of this work lies in developing an optimal thermo-mechanical processing mode, involving maximum exposure of the composition in a press mould within a thermal field for 2 hours, which enhances the mechanical properties of glutinous biocomposite materials

Keywords: glutinous matrix; thermo-mechanical treatment; compressive strength; impact toughness; IR spectrogram; structuring

Introduction

The ever-increasing demand for biodegradable and cost-effective materials is driving many research efforts towards the development of biocomposites based on natural components. The authors R. Scaffaro *et al.* (2022) in their works optimised the composition taking into account new requirements and recommendations of the circular economy and zero waste. The scientists R. Scaffaro *et al.* (2021) identified the advantages of natural fillers, which are undoubted from the economic and environmental points of view, but their introduction into bioplastics often causes deterioration of mechanical properties, especially under the influence of high loads. An important challenge in the field of polymer composite materials is the development of biocomposite compositions and forming technologies through the incorporation of natural fillers into bioplastics, which are produced in relatively large quantities. The researchers S.M. Shahabaz *et al.* (2021) identified positive effects as a result of obtaining environmentally friendly materials based on renewable raw materials, which will be able to combine high economic efficiency with satisfactory mechanical strength.

For the development of biocomposite materials, the authors T. Shevchenko *et al.* (2022) widely used biopolymers such as polylactic acid (PLA), cellulose esters, polyhydroxyalkanoates (PHA) and starch-based plastics. T.D. Moshood *et al.* (2022) defined the advantages of biological resins over synthetic polymers because they are energy-efficient in production (65% less energy required for production), safe (non-toxic at all stages of the life cycle and especially at the disposal stage, as biological decomposition into eco-friendly components occurs), suitable for recyclable, renewable (made from biomass) and environmentally friendly (68% less greenhouse gas emissions).

Mainly, the properties of natural fibre-reinforced biocomposites depend on the chemical composition of the fibre and the polymer matrix. The type and orientation of natural fibres or microfibrils, fibre modification, modifier type, fibre-to-polymer mass ratio, the type of moulding or processing technology, physical properties, and the quality of the interfacial connection between the reinforcing materials and the matrix are the parameters that determine the mechanical properties of biocomposites. The researchers M. Akter *et al.* (2022) found that high adhesive strength ensures full load transfer between the fibre and the polymer matrix.

Natural fibres have a porous structure that provides high heat and noise insulation. This is a class of materials that can be easily processed, so they are suitable for a wide range of applications, such as the manufacture of packaging and consumer goods, in the construction industry (roofing, flooring, windows, doors, furniture), in the automotive and aerospace industries, in the military, electronics and medical industry (prostheses, bone plates, orthodontic arches). M. Melnychuk *et al.* (2023) improved the adhesion between the filler and the polymer using a special chemical treatment of the components with the addition of talc as an intermediate agent to improve compatibility. A significant disadvantage of natural fibres is the presence in the chemical composition of hydroxyl groups (OH), which are able to attract water molecules, as a result of which the fibres become saturated with moisture. The authors M.R. Mansor *et al.* (2020) described the effect of such a defect on the formation of the structure, which leads to the formation of cavities at the interface of the biocomposite components, which effects on their mechanical properties and loss of dimensional stability.

The positive effect of the use of secondary raw materials of the agricultural sector and food industry waste, in particular straw or husks, was determined in the work of M. Jerman *et al.* (2021). This ensures the expansion of the spectrum of possible areas of application of biocomposite materials and at the same time allows to reduce the negative impact on the environment.

The authors J. Dušek *et al.* (2021) introduced a highly energy-efficient and eco-friendly composite building material utilising rapeseed straw and a sustainable binder. The binder comprises bone glue combined with sodium lignosulfonate. In order to enhance the properties of the material, the rapeseed straw particles undergo a surface modification process involving treatment with water and sodium hydroxide. This treatment increases the bulk and matrix density, thereby improving the adhesion strength between the chopped rapeseed straw particles and the bone glue, as compared to the reference material. Significant moisture saturation of all developed biocomposites in conditions of relative humidity above 75% limits their practical application. Therefore, the use of the developed biocomposite materials is possible in contact with a dry environment, for example, for the manufacture of packaging of solid or loose products, cladding and insulation of interior

walls. The scientists V.P. Kashytskyi *et al.* (2023) developed biocomposite materials containing sodium sulfate, which is used as a modifying additive to intensify the structuring process of biocomposites. The work established the effect of the modifying additive on the compressive strength of biocomposites and features of structuring at different temperatures.

The purpose of the study was to determine the influence the density, the optimal content of fine filler and the mode of thermo-mechanical treatment of the composition on the mechanical characteristics of glutinous biocomposite materials filled with coffee grounds.

Materials and Methods

Samples of biocomposite materials for research were formed on the basis of a biopolymer matrix (glutin) and filler from food waste (coffee grounds). The biopolymer binder was prepared by dissolving granules of bone glue (glutin) in water. The physicochemical properties of bone glue granules correspond to the technical data of 63000 Bone Glue, Pearls (2016). The coffee grounds were previously dried and sieved. The preparation of the biocomposite material composition was carried out by mechanically mixing the components in a specified ratio. Mixing was carried out using a laboratory mill with a high frequency of rotation (20 kHz) of a petal-type working body. Before the formation of biocomposite samples, moisture was removed from the composition up to 20% by holding the mixture in a thermal field at a temperature of 50-60°C for 20-30 minutes. Biocomposite samples were formed in a mould by pressing the composition with subsequent exposure in a thermal field. The main mode of heat treatment of the composition consists of two stages, that ensures the process of forming the biocomposite material. After the first stage of exposure of biocomposite samples with a duration of 1 hour at a temperature of 150°C, additional pressing is carried out in order to eliminate voids and cavities, which are formed as a result of removing moisture at high temperature. The dense structure of the composites is achieved through the formation of physical and chemical bonds between the components while the binder remains in a liquid state. The material is then subjected to thermal treatment for 1 hour at a temperature of 150°C. Following the second stage of thermal exposure, the mould is removed from the drying chamber and allowed to cool gradually to room temperature to prevent the development of internal stresses. Once cooled, the biocomposite samples are extracted from the mould and tested.

Compressive strength was determined according to the ASTM D695-23 (2023) method on cylindrical samples with a height of 30 mm and a diameter of 20 mm. Impact toughness was determined on samples 60 mm long with a square section (10×10 mm) according to the ASTM D256-23e1 (2023). The structuring of biocomposites was investigated using an IR spectrometer IRAffinity-1S (Shimadzu, Japan) in the frequency range 400-4000 cm^{-1}. The single-beam method in reflected light was used. Wave numbers were determined using the LabSolution IR computer program.

Results and Discussion

Food industry waste in the form of a finely dispersed powder, which is obtained as a result of processing coffee grounds, can be used as fillers for glutinous biocomposite materials. The exploration of optimal finely dispersed filler content in the biopolymer matrix, along with the assessment of density and thermo-mechanical processing modes, facilitated an in-depth analysis of the impact of mechanical and thermal fields on the properties of biocomposite materials enriched with coffee grounds.

Biocomposite materials containing 190 wt. parts coffee grounds per 100 wt. parts of biopolymer binder with density of 1.17 g/cm^3 have a compressive strength of 68.5 MPa (Fig. 1). The limit of compressive strength (65.3 MPa) of the biocomposite with a higher density of 1.38 g/cm^3 is slightly reduced by 4-5% in comparison with the strength of biocomposites with a density of 1.17 g/cm^3. This occurs due to the development of internal stresses in the system, resulting from the limited mobility of macromolecular segments within the glutin matrix after moisture removal and the binder's transition to a solid state. The compressive strength of the biocomposite material with a density of 1.59 g/cm^3 further decreases by 11-12% in comparison with the mechanical strength of biocomposites with a density of 1.17 g/cm^3. The biocomposite material is in a compressed state, which makes it difficult to move segments of macromolecules of the glutin matrix and reduces resistance to static load. The highest value of compressive strength (75.8 MPa) was obtained for biocomposite materials with the content of 200 wt. parts coffee grounds and a lowest density of 1.17 g/cm^3. The mechanical properties of these biocomposites improve by 9-10% compared to those with a filler content of 190 wt. parts, assuming a similar material density of 1.17 g/cm^3. The enhancement in compressive strength is attributed to the partial substitution of the biopolymer matrix with filler particles. This indicates the ability of the filler to establish robust adhesive bonds with the glutinous matrix and its greater resistance to compression compared to the biopolymer matrix. The mechanical characteristics of such biocomposites are also determined by the size of areas which have high cohesive strength of the polymer matrix and fillers. The compressive strength of the composites decreases to 65.3 MPa as the density of the composites increases to 1.38 g/cm^3. The compressive strength of biocomposites is 60.5 MPa in the case of their density of 1.59 g/cm^3. It was found that the compressive strength decreases by 13-15% for biocomposites with a density of 1.38 g/cm^3 and by 20-22% for biocomposites with a density of

1.59 g/cm^3 in comparison to the compressive strength of biocomposites with a density of 1.17 g/cm^3. A significant decrease in this characteristic occurs due to an increase in the density of biocomposites up to 1.59 g/cm^3, as a stress state of materials is formed. The compressive strength for biocomposites with a filler content of 200 wt. parts is higher by 12-13% for biocomposites with a density of 1.38 g/cm^3 and by 7-8% for biocomposites with a density of 1.59 g/cm^3 compared to the strength of biocomposites containing filler of 190 wt. parts. This is attributed to the reduced content of the biopolymer matrix in the case of testing biocomposites with a filler content of 200 wt. parts due to the low ability of the glutinous polymer to relax residual stresses, as a stable glutinous structure with high stiffness of amino acid macromolecule chains is formed. It is necessary to increase the mobility of segments of macromolecules of the glutin matrix in the case of the formation of biocomposite materials with a high density. A similar issue is considered in the works of authors P.P. Parlevliet *et al.* (2007) and S. Chava *et al.* (2022), who investigated the effect of residual stresses on the mechanical properties and durability of polymer composites based on thermoplastic polymers. Several mechanisms for removing thermal residual stresses, which are based on the modification of the components of composite materials and the development of the heat treatment mode, are considered. The effect of the duration of the thermal field on the compressive strength was investigated in order to optimise the technological process of forming biocomposite materials with a density of 1.17 g/cm^3, as a result of which thermo-mechanical processing regimes with different durations at the first and second stages were developed (Table 1).

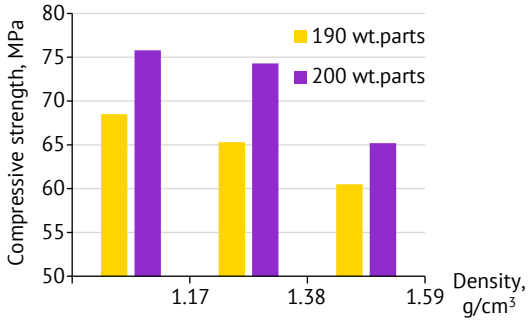

Figure 1. *Compressive strength of biocomposite materials depending on the content of coffee grounds in the biopolymer matrix and the density of biocomposites*
Source: *developed by the authors*

Table 1. *Modes of thermo-mechanical treatment of biocomposite samples*

Content of coffee grounds, wt. parts	Modes of thermo-mechanical treatment			
	1	2	3	4
190	1 hour 150°C + pressing + 1 hour 150°C	1 hour 150°C + pressing + 30 min. 150°C	30 min. 150°C + pressing + 1 hour 150 °C	30 min. 150°C + pressing + 30 min. 150°C
200				

Source: *developed by the authors*

Among biocomposite materials with a density of 1.17 g/cm^3 and a filler content of 190 wt. parts the highest compressive strength (73.2 MPa) has the materials formed according to the main mode of thermo-mechanical treatment (1 hour at 150°C + pressing + 1 hour at 150°C, mode No. 1 of Table 1) (Fig. 2). The characteristics of biocomposites decrease by 19-20% in the case of shortening the exposure time at the second stage of thermo-mechanical treatment to 30 min. (1 hour 150°C + pressing + 30 min. 150 °C, mode No. 2 of Table 1) compared to the strength of biocomposites, which are formed according to the main processing mode. This is due to insufficient thermal influence on the processes of formation of new physicochemical bonds between active groups of macromolecules as a result of compaction of components after applying the compression operation.

Reducing the exposure time at the first stage of thermo-mechanical processing to 30 minutes followed by an exposure of 1 hour at the second stage (30 min. at 150°C + pressing + 1 hour at 150°C, mode No. 3 of Table 1) leads to a decrease of 28-30% compressive strength (52.5 MPa) compared to the strength of biocomposites formed by the main processing mode. This suggests that thermal energy plays a more dominant role in the structuring processes of biocomposite materials compared to the heating of the composition in the second stage. This stage involves the transition of the glutinous binder into a liquid state, its redistribution within the biocomposite, and the wetting of the coffee grounds particle surfaces, followed by the penetration of the binder into the porous structure of the organic filler. In the work of the authors V. Kashytskyi *et al.* (2023) attribute a high compressive strength of biocomposite materials to the uniform distribution of the biopolymer binder between the filler particles, which occurs during the melting of the glutin solution under the influence of a temperature of 150°C. Biocomposites have higher values of compressive strength in the case of exposure in a thermal field for 2 hours compared to exposure for 4 hours. Shortening the exposure time in two stages of thermo-mechanical treatment to 30 minutes (30 min. 150 °C + pressing + 30 min. 150 °C, mode No. 4 of Table 1) leads to the formation of a biocomposite

material with the lowest of compressive strength (47.7 MPa). This is due to the fact that the composition receives an inadequate amount of thermal energy, which is essential for the redistribution of the glutinous binder and the formation of physicochemical bonds between the components of the biocomposite material. The authors T. Gurunathan *et al.* (2015) focused attention on various methods of surface modification, which made it possible to improve the adhesion of the fibre to the matrix and accordingly the mechanical properties of biocomposites.

Experimental results showed that the highest compressive strength 79.6 MPa has biocomposites containing 200 wt. parts of filler and with a density of 1.17 g/cm^3. These biocomposite materials were formed according to the main mode of thermo-mechanical processing (1 hour at 150°C + pressing + 1 hour at 150°C, mode No. 1, Table 1). Compressive strength of biocomposites with a coffee grounds content of 200 wt. parts decreases by 24-25% in the case of a reduction in the duration of exposure at the second stage of heat treatment (1 hour 150°C + pressing + 30 min. 150°C, mode No. 2 of Table 1) compared to an exposure time of 1 hour during thermo-mechanical treatment according to main mode. The reduction in characteristics is attributed to the insufficient duration of exposure in the thermal field, which is essential for the formation of the biocomposite material's structure following the additional compression of the composition. This leads to an uneven distribution of the glutinous binder in the composition with a higher content of filler particles compared to the degree of filling of 190 wt. parts. In this case, the compressive strength limit of biocomposites with a content of 200 wt. parts differs by only 2% compared to the strength of biocomposites containing 190 wt. parts of filler. A similar difference in the strength values of biocomposites with different filler content (190 wt. parts and 200 wt. parts), which are formed according to the main processing mode, is 8-9%. This indicates the dominant effect of thermal energy in the first stage of processing compared to an increase of 10 wt. parts of the amount of filler in the system.

A decrease in compressive strength by 30% and 36% occurs in the case of a decrease in the duration of exposure at the first stage of thermo-mechanical treatment (30 min. 150°C + pressing + 1 hour 150°C, mode No. 3, Table 1) and at two stages processing (30 min. 150°C + pressing + 30 min. 150°C, mode No. 4, Table 1) respectively (Fig. 2). These results correlate well with the compressive strength values of biocomposite materials with a filler content of 190 wt. parts, which is explained by the insufficient amount of thermal energy for the formation of glutinous biocomposites. Resistance to dynamic loads was determined on biocomposite samples with a filler content of 190 wt. parts and 200 wt. parts. The samples were obtained using the method of pressing at the initial stage of forming the composition followed by thermo-mechanical processing according to the basic mode (1 hour at 150°C + pressing + 1 hour at 150°C). The highest value of impact toughness (3.55 kJ/m^2) has biocomposite materials (Fig. 3) with a filler content of 190 wt. parts and a pressure formation of 8 MPa. Formation of biocomposite materials under the pressure of 11 MPa leads to a 9-10% decrease in impact toughness compared to samples with a pressure formation of 8 MPa. This is due to the deformation of the filler particles, which have low mechanical characteristics, as a result of which their rapid destruction occurs during the movement of the crack. The work of the authors R. Gunti *et al.* (2018) presented that resistance to dynamic loads increases as strength and filler content increase. The use of processed sisal and jute fibres provides an increase in impact toughness by 111.5% and 22.3%, respectively. However, the technological process of forming biocomposite products becomes more complex in this case.

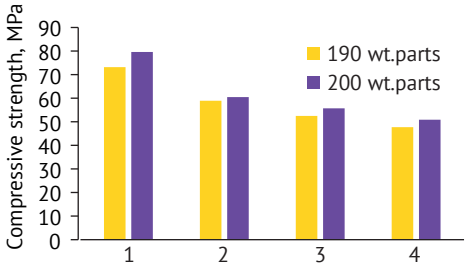

Figure 2. *Compressive strength of biocomposite materials depending on the mode of thermo-mechanical treatment (Table 1)*

Note: *1 – 1 hour 150°C + pressing + 1 hour 150°C; 2 – 1 hour 150°C + pressing + 30 min. 150°C; 3 – 30 min. 150°C + pressing + 1 hour 150°C; 4 – 30 min. 150°C + pressing + 30 min. 150°C*
Source: *developed by the authors*

Impact toughness of biocomposite materials with a filler content of 200 wt. parts and a pressure formation of 8.0 MPa is 3.33 kJ/m^2. The impact toughness of biocomposites (3.06 kJ/m^2) increase in 6.5% with an increase in the specific compression load of the composition to 11.0 MPa compared to the impact toughness of biocomposites formed under a specific load of 8 MPa. The formation of biocomposite materials using a higher pressure of formation (11 MPa) provides a higher density of the material, but at the same time, the degree of deformation of the particles, which have less resistance to the influence of dynamic loads, increases.

The lower values of the impact viscosity of biocomposite materials with a higher content of filler (200 wt. parts) are explained by the presence of a larger number of deformed particles of coffee grounds, that are not able to resist the crack movement (Fig. 3).

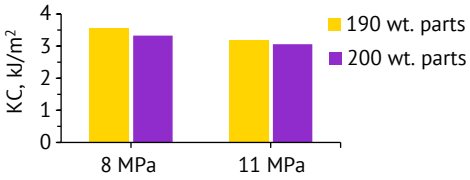

Figure 3. *Impact toughness of biocomposite materials depending on the pressing pressure during the formation of samples*
Source: *developed by the authors*

The crack propagation direction of biocomposite samples, which were formed under the action of a specific load of 8 MPa, has a deviation of 9-11° (Fig. 4, a) from the direction of the dynamic load action vector. In the case of destruction of biocomposite samples, which were formed under the action of a specific load of 11 MPa, the deviation is 1-2° (Fig. 4, b) from the direction of the dynamic load action vector. This indicates the biocomposite material's low resistance to dynamic loads, which was formed under a specific load of 11 MPa, as the crack propagates with minimal energy required to overcome the obstacles created by the deformed coffee grounds particles. A complex set of absorption bands at frequencies of 1400-1800 cm^{-1} was recorded on the IR spectrograms (Fig. 5) for the biocomposite materials with coffee grounds formed under pressure of 8 MPa and 11 MPa. There are characteristic absorption bands on the IR spectrogram (Fig. 5, a) for the biocomposite material formed under a pressing pressure of 8 MPa at frequencies of 1458.25 cm^{-1} with optical density D = 0.625 and peak area S = 23.22%, 1523.83 cm^{-1} with optical density D = 0.618 and peak area S = 17.46%, 1543.12 cm^{-1} with optical density D = 0.627 and peak area S = 11.69%. These absorption bands at the specified frequencies correspond to asymmetric deformation $-CH_3$ and deformation $-N-H$ vibrations. Absorption bands at frequencies of 1639.56 cm^{-1} (D = 0.662, S = 9.01%) and 1655.00 cm^{-1} (D = 0.669, S = 18.02%) indicate the presence of valence –C = O– and –C = C– oscillations. Absorption bands at frequencies of 2345.54 cm^{-1} (D = 0.580, S = 25.37%) and 2372.55 cm^{-1} (D = 0.584, S = 31.17%) inform about the presence of valence vibrations in the biocomposite material –P–H groups. There are on the IR-spectrogram a transmission band at a frequency of 2924.21 cm^{-1} (optical density D = 0.719 and peak area S = 87.89%), which corresponds to asymmetric valence vibrations of CH_3 groups. The identified characteristic absorption bands corresponding to certain functional groups indicate a sufficient degree of structuring of the biocomposite material formed under a pressing pressure of 8.0 MPa. The authors J.-M. Raquez *et al.* (2010) determined the effectiveness of using biopolymer matrices with a high modulus of elasticity, strength, durability and resistance to thermal stress and chemical effects, which is ensured by high cross-linking density as a result of the formation of additional connections between the components.

Figure 4. *The general appearance of biocomposite samples with a filler content of 190 wt. parts after the impact toughness test*
Note: *biocomposites are formed under pressure: a – 8 MPa; b – 11 MPa*
Source: *developed by the authors*

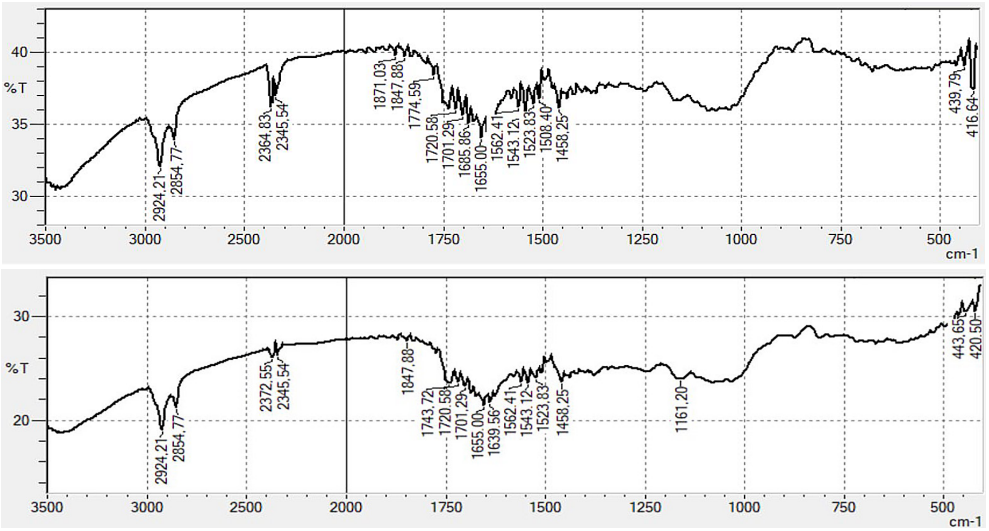

Figure 5. *IR spectrograms of biocomposites formed under a pressing pressure*
Note: *a – 8 MPa; b – 11 MPa*
Source: *developed by the authors*

Characteristic absorption bands at similar frequencies were recorded for the biocomposite material formed under a pressure of 11 MPa (Fig. 5, b): 1458.25 cm^{-1} (D = 0.442, S = 9.74%), 1523.83 cm^{-1} (D = 0.438, S = 12.13%), 1543.12 cm^{-1} (D = 0.447, S = 12.16%), 1655.00 cm^{-1} (D = 0.468, S = 15.08%). These absorption bands are characterised by significantly lower values of optical densities and smaller peak areas, which indicates a lower degree of structuring of biocomposite materials at a higher forming pressure (11 MPa). The absorption band at the frequency of 2364.83 cm^{-1} (D = 0.441, S = 21.10%) is shifted to the region of lower wave numbers, indicating the enhanced structuring of the biocomposite formed under higher pressing pressure. The recorded absorption band at higher frequencies of 2924.21 cm^{-1} is also characterised by lower values of optical density (D = 0.494) and peak area (S = 73.82%).

Therefore, the developed biocomposite materials, formed under different pressures of 8 MPa and 11 MPa, have a high degree of structuring. This is indicated by the complex spectrum of absorption bands present on the IR spectrogram, which correspond to the existence of functional groups. Biocomposites formed under a lower pressing pressure of 8 MPa have lower values of optical densities and larger peak areas of characteristic absorption bands compared to biocomposite materials formed under a higher pressing pressure (11 MPa). This indicates a higher degree of structuring of biocomposites formed at a lower pressing pressure of 8 MPa due to the formation of a greater number of bonds in the materials. This can be explained by the fact that under higher pressure the fibres are additionally deformed and destroyed. The elastic aftereffect is more pronounced at a higher pressure, which leads to the destruction of already formed bonds in the material. These results explain the obtained lower values of impact toughness for biocomposites formed under higher pressing pressure (11 MPa).

As a result of analysing other authors' sources, it was found that the authors R. Bodîrlău *et al.* (2014) found a decrease in the flexibility of starch polymer chains in composites due to the use of modified cellulose microparticles in a plasticised starch matrix. Authors M. Morreale *et al.* (2015) explain that the modulus of elasticity increases without decreasing the tensile strength of biocomposite materials containing wood flour due the high adhesion between the filler particles and the biopolymer matrix, which was confirmed by SEM analysis. The scientists R. Scaffaro *et al.* (2021; 2022) indicated that the improvement of the mechanical characteristics of biocomposite materials with a hybrid content of lamellar and fibrous fillers or fillers from marine and agricultural waste is associated with the formation of strong interfacial regions, which have high adhesive strength between the components.

In the work of the researchers J. Dušek *et al.* (2021) the density of the biocomposite material increased as a result of surface treatment of rapeseed straw with water or sodium hydroxide. This treatment preserves the integrity of the filler and enhances the adhesion between rapeseed straw and bone glue, resulting in improved mechanical properties of the biocomposites. A negative consequence of this treatment is the intensive absorption of moisture by the filler, which requires an additional thermal operation in order to remove it. The authors K. Georgios *et al.* (2016) found that biopolymer matrices have an increased susceptibility to hydrolytic degradation during melt processing in the presence of a small amount of moisture, which negatively affects the adhesion mechanism due to the high hygroscopicity of natural fibres. Natural fibre is hydrophilic and polar in nature, so it may have limited compatibility with the polymer matrix. In the work of A. More (2021) methods of improving the interfacial adhesion between the flax fibre and the polymer matrix due to chemical and physical treatment of the fibre surface are defined. The results of similar studies are presented in the paper of S. Kalia (2016). The scientist focused on environmentally friendly methods of improving compatibility between hydrophilic natural fibres and hydrophobic polymer matrices using plasma treatment of natural fillers.

Conclusions

The study revealed that biocomposite materials with a filler content of 200 wt. parts exhibit higher compressive strength (75.8 MPa) compared to those with a lower filler content of 190 wt. parts. The strength of biocomposites increases at a higher content of filler particles (200 wt. parts), which is determined by the ability of coffee grounds particles to deform as a result of compression during formation. Under pressure, the degree of tension in the local volumes of coffee grounds particles decreases due to the mobility of the filler molecules, in contrast to the rigid framework of the glutin matrix macromolecules, which form a structure with an increased stress state during the formation process. The increase in compressive strength in the case of forming biocomposites with a lower density (1.17 g/cm^3) is associated with the optimal degree of compaction of the biocomposite material, the filler particles of which form physical and chemical bonds with the active groups of glutin macromolecules.

Formation of biocomposite materials according to the main mode of thermo-mechanical treatment (1 hour 150°C + pressing + 1 hour 150°C) provides the highest value (79.6 MPa) of compressive strength. The fluidity of the glutinous binder increases at the optimal length of exposure in the thermal field, as a result of which glutinous macromolecules penetrate and are evenly distributed on the surface and in the voids of the coffee grounds particles. This aids in the structuring of the biocomposite material, which involves the formation of additional physical and chemical bonds

between the compacted components of the composition under the influence of a thermal field.

The impact toughness of biocomposite materials increases to 3.55 kJ/m^2 in the case of use in the process of forming biocomposites with a specific load of 8 MPa, that is due to the content of coffee beans particles in the glutinous matrix. Coffee beans particles have low mechanical characteristics and are less deformed during pressing under the influence of a specific load of 8 MPa compared to pressing under a pressure of 11 MPa. The increase in resistance to the influence of dynamic loads occurs due to the formation of the optimal density of the biocomposite material, which is determined by the low degree of deformation of the coffee grounds particles. The use of a specific load of 8 MPa during the formation of a biocomposite material allows to improve the structuring of glutinous biocomposites due to the formation of new physicochemical bonds that is confirmed by the presence of asymmetric deformation $-CH_3$ and deformation –N–H vibrations, as well as valence –C = O– and –C = C– oscillations. The formation of biocomposites using a specific load of pressing of 11 MPa leads to the intensification of the structuring process, which is determined by the shift of the absorption bands to the region of lower wave numbers. This indicates the formation of a material with an increased degree of tension and reduced resistance to the influence of dynamic loads.

In the future, it is planned to determine the mechanical properties of biocomposite materials depending on the concentration of glutin in the water solution and the temperature of thermo-mechanical treatment.

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None.

Conflict of Interest

None.

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Розробка клейових біокомпозитних матеріалів, наповнених кавовою гущею

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Анотація. Інтенсивний розвиток біокомпозитних матеріалів пов'язаний з використанням відходів сільськогосподарського виробництва або харчової промисловості як сировини. Така сировина є відновлювальною та екологічно чистою, але потребує спеціальної обробки для підготовки до використання як наповнювач і розробки методів формування біокомпозитних виробів, що визначає високу актуальність досліджень у цьому напрямку. Метою роботи було вивчення інтенсивності впливу механічних і теплових полів на механічні властивості та характер структуризації клейових біокомпозитних матеріалів з високим вмістом кавової гущі (190-200 мас. частин). Технологія формування біокомпозитних матеріалів полягала в термічній обробці композиції. Наступні етапи – пресування та витримка композиції при температурі 150 °С під тиском 8-11 МПа. У роботі використано методи визначення міцності при стисненні та ударної в'язкості. Також застосовано метод інфрачервоної спектроскопії для вивчення процесів структуризації. Було встановлено, що використання кавової гущі в кількості 200 мас. частин забезпечує підвищення міцності при стисненні до 75,8 МПа за умови формування біокомпозитного матеріалу з густиною 1,17 г/см^3. Збільшення стійкості біокомпозитів до динамічних навантажень спостерігається при введенні наповнювача в кількості 190 мас. частин із попереднім пресуванням при специфічному навантаженні 8 МПа. Практичне значення цієї роботи полягає в розробці оптимального режиму термомеханічної обробки, що передбачає максимальне витримування композиції в прес-формі в тепловому полі протягом 2 годин, що підвищує механічні властивості клейових біокомпозитних матеріалів

Ключові слова: клейова матриця; термомеханічна обробка; міцність при стисненні; ударна в'язкість; ІЧ-спектрограма; структуризація

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