

ТЕХНІЧНІ НАУКИ

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OVERVIEW OF THE CURRENT STATE OF SCIENTIFIC RESEARCH AND PRACTICAL ACCESS IN THE AREAS OF BIOLOGICAL DAIRY PACKAGING

Sandra Muižniece-Brasava¹, D-r of Sc., Engineering, Professor
<https://orcid.org/0000-0001-6033-6241>

Sergii Verbytskyi², PhD, Engineering, Head of Department
of Informational Support, Standardization and Metrology
<https://orcid.org/0000-0002-4211-3789>

Oleksandr Kuts², PhD, Economics, Deputy Head of Department
of Informational Support, Standardization and Metrology
<https://orcid.org/0000-0002-2855-0659>

Antonina Minorova², PhD, Engineering,
Head of Department of Dairy Products and Baby Food Products
<https://orcid.org/0000-0002-7557-1444>

Nataliia Patsera², Researcher
of Informational Support, Standardization and Metrology
<https://orcid.org/0000-0001-8737-9997>

Olha Kozachenko², Chief Specialist
of Informational Support, Standardization and Metrology
<https://orcid.org/0000-0002-2189-9583>

Liana Nedorizanyuk², Researcher,
Department of Technology of Meat Products
<https://orcid.org/0000-0002-2190-5648>

¹Latvia University of Live Sciences and Technologies, Jelgava, Latvia

²Institute of Food Resources of NAAS, Kyiv, Ukraine

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Subject. Packaging materials made from biodegradable plastics used for packaging dairy products, as well as the technological properties of these materials that allow their use. **Purpose.** To justification of the feasibility of using biodegradable packaging materials, in particular bioplastics, for packaging milk and dairy products. **Methods.** During the research, a systematic approach was used to research factual materials, in particular scientific and scientific-practical literature, regulatory legal acts, regulatory documents and the like; abstract-logical approach to the synthesis of research results and the formulation of conclusions. **Results.** The dairy industry uses biodegradable plastics; bio-based materials derived from renewable resources that can be used for dairy products with a limited shelf life. Biodegradable materials must protect the dairy product from environmental influences and ensure that quality is maintained during transportation and storage. In this sense, mechanical and barrier properties regarding oxygen, carbon dioxide, water, light and odors are important. You should also consider technological aspects of safety (migration, microbial growth), sustainability (heat and chemical resistance), process requirements (weldability and formability), convenience and compliance with marketing principles (communication, printing options). Acceptable mechanical properties are important, which ensure the quality and food safety of the dairy product even during long-term storage and transportation. The mechanical properties of polylactide (PLA) in semi-crystalline form are suitable, the mechanical properties of starch-polycaprolactone (PCL) are somewhat worse. Since hot fill and sterilization can be used for liquid dairy products with a long shelf life, it should be kept in mind that PLA containers are only stable up to a temperature of 55°C, while materials based on starch-PCL mixtures were stable between 60 and 90°C. Good water vapor barrier properties are critical when packaging dairy products such as butter and cheese, where preventing moisture loss and surface drying is key. Dairy products are often sour, salty or high in fat, it is important to evaluate the chemical resistance as

acceptable for PLA. Some microorganisms can use bio-based packaging materials as energy sources. PLA biofilms prevent the growth of molds, and packaging materials based on starch-PCL promote the growth of molds that can affect food products – therefore, it is advisable to include antimicrobial compounds in the material. Migration, the transfer of substances from packaging to food products, according to standards should not exceed 10 mg/dm². The analysis of scientific and technical information proves the possibility and feasibility of using biodegradable materials, in particular bioplastics, as innovative packaging materials for use in the dairy industry. These materials do not differ significantly in mechanical and other technological properties from traditional plastics made from hydrocarbon raw materials. For the practical research was used Soft cheese Kleo (produced in Latvia). It was packaged by the Ceramis®-PLA-SiOx coating film known as the first new biodegradable PLA film with improved barrier properties. However the tests on soft cheese packaging using Ceramis®-PLA-SiOx film gave a negative result, since this packaging material ensured the storage of a perishable product only for 10 days. Therefore, it is expedient to include other PLA films and other polymeric biodegradable materials. **Scope of results.** The results obtained will be used to improve production technologies for various types of dairy products, improve their food safety and quality, and also to preserve the environment by ensuring the biodegradability of packaging materials.

Key words: milk, dairy products, packaging, biodegradable plastics, starch, polylactide, polycaprolactone.

ОГЛЯД АКТУАЛЬНОГО СТАНУ НАУКОВИХ ДОСЛІДЖЕНЬ ТА ПРАКТИЧНИХ ЗДОБУТКІВ У ЦАРИНІ БІОЛОГІЧНОГО ПАКУВАННЯ МОЛОЧНИХ ПРОДУКТІВ

Муйжнієце-Брасава С.¹, д.т.н., проф.

<https://orcid.org/0000-0001-6033-6241>

Вербицький С. Б.², к.т.н., завідувач відділу

інформаційного забезпечення, стандартизації та метрології

<https://orcid.org/0000-0002-4211-3789>

Куць О. І.², к.е.н., заст. завідувача відділу

інформаційного забезпечення, стандартизації та метрології

<https://orcid.org/0000-0002-2855-0659>

Мінорова А. В.², к.т.н., завідувач відділу

молочних продуктів та продуктів дитячого харчування

<https://orcid.org/0000-0002-7557-1444>

Пацера Н. М.², н.с. відділу

інформаційного забезпечення, стандартизації та метрології

<https://orcid.org/0000-0001-8737-9997>

Козаченко О. Б.², гол. фак. відділу

інформаційного забезпечення, стандартизації та метрології

<https://orcid.org/0000-0002-2189-9583>

Недорізанюк Л. П.², н.с. відділу технології м'ясних продуктів

<https://orcid.org/0000-0002-2190-5648>

¹Латвійський університет наук про життя та технології, Єлгава, Латвія

²Інститут продовольчих ресурсів НААН, Київ, Україна

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Предмет. Пакувальні матеріали з біорозкладних пластиків, використовувані для пакування продукції молочної промисловості, а також технологічні властивості зазначених матеріалів, що уможливають їхнє використання. **Мета.** Обґрунтування доцільності використання біорозкладних пакувальних матеріалів, зокрема біопластиків, для пакування молока та молочних продуктів. **Методи.** Під час досліджень використовували системний підхід до досліджень фактологічних матеріалів, зокрема наукової та науково-практичної літератури, нормативно-правових актів, нормативних документів тощо; абстрактно-логічний підхід щодо узагальнення результатів дослідження та формулювання висновків. **Результати.** У молочній промисловості використовують біорозкладні пластики; матеріали на біологічній основі, отримані з

поновлюваних ресурсів, які можуть використовуватися для молочних продуктів з обмеженням терміном придатності тощо. Біорозкладні матеріали повинні захищати молочний продукт від впливу навколишнього середовища і забезпечувати збереження якості під час транспортування та зберігання. У цьому сенсі важливими є механічні та бар'єрні властивості щодо кисню, вуглекислого газу, води, світла та запахів. Також слід враховувати технологічні аспекти безпеки (міграція, ріст мікробів), стійкість (термостійкість і хімічна), технологічні вимоги (придатність до зварювання і формування), зручність і відповідність засадам маркетингу (комунікація, варіанти друку). Важливими є прийнятні механічні властивості, що уможливають якість та харчову безпечність молочного продукту навіть при тривалому зберіганні і транспортуванні. Відповідними є механічні властивості полілактиду (ПЛА) у напівкристалічній формі, децю гіршими – механічні властивості крохмалю-полікапролактону (ПКЛ). Оскільки гаряче наповнення і стерилізація можуть використовуватися для рідких молочних продуктів з тривалим терміном зберігання, слід мати на увазі, що тара з ПЛА залишається стабільною тільки до температури 55°C, натомість матеріали на основі сумішей крохмаль-ПКЛ не втрачають стабільності у діапазоні від 60 до 90°C. Добрі бар'єрні властивості щодо водяної пари мають вирішальне значення при пакуванні молочних продуктів, таких як масло і сир, де ключовим параметром є запобігання втрати вологи і висихання поверхні. Молочні продукт часто є кислими, солоними або з високим вмістом жиру, важливо оцінити хімічну стійкість, як для ПЛА є прийнятною. Деякі мікроорганізми можуть використовувати пакувальні матеріали на основі біологічних джерел в якості джерел енергії. Біоплівки з ПЛА перешкоджають появі пліснявих грибів, натомість пакувальні матеріали на основі крохмалю-ПКЛ сприяють росту пліснявих грибів, якими можуть бути вражені харчові продукти – отже, доцільно включати до складу матеріалу антимікробні сполуки. Міграція, перенос речовин з пакування до харчових продуктів, за нормами не повинна перевищувати 10 мг/дм². Виконаний аналіз науково-технічної інформації доводить можливість та доцільність використання біорозкладних матеріалів, зокрема біопластиків як інноваційних пакувальних матеріалів для використання у молочній промисловості. Ці матеріали суттєво не відрізняються, за механічними та іншими технологічними властивостями, від традиційних пластиків з вуглеводневої сировини. Для практичних досліджень використовувався м'який сир Клео (виробництво Латвія). Він був упакований плівкою Ceramis®-PLA-SiOx, що покриває, відомою як перша нова біорозкладна плівка PLA з полішеними бар'єрними властивостями. **Сфера застосування результатів.** Отримані результати використовуватимуться для вдосконалення технологій виробництва різних видів молочної продукції, підвищення її харчової безпечності та якості, а також для збереження довкілля завдяки забезпеченню біорозкладності пакувальних матеріалів.

Ключові слова: молоко, молочні продукти, пакування, біорозкладні пластики, крохмаль, полілактид, полікапролактон.

Formulation of the problem. Since milk and dairy products are an important source of nutrients needed by the human body, it is necessary to organize and technically/technologically ensure their production process in such a way that these products retain their beneficial properties as much as possible – incl. the use of packaging that guarantees safety and quality of dairy products within the shelf life determined by scientific research and implemented by standards and specifications.

The modern food market is characterized by an increase in the share of milk processing products produced in consumer packaging. At the same time, the market requires an increase in the supply of light-weight and small-sized packaging, which, at the same time, entails a significant increase in the burden on the environment, since the overwhelming majority of packaging materials (polymer films, polymer containers for liquid products, glass containers, etc.) actually do not biodegrade in natural environment. Despite the existence of research on modern environmental packaging materials, it has not yet been possible to develop packaging methods using environmental materials that have found application in domestic food enterprises – mainly due to inadequate sustainability and the high cost of implementing appropriate technologies [1].

The use of biodegradable packaging materials which is obtained from renewable sources is among the essential factors to increase food sustainability. Scientific studies have proven that recycled plastics can be used for packaging materials, thus not causing pollution by accumulating a large amount of waste that adversely affects the existence of our planet's ecosystem. Therefore, companies are willing to invest in the use of more eco-friendly plastics that can be used as bio-based packaging material that may store packaged products and take advantage of residues that would be discarded otherwise as well as increase the storage time of foods products [2–5].

Today there are many opportunities for the industrial production of various biodegradable materials. It is proposed [6–8] to distinguish three groups of biodegradable materials:

- plant polymers used alone or in mixture with biodegradable synthetic polymers (Fig. 1);
- microbial polymers obtained by fermentation of agricultural raw materials used as a substrate. Among these polymers, polyhydroxyalkanoates or PHAs are also distinguished [6], the most famous representative of which is PHBV (polyhydroxybutyrate covaleriat);
- monomers or oligomers polymerized by conventional chemical processes and obtained by fermentation of agricultural raw materials used as a substrate. Among the materials in this category, the most famous is polylactide (PLA), shown in Figure 2.

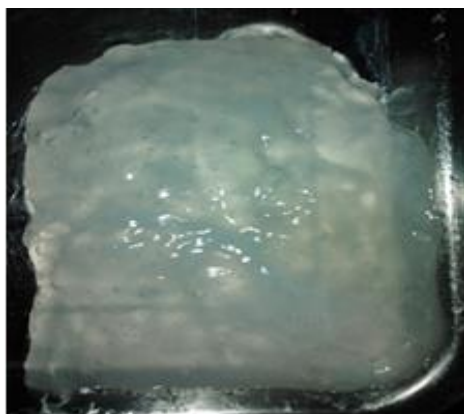


Fig. 1. Bioplastic of starch [9]



Fig. 2. Polylactide (PLA) [10]

In the classification proposed by the author [11], a fourth class was also added to the three classes listed above:

- products obtained by synthesis from petrochemical raw materials. These are several polymers or subgroups: polycaprolactones (PCL); polyetheramides (PEA); an aliphatic copolyester such as polybutylene succinate adipate (PBSA); an aromatic copolyester such as polybutylene adipate coterephthalate (PBAT).

Biodegradable polymers PCL and PLA are the most common on the market, second only to starch derivatives [12]. The hierarchy of biodegradable polymers, as well as the raw materials used for their production, is presented in Fig. 3.

Biodegradable materials used for food packaging are made from proteins – both plant (soybean, corn, wheat, peas, etc.) and animal (casein, collagen, whey, keratin, gelatin, etc.) [13, 14].

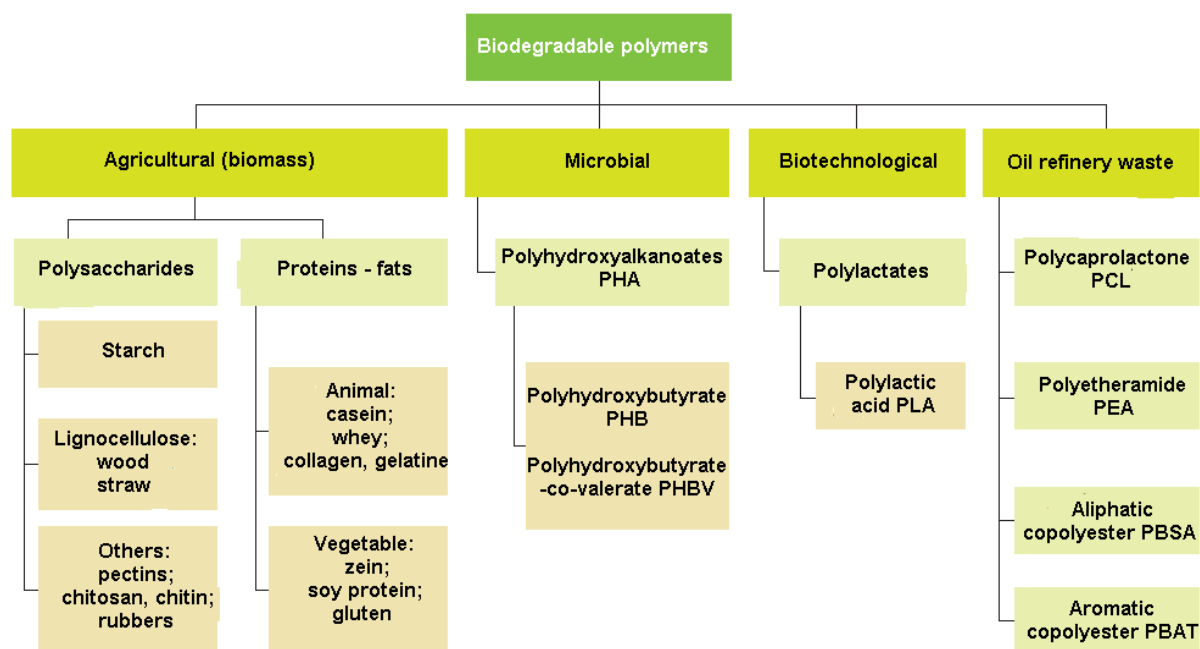


Fig. 3. Hierarchy of biodegradable polymers – modified from sources [6, 11, 12].

Coatings act as barriers to water loss and gas exchange while controlling the transfer of moisture, oxygen, lipids and aroma components (Fig. 4) with an effect similar to that of maintaining these properties under controlled conditions or in a modified atmosphere [15, 16].

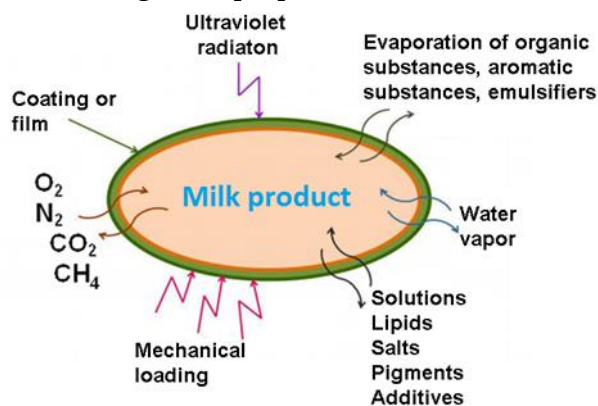


Fig. 4. Factors for which biodegradable films used for food packaging must have barrier properties [6, 15, 17]

It is important to properly ensure that the packaging methods used in practice for dairy products and the packaging materials used for this purpose comply with modern environmental requirements and to develop technologically efficient, resource-saving and environmentally friendly packaging methods for typical dairy products. This is not possible without an effective combination of the criteria of manufacturability and environmental friendliness of packaging milk and dairy products with the innovative nature of the development of the dairy industry at the present stage, which is characterized by the intensive use of new food production

technologies, new packaging materials and relevant technologies, as well as the growing demands of consumers for these products, including their packaging. Methods and materials used for packaging the main types of dairy products, ways to improve the environmental friendliness of the packaging used, their convenience for consumers, etc. should be assessed based on such criteria as resource efficiency (including energy efficiency of the technologies used) and the impact on the economic performance of production in general. The listed requirements are fully met by biodegradable packaging, light-weight and small-sized packaging, coating packaging of biological origin, as well as other modern methods of packaging dairy products. The use of environmental coatings will improve the overall technical level of the dairy industry by reducing the energy and material consumption of packaging methods used, and using new materials for this purpose, including biodegradable ones, which will help reduce the burden on the environment. Eliminating environmental risks caused by the unrestricted use of synthetic packaging films and other packaging materials and/or containers, reducing the overall burden on

the environment is an urgent technical and economic task, the implementation of which will contribute to the progress of the dairy industry.

Experts are aware of the dualistic contradiction inherent in the problem of modern mass packaging of food products, including dairy products, which consists in the fact that both the fundamentals of food safety and modern resource-saving requirements for extending the permitted shelf life of food products require packaging that is resistant in the chemical and biochemical sense, as well as mechanically strong materials. However, materials with these characteristics are extremely difficult to decompose under natural conditions, which can take from several years to many centuries. Understanding the relevance of solving this issue encourages the search for materials that effectively decompose in the natural environment after use, and proper regulatory registration of the use of packaging of dairy products that are made from these materials [1].

Enhancing the scientific knowledge on the biodegradable polymer materials which are of practical significance for the milk processing industry is the principal goal of the Ukrainian-Latvian Joint Scientific and Technological Cooperation Project “Enhanced use of environment friendly biodegradable packages for dairy products (BIOPACK Dairy)” which is to start in 2023 and to be fulfilled by the researchers of the Institute of Food Resources of NAAS (Kyiv, Ukraine) and Latvia University of Live Sciences and Technologies (Jelgava, Latvia).

Materials and methods. The subject of this material is to assess the environmental, technical and technological feasibility of using bioplastics for packaging milk and dairy products. During the research, we used a systematic approach to the study of factual materials, in particular, scientific and scientific-practical literature, regulations, normative documents, etc.; an abstract-logical approach to summarizing research results and formulating conclusions.

For the practical research was used Soft cheese Kleo (produced in Latvia). It was packaged by the Ceramis®-PLA-SiOx coating film known as the first new biodegradable PLA film with improved barrier properties [18]. The thickness of the film was $50 \pm 2 \text{ }\mu\text{m}$ [19].

Results and discussion. Milk products are packaged using:

- cellulose-based paper materials for liquid and dry dairy products, parchment wrappers for butter, curd products, etc.;
- polymer materials (bags, boxes, cups, etc.) for milk, liquid dairy products, yogurt, sour cream, sterilized products, etc.;
- glass containers (bottles, jars, etc.) for milk, liquid dairy products, canned milk, etc.;
- aluminum laminated or laminated foil for butter, curd products, processed cheeses, etc.;
- metal cans for condensed milk, milk powder, canned cheeses, etc.;
- plastics, including biodegradable plastics, used to package almost every category of dairy products;
- bio-based materials derived from renewable resources that can be used for dairy products with a limited shelf life.

Biological materials are materials primarily obtained from annually renewable sources. These materials may be composted, which in itself is not a key point since overall waste management of composted materials is not perfect [1].

Biologically based materials must protect the dairy product from environmental influences and ensure quality preservation during transportation and storage. Critical aspects are the mechanical and barrier properties of oxygen, carbon dioxide, water, light and odors. In addition, safety (migration, microbial growth), sustainability (heat and chemical resistance), process requirements (weldability and formability), convenience, and marketing requirements (communication, printing options) should be considered when selecting packaging materials for dairy products [20–23].

Mechanical properties are critical and must be adapted so that the dairy product is protected even during long-term storage and transport. Polymers can be tailored to some extent to match certain mechanical properties, for example by selecting raw materials or blending with

other polymers or fillers, or by adding fibers, cross-linking, plasticization. A positive correlation can be obtained between the amount of plasticizer in the polymer and the tensile strength. In addition, polymer orientation during processing can improve the mechanical strength and thermal stability of PLA polymer [20, 24–27]. The corresponding mechanical properties are characteristic of PLA in semi-crystalline form, rather than in amorphous form. Since crystallinity can be determined by the enantiomeric forms of PLA, their mechanical properties are controlled by the ratio between poly-L-lactic acid (PLLA) and poly-D-lactic acid. There are various processing parameters that can be varied to produce specific mechanical properties of biopolymers that mimic those of conventional oil-based polymers, both rigid (polyethylene terephthalate, PET) and flexible materials (e.g., polyethylene, PE) [20, 24, 25]. Mechanical properties of polyhydroxybutyrate (PHB) resemble the properties of isotactic polypropylene (PP) [24], and PLA has mechanical properties similar to conventional packaging materials such as PE, PP and PET [28, 29].

Comparative tests showed that the tensile strength, elongation and tensile strength of PLA and starch-PCL films were lower than those of low-density polyethylene (LDPE) and high-density polyethylene (HDPE) [30, 31] starch-based, PLA and PHB was in the same range as for containers made of PP, polystyrene (PS) and polyethylene [31, 32].

Natural starch does not meet the requirements of food packaging because its mechanical strength and stability are too low [33]. Such results have also been reported for LDPE-starch blends, where the negative effect on mechanical properties varied with increasing starch content [34, 35]. Studies have shown that PLA polymers are sensitive to moisture and heat, resulting in loss of mechanical properties. PLA films lose mechanical properties more often when stored at high temperatures and humidity than when stored under the opposite conditions [36, 37]. However, another study showed that PLA was mechanically stable when packaging food products with moisture content ranging from dry to wet and at storage temperatures from cooled (5°C) to ambient temperature (25°C) [38]. Comparative characteristics of traditional and biodegradable packaging materials are presented in Table 1.

Table 1

Comparative characteristics of traditional and biodegradable packaging materials.
(Adapted from [39–42])

Polymer	Density, g/cm ³	Tensile strength, MPa	Tensile modulus, MPa	Fracture elongation, %	Melting point, °C
PHB	1.18–1.26	25–40	3500	5–8	168–182
PLA	1.21–1.25	48–60	3500	30–240	150–162
PP	0.9–1.16	30–40	1100–1600	20–400	161–170
PS	1.05	34–50	2300–3300	1.2–2.5	70–115

The consumption temperature for most dairy products is between 0 and 40°C. However, hot filling and sterilization can be used for liquid dairy products with a long shelf life. In addition, when processing packaging materials (molding, sealing), they are exposed to high temperatures. Therefore, packaging materials must resist deformation at high temperatures for a certain period of time depending on the products being packaged.

Thermal applications of bio-based packaging materials are expected to be relatively limited as stability decreases with increasing temperature, as has been observed for PLA [20, 25], especially when exposed to high humidity [43]. First generation PLA containers are only stable up to 55°C. however, information on oriented PLA film (OPLA) with use temperatures up to 150°C is [44–46].

The barrier properties of water vapor depend on the type of product. For example, superior water vapor barrier properties are critical in packaging dairy products such as butter and cheese, where preventing moisture loss and surface drying is then key issue. In addition, packaging of

products with a short shelf life is less critical since the temperature is low and the shelf life is less than 10 days. Thus, a thin layer of polyethylene is a sufficient barrier to moisture in milk cartons.

The barrier properties of gases also depend on the nature of the product. For example, high barrier properties are required for packaging products in modified environments (sliced cheeses and milk powder), a less dense gas barrier is sufficient for packaging products with a short shelf life (drinking milk and yoghurts) [20].

There are numerous reports on the barrier properties of bio-based materials [14, 27, 31, 34, 44-60]. However, comparisons between different materials are difficult or even impossible due to the use of different processing equipment, variations in raw material parameters, and different measurement conditions. The decision depends on the results of research into the shelf life of the product and the packaging material used. It is important to consider the dimensions of the package and avoid large surface areas over the total volume of the package. The reason for this is that bio-based polymers are often hydrophilic and therefore may not function well if distinct water vapor barrier properties are required. However, when comparing the water vapor transmission rates (WVTR) of various bio-based packaging materials with those based on mineral oils, it becomes apparent that it is indeed possible to produce biomaterials from acceptable WVTR, especially for short-term storage of dairy products. Research and development efforts are currently focused on improving the vapor barrier for bio-based materials, and future materials may have water vapor barrier properties similar to conventional [20] materials.

Water vapor barrier properties for bio-based materials (starch, protein and chitosan) are worse than for conventional food packaging materials [24, 51–53]. WVTR of films and containers based on starch and oil were compared with this indicator for LDPE and HDPE films, as well as PP. Containers made from PP and PS had the same thickness. The results showed that the WVTR of starch-based films was 4-6 times greater than that of conventional films. In addition, starch-based containers had 100-300 times more ballast than those made from PP and PS, and 5–9 times more than containers made from PS [31]. However, technological developments, in particular the combination of various biopolymers, may lead to the production of starch-based materials suitable for short-term storage of dairy products. In [54] there was a noticeable improvement in the water vapor barrier of starch films by adding chitosan. It should be noted that the criteria for assessing the effectiveness of water vapor barrier properties should be the shelf life and quality of individual products, rather than comparison with properties, in some cases, more acceptable than those of conventional materials.

PLA provides better protection against water vapor than starch-based materials. The source [31] notes that the WVTR of PLA films was only 4 times greater than that of conventional films (PVC and LDPE), 2 times greater than for PS containers, and 40–60 times greater than for PP and PS containers. PLA is moderately polar and therefore moisture is expected to affect its water vapor barrier properties. However, there was no effect on the permeability of PLA by different relative humidity inside and outside [14]. PHAs have low WVTR values similar to those characteristic of LDPE [23]; this makes the material promising, for example as a moisture barrier in milk cartons or butter wrappers.

The oxygen transmission rates (OTRs) of most biomaterials demonstrate significant performance in a wide range of traditional materials based on mineral oils. High is the OTR indicator for PLA [32]. In [49] it is reported that the SPC for PLA is 10 times lower than that of oriented polystyrene (OPS), and approximately 6 times higher than that of PET. 20-micron thick plastic melts based on PLA, a mixture of wheat starch and PCL, as well as a mixture of corn starch and PCL, have a small SPC, which is significantly lower than that of the LDPE and HDPE [31] melts. OTR of durable containers based on PLA and PHB was also lower than that of PP, PS and PE [29]. We can add PLA and PHB, combining them with a ball of chitosan, protein or spilt with modified starch, which is mixed with high barrier power until sour [24, 46]. These

materials may become an affordable alternative to volatile gas barrier materials, ethylene vinyl alcohol (EVA) and polyamide.

The selectivity (level of permeability) of bio-based materials towards other gases is in the range that is typical for conventional packaging materials used in the food industry.

Typically, mineral oil-based polymers have a carbon dioxide : oxygen ratio of 4:1 to 6:1 [23]. The permeability ratios of the two specific PLA films were 7:1 [31], which is in the range of conventional plastics. A ratio of 15:1 has been reported in the literature for wheat gluten films [47]. Increasing the ratio at higher relative humidity means that the films gradually become more permeable to carbon dioxide compared to oxygen [44]. This may be a preferred property for products that generate large amounts of carbon dioxide during storage, such as Emmental cheeses.

A significant increase in the OTR with increasing moisture content is observed for materials such as EVA and chitosan [55, 56]. The barrier properties of PLA and PHA do not depend significantly on humidity [23, 49]. The OTR is reported to decrease slightly with increasing relative humidity. However, this phenomenon was observed only at 40°C, while at 5°C and 23°C no significant effect was observed [57]. Accordingly, humidity does not affect the OTR during refrigerated storage of dairy products. Therefore, PLA and PCL can protect the moisture-sensitive gas barrier provided by chitosan, polysaccharide or protein [58, 59]. In addition, developments have improved the waterproof and gas barrier properties of bio-based materials, mainly through plasma deposition of glassy silica or by applying nanocomposites from natural polymers and modified clays [60–62].

Odor barrier properties are an important characteristic, especially for products such as butter and milk, which can take on flavors such as citrus fruits. In addition, poor odor barrier properties can lead to loss of odor in mature cheeses, which leads to deterioration in quality. Unfortunately, there is virtually no data on aroma permeability. PLA has been found to be an effective barrier to ethyl acetate and D-limonene and is thus expected to be a good odor barrier. Based on the literature, odor barrier properties are not a specific problem for biobased materials. Light-protective properties are important to prevent photo-oxidation of proteins, lipids and nutrients. However, these properties can be modified to suit the requirements of dairy products by using biodegradable dyes.

Exposure of packaging materials to oils as well as acids can reduce the effectiveness of the polymer. Because many dairy products are sour, salty and/or high in fat, it is important to evaluate the chemical resistance of the materials. A comparison of [49] OPLA with PET and OPS showed that exposure to acids (pH 6 to 2) and vegetable oils resulted in only minimal degradation in strength, instead OPLA with 40% recycled content actually showed an improvement. In the second study of OTR of PLA containers, nothing changed after 4 months of exposure to rapeseed oil – this also applies to the mechanical properties of [64].

Microorganisms can use bio-based packaging materials as energy sources. Thus, there is a potential risk of unwanted mold and bacteria growing on packaging, and if the packaging degrades during food storage, external microbial migration may occur, resulting in food contamination. There are only a few reports of increased microbial populations on bio-based packaging materials. Research shows that PLA and PHB inhibit the growth of molds [50, 65], and starch-PCL packaging materials promote the growth of molds that can affect food products. Therefore, the authors proposed a modification, that is, the inclusion of antimicrobial compounds in starch-based packaging materials.

In food packaging terminology, the term migration is used to describe the transfer of substances from packaging to food, which is an important aspect to consider when using food packaging materials. According to European Union standards, total migration should not exceed a limit of 10 mg/dm². Migrants from biopackaging materials may include, for example, lactic acid, linear and cyclic lactide dimer, various small oligomers of PLA [66], food grade and

hydrolyzed starch. These migrants may be naturally present in foods and therefore may be considered safe for food packaging purposes [67].

Additional studies have shown that migration from various PLA polymers to water, octic acid, isooctane, olive oil and solid stimulant – modified phenylene oxide – is significantly lower than 10 mg/dm^2 [50, 66, 68]. Therefore, PLA is clearly recognized for its direct role as a polymer for the preparation of vegetables, which is used for curing, and as a packaging material for grub products [66].

Brazilian designers have found a solution that can replace the negative effects of most common bioplastics with starch – its irreplaceable value. Significant authors have recommended placing a container for milk prepared with starch-based bioplastics in a rigid box made of cardboard (Fig. 5). Safe bioplastic comes into contact with milk, and the rigidity is ensured by the outer cardboard structure [69].



Fig. 5. Innovative biodegradable packaging for milk and liquid-like milk products [69]

The research of a soft cheese belonging to perishable food was conducted [19]. Commercially available Ceramis®-PLA-SiOx and plain polylactide PLA films were used for packaging of the soft cheese Kleo. Considering all experimentally obtained results, it was recognized that the shelf life of cheese Kleo could be acceptable when packaged in the biodegradable Ceramis®-PLA-SiOx-coated film and stored till 30 days, which is similar to conventional packaging materials PE/OPA and Multibarrier 60. Whereas the PLA film, which is without barrier properties, provided the shelf life of only 10 days for the soft cheese Kleo,

therefore it can be concluded that the PLA material is not useful for packaging of perishable products [70]. Experiments were also carried out to use the Ceramis®-PLA-SiOx for Sous vide packaging of soft cheese Kleo under conditions of mild thermal treatment (60–62°C), and it was found that the shelf life of cheese Kleo exceeded 30 days.

As a direction of the future research a study of determination and / or predicting the shelf life of milk products in biodegradable packaging can be recommended. Based on the methodology described in [17, 71], the problem of predicting the shelf life of a food product in a biodegradable package can be solved, having previously substantiated the nomenclature of factors $X_1 \dots X_4$, the most significant in terms of finding the parameters that determine the quality of these products and the technological suitability of the package after a specific shelf life. In this case, it is advisable to use the following factors when performing the shelf life capacity calculation (Fig. 6):

- X_1 is a complex factor of dairy product quality;
- X_2 is the factor of the barrier properties of the packaging material;
- X_3 is the mechanical strength factor of the packaging material;
- X_4 is the biodegradation resistance factor of the packaging material.

When the values of these variables are determined in the course of practical studies, it is possible to obtain interpolation formulas that can be used to reliably predict the duration of storage of dairy products in ecological biodegradable packaging.

Also the research and development concerning biodegradable packaging materials for the food, including milk, products can be focused on modifications of regulatory documents of various levels on specifications for food products, in the sense of adding provisions governing the procedure and rules for their ecological packaging. This can allow in a sufficient and expedient way updating domestic and international regulatory documents in force [72]. So this is

a confirmation of the opinion containing in [65] that packaging materials and techniques for dairy products and liquid milk kept evolving with the advancements in materials engineering and technologies along with the user aspirations and behavior. Biodegradable packaging answers the ecological viewpoint while the durability of low waste materials has a correlation with product shelf life which needs to be addressed [17].

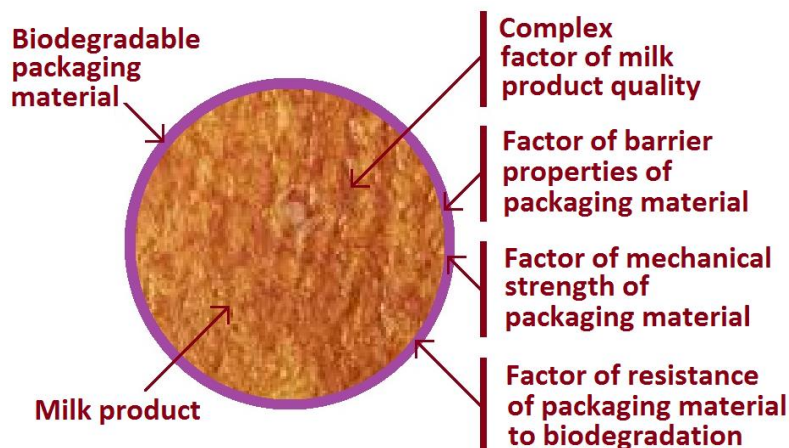


Fig. 6. Factors to be taken into account in the calculation scheme for determining the storage capacity of milk products in biodegradable packaging [17]

Conclusion. Scientific and technical information collected and analyzed confirms the possibility and feasibility of using biodegradable materials, in particular bioplastics, as innovative packaging materials for use in the dairy industry. These materials, primarily PLA, do not differ significantly in mechanical and other technological properties from traditional plastics made from hydrocarbon raw materials.

Experiments carried out on packaging soft cheese using Ceramis®-PLA-SiOx film gave a negative result, since this packaging material ensured the storage of a perishable product only for 10 days. Therefore, within the framework of the Ukrainian-Latvian project, it is advisable to introduce other PLA films and other polymer biodegradable materials.

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