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Biodegradable Polysaccharide Films for Eco-friendly Packaging: Composition Optimization, Properties and Design

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ABSTRACT

The use of biodegradable materials remains limited in comparison to traditional plastics. The main markets for biodegradable materials are located in North America and Europe, where strict environmental regulations and public awareness are high. Our questionnaire survey revealed that the development of biodegradable packaging and its appearance is a hot issue in our country. The aim of this research was to develop polysaccharide-based film formulations, analyse packaging design models and create graphic visualizations of production. The paper identifies the main components for creating polysaccharide-based bioplastics. The results of experiments on different prototype compositions, analyzing their solubility in aqueous medium for comparative analysis against each other and conventional polyethylene, are presented. Additionally, the environmental friendliness and application efficiency of the new compositions are evaluated, and graphic visualizations of processes and logo design solutions are proposed. In general, each of the obtained prototypes has unique biopolymer properties, which allows for the selection of the most suitable one depending on the specific task and material requirements. Results indicate that compositions with higher gelatin content demonstrated optimal strength and rapid degradability, making them suitable for sustainable industrial packaging. These findings emphasize the practical value of introducing polysaccharide-based materials into mass production.

1. INTRODUCTION

In recent decades, environmental and sustainability issues have become top priorities for global society. One of the most relevant themes within this issue is eco-transition in packaging, designed to reduce the negative impact of human activities on the environment. In an era where the challenges of pollution and climate change are becoming increasingly unstoppable, green transition of the packaging industry is of strategic importance. Packaging waste, especially plastic packaging, is emerging as a major challenge for planetary health. Food packaging plays an important role in the food industry, but the current trend in the sector is towards developing lightweight and biodegradable packaging materials to reduce petroleum raw material consumption, waste utilisation and energy costs for transport. The degradation process of traditional polythene packaging and plastic has certain limitations, as it requires a long time to degrade [1, 2]. In contrast, degradable packaging materials stand out as an innovative solution that provides environmentally sustainable alternatives [3-6]. They not only degrade naturally with minimal environmental impact but are also produced using renewable resources, thus contributing to the transition to a circular economy.

Packaging design can also serve as a means of educating and informing consumers about the benefits of sustainable materials. Innovative shapes, colours and graphic solutions can convey important messages about the nature of products and their environmental impact [7-10]. Effective design can also help to reduce excess packaging, which is another important aspect of reducing the environmental impact of packaging materials. A detailed analysis will highlight innovations in packaging design that contribute to an effective environmental transition in this area.

Recent research in the field of biodegradable polysaccharide-based packaging is mainly focused on food packaging and its impact on food quality. Studies conducted over the past five years [11-14] on polysaccharide-based eco-packaging indicate that the primary disadvantage of these materials is their sensitivity to moisture and limited mechanical durability. However, specific experimental work on non-food packaging and systematic comparative studies on the water solubility of different polysaccharide compositions have not been extensively reported. There is also a lack of up-to-date research on methods of their further promotion by offering design solutions, using these films as packaging for non-food consumer goods, developing their logos and attractive appearance. This issue is also important because the development of corresponding logos, packaging aesthetics, and various packaging forms made from such films will contribute to an effective and rapid transition toward biodegradable materials. The novelty of the study lies in the development of techniques and solutions that integrate biological and environmental aspects with ergonomic design in the field of polysaccharide film fabrication.

This study focuses on polysaccharide eco-packages and their design, with a particular emphasis on the solubility of bio-packages in aqueous media. The aim of this study is to develop an optimal, rapidly degradable film composition for packaging and to investigate the feasibility of replacing polyethylene and plastic through mold design and aesthetic improvements.

2. REVIEW OF THE LITERATURE

Main characteristics and advantages of polysaccharide-based materials. Currently, polysaccharide films represent an innovative solution in the field of sustainable packaging materials. Having considered the main properties of starch that make it suitable for the production of such films, and having assessed the advantages of using starch compared to traditional materials used as packaging, the following positive properties have been identified:

Biodegradability: Starch is a biodegradable material, which means that it is able to decompose in nature under the influence of microorganisms. This significantly reduces the time period during which the material remains in the environment and reduces the negative impact on ecosystems. To address the long decomposition time associated with plastics, research is being conducted on readily biodegradable materials for use as packaging materials in various industries. Among various biopolymers, starch-based films have attracted particular attention due to their relatively low cost [4, 15-17].

Renewable resources: Starch is produced from plant sources such as maize, potatoes or wheat. This means that it is based on renewable resources, which makes it more sustainable in terms of natural resource consumption.

Energy saving: The production of packaging films from starch generally requires less energy compared to the processes used to create traditional plastics. This helps to reduce the overall environmental footprint of production.

Reduced dependence on petroleum: Unlike many traditional plastics, starch as a raw material does not require petroleum resources for its production [5, 6].

Diversity of applications: polysaccharide films have a wide range of applications, with much of the research focusing on their use as food packaging [18-22].

Thus, studies in the last 10-15 years on starch-based biodegradable films focus on current trends in biodegradable polymers, packaging materials mainly for food products, the application of nanotechnology and nanocomponents for the production of the films being investigated [3, 23-25], analyses of the challenges and opportunities associated with polysaccharide-based materials, and extraction methods and sources of starch to create biodegradable films [26-29]. Thus, these researches consider starch production and processing, sources, current industrial applications of polysaccharide-based biodegradable films, their properties, addition of nanomaterials, introduction of antimicrobial agents, and shelf-life evaluation of food products packaged in biodegradable starch-based films.

Disadvantages and problems of existing research: Despite a significant amount of experimental data on the properties of polysaccharides and on the production of film materials from polysaccharides, current research has certain disadvantages:

Limited comparative data: Currently, there are no comparative experimental data on the degree of solubility in an aqueous medium of biodegradable materials obtained using various variations.

Insufficient attention to practical aspects: Research often focuses on laboratory results and does not fully cover issues of further marketing and design for their use as packaging.

Lack of standards: The lack of generally accepted standards for assessing the biodegradability and durability of such materials makes their mass adoption difficult.

This work presents the results of research on four formulations of different components of biodegradable films. It also includes their comparative analysis for moisture resistance and the development of an attractive appearance of eco-packaging.

3. MATERIAL AND METHOD

Methodological approaches applied to solve the set tasks were based on the use of general scientific methods, such as theoretical and methodological analysis of literary sources, empirical methods (observation, description, measurement, experiment, and comparative analysis). With the help of these methods, detailed analysis and systematisation of the obtained data were conducted, resulting in objective results.

For the creation of single-use eco containers, various combinations of the components of the prototypes were selected by experimentation until the most optimal compositions were obtained.

At the same time, a sociological method of questionnaire survey was used to create consumer-oriented ecopackaging.

To study public opinion on the use of plastic bags and polyethylene containers, as well as the development and general use of biodegradable eco-materials for packaging, a questionnaire survey was conducted among residents of Kazakhstan (Figures 1-10).

1. Your age?

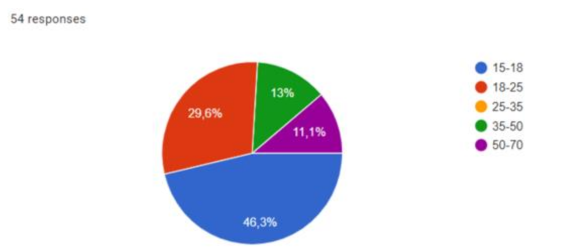


Figure 1. Age of the respondents

2. What role does product packaging play for you when choosing a product?

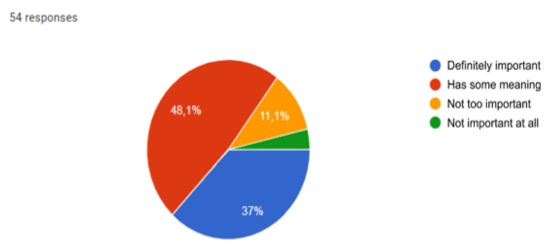


Figure 2. Diagram of answers of respondents to question No.2

3. What is more important to you when choosing packaging?

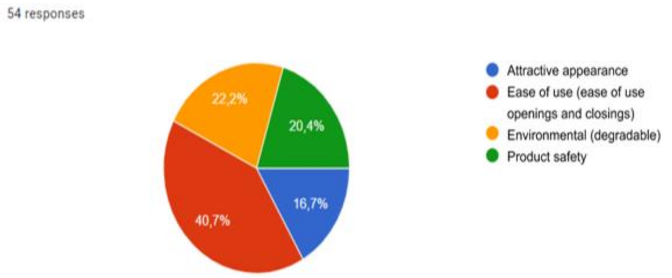


Figure 3. Diagram of answers of respondents to question No.3

4. Have you ever thought about where the packaging goes after being sent to the rubbish?

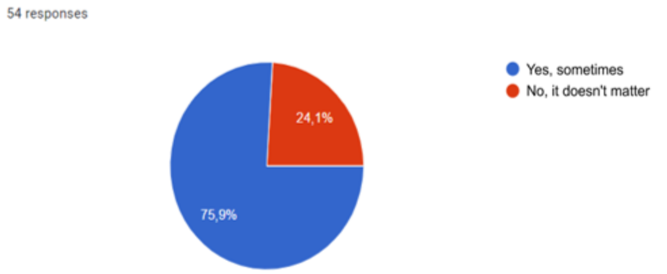


Figure 4. Diagram of answers of respondents to question No.4

5. What do you think makes packaging "eco"?

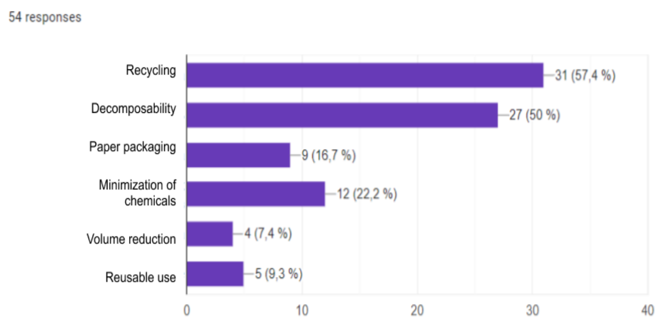


Figure 5. Diagram of answers of respondents to question No.5

6. Is it important to you that companies use more eco-friendly materials when packaging their products?

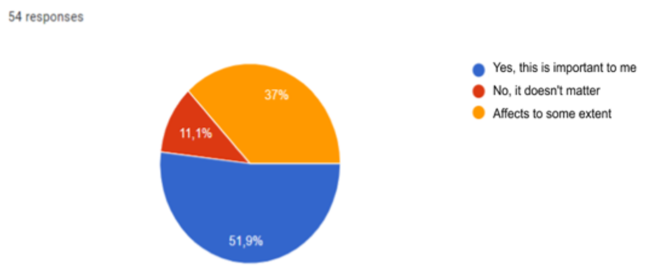


Figure 6. Diagram of answers of respondents to question No.6

7. What types of materials do you feel are the most environmentally friendly for packaging?

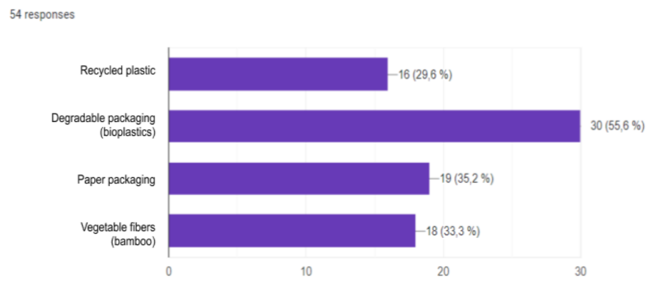


Figure 7. Diagram of answers of respondents to question No.7

8. Would you be willing to purchase goods in degradable packaging?

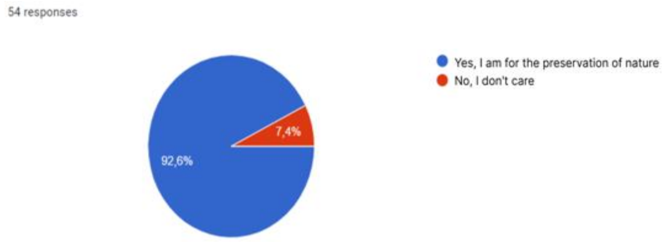


Figure 8. Diagram of answers of respondents to question No.8

9. What types of products do you think would most benefit from a move to eco-friendly packaging?

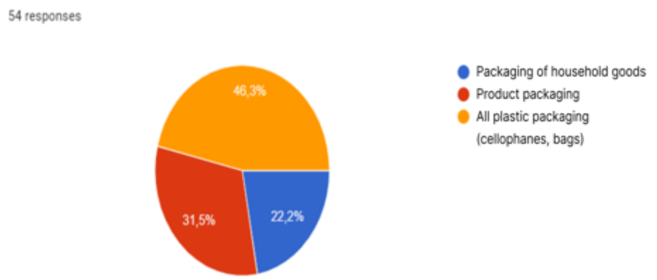


Figure 9. Diagram of answers of respondents to question No.9

10. Have you come across eco-packages in the shop shelves of our country?

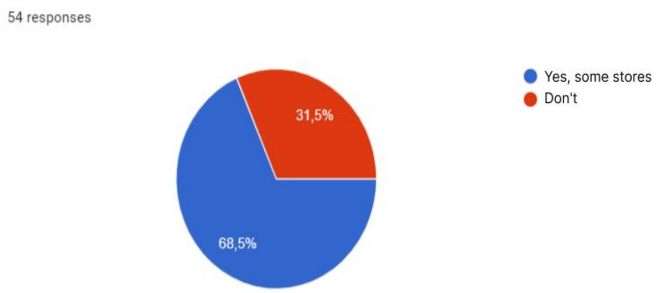


Figure 10. Diagram of answers of respondents to question No.10

The questions and answers are given above. The results and conclusions of the sociological survey are given in the results and discussion section.

Further, in order to identify the most rapidly degradable materials for eco-packaging in aqueous environment in time, the work was continued by determining the optimal composition and their comparative analysis.

In the process of creating biopolymer samples, materials such as potato starch, agar-agar (red algae) and other components that promote the hydrolysis of starch and agar-agar were used. Acetic acid and salts (table salt, baking soda) were used to obtain linear starch structures, as well as glycerol, which gives the biopolymer flexibility and softness. Obtaining a certain degree of viscosity and packing thickness depended on the amount of added water involved in the starch hydrolysis reaction.

To better understand the aspects involved in the development of polysaccharide-based material for eco-packaging and to facilitate the search for optimal approaches to its preparation, it was necessary to realise the mechanics of the reactions occurring in the process and their functional purpose. The main building blocks here were natural biopolymers, starch and agar-agar. These components play a key role in forming the structure of the bioplastic and determine its properties. Understanding the chemical nature of starch and the interaction of its constituent elements, is the basis for the development of efficient methods to produce these eco-materials with desired characteristics. Linear amylose molecules are more favoured for plastic production, which explains the presence of acids and salts in the formulations. The ions of these chemical compounds in solution help to break the bonds that connect the branches of amylopectin. What occurs is the splitting of amylopectin into many shorter chains of amylose. These molecules interact and form strong bonds, giving the plastic the strength it needs.

The production of prototypes of eco-packages using the following materials was carried out using the following technology: pre-dosed mixtures were jointly heated to a temperature of 95°C (before foaming for about 3-5 minutes), by constant stirring until a homogeneous mass was obtained with different consumption of the components of the composition, mass %:

Composition	**No.1 (counting at 100%)**
Water	96
Glycerin	2
Agar-agar	2
Composition	**No.2 (counting at 100%)**
Water	89
Potato	Starch 7
Vinegar	1.5
Glycerin	2.5
Composition	**No.3 (counting at 100%)**
Water	89
Gelatin	6.5
Pectin	2
Glycerin	2.5
Composition	**No.4 (counting at 100%)**
Water	93
Gelatin	4.5
Glycerin	2.5

The mixtures were then removed from the heat, with continued stirring until foam was deposited. The resulting masses were transferred to pre-prepared silicone molds. After cooling to room temperature, the samples of the experimental batches were dried and gained strength.

For the experiment on solubility, a quantitative analysis was conducted, including measurements of the dissolution rate and the percentage of mass reduction. Figure 11 presents the indicators of sample weighing on analytical balances, expressed in grams.

Sample No.1	Sample No.2	Sample No.3	Sample No.4	Control No.5
0,0391 g Before the experiment	0,137 g	0,038 g	0,047 g	0,003 g
0,039 After 10 minutes	0,137 g	0,038 g	0,047 g	0,003 g
0,0052 g Two hours later	0,111 g	0,0281 g	0,035 g	0,0028 g
0,0046 g Three days later	0,089 g	0,0068 g	0,014 g	0,0028 g

Figure 11. Weighing results of test and control samples on analytical scales (average of 3 measurements)

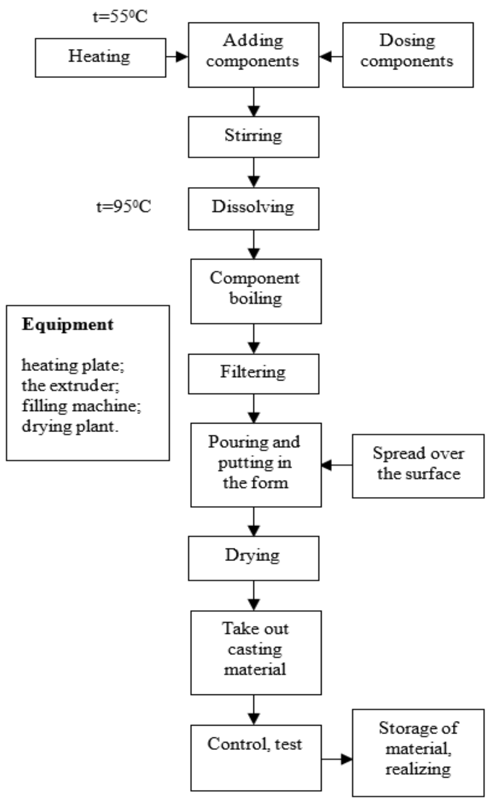


Figure 12. Technological scheme of production of biodegradable film materials for eco-packaging

Figure 11 presents the rate of dissolution and the decrease in mass.

A statistical assessment of the significance of sample dissolution was performed at the initial weight and three days later. The statistical analysis of the weighting method is given below.

Average weight loss: 0.0292 g. Standard deviation of mass reduction: 0.0158 g. t-statistic: 9.56. p-value: 0.0024. The p-value is less than 0.05, which indicates statistically significant differences between the samples and the control sample. This means that samples 1, 2, 3, and 4 differ significantly from the control sample in terms of weight reduction.

A technological scheme for the production of biodegradable film materials for eco-packaging has been developed. A simple flowchart is shown in Figure 12.

4. RESULTS AND DISCUSSION

According to the results of the survey, it can be concluded that for the majority of respondents product packaging is of some importance or definitely important when choosing a product. The survey was conducted in Google Forms format with the consent of all participants, which involved fifty-four respondents aged 15-70 years.

Usability and environmental friendliness are considered important characteristics of packaging. Most of them think about the fate of the packaging after use and consider the environmental aspects of the packaging material as well as their design important. Most respondents like the use of recycled plastic, degradable packaging, paper and vegetable fibres as the most environmentally friendly packaging materials. They are willing to purchase goods in packaging that degrades quickly and looks attractive. Product packaging and all plastic packaging are considered the categories that would benefit most from a shift to sustainable packaging. A significant number of domestic respondents have not encountered rapidly degradable eco-packaging in retail outlets.

To assess the reliability and validity, an expert assessment and constructive validity of the survey were conducted. Thus, based on the analysis of the questionnaire responses, it was found that the development of biodegradable packaging and its appearance, as well as the early transition to eco-packaging is still a relevant and important issue in our country.

The organoleptic results of the prototypes allowed us to draw several conclusions about the obtained biopolymers:

1. Sample No.1 (using agar-agar) has good elasticity and strength, so it can be used to create eco-packaging as wrapping materials, with the possibility of an average degree of preservation.
2. Sample No.2 (with potato starch, vinegar and glycerin), the resulting biopolymer sample has a sufficiently high elasticity and strength, which makes it suitable for creating eco-packaging or containers requiring preservation.
3. Sample No.3 (with a high gelatin content) gives a more solid and stable structure, suitable for creating durable packaging materials.
4. Sample No.4 (with gelatin, glycerin and pectin) provides the biopolymer with a high degree of strength and elasticity, which makes it suitable for industrial use, for example, as a packaging material for dry products.
5. Control sample No.5 (polyethylene) a thermoplastic polymer made of ethylene belongs to the class of polyolefin.

In general, each of the obtained prototypes has unique properties of a biopolymer, which allows you to choose the most suitable one depending on the specific task and material requirements. Photo of samples of the resulting finished films are shown in Figure 13.

Figure 13. Photo of the obtained biopolymer samples

In order to identify the nature of solubility and decomposition of samples in an aqueous medium, a series of experiments were conducted, the results of which are shown in Figure 14. A made of ordinary polyethylene was taken as a control.

The first row of photos shows the samples before adding water, then after 10 minutes in an aqueous medium, after 2 hours, and after 3 days.

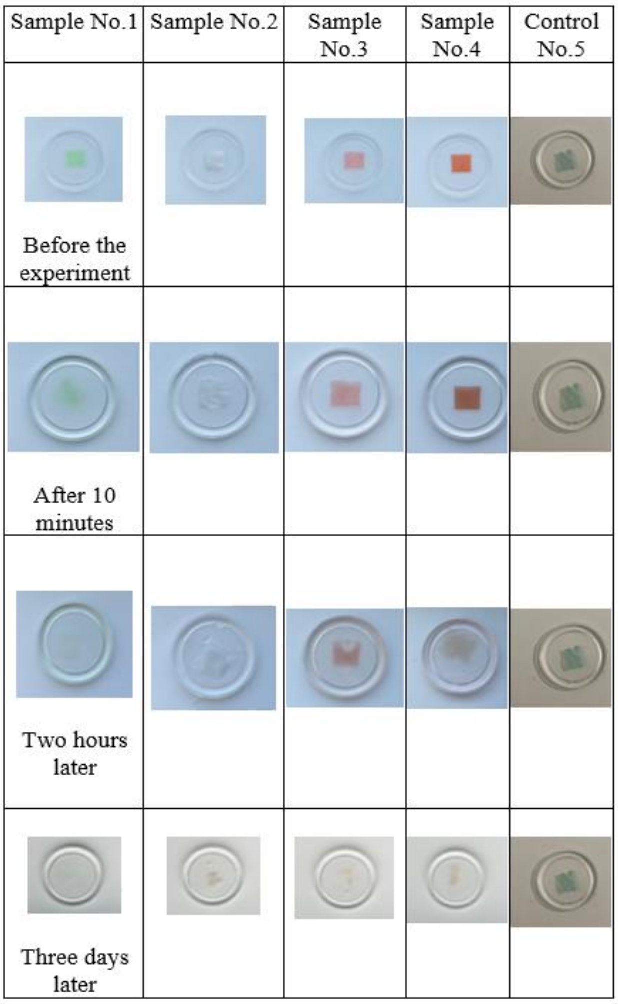


Figure 14. Photo of solubility tests of the sample compositions in aqueous medium

As Figure 14 shows, experimental samples No.1 and No.2 began to dissolve in water already after 10 minutes. All experimental samples were almost completely dissolved in aqueous medium by the end of the third day of experiments. The control sample, i.e., polyethylene, does not dissolve in water because it is insoluble and resistant to ketones, alkalis, and strong acids [30].

The developed eco-packaging formulations showed better results in terms of solubility in aqueous medium compared to the control one. The obtained rapidly degradable experimental compositions can be used as eco-packages for various dry non-food and food products that do not require long-term storage.

The graphs (Figures 15 and 16) show the curves of change in the mass of each sample over time. It can be seen that the mass of samples 1-4 decreased significantly, in contrast to the control sample, where there were no changes.

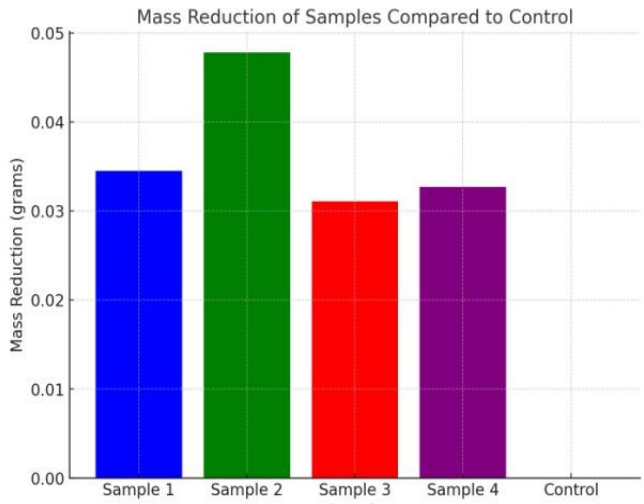


Figure 15. Diagrams of mass reduction the prototypes

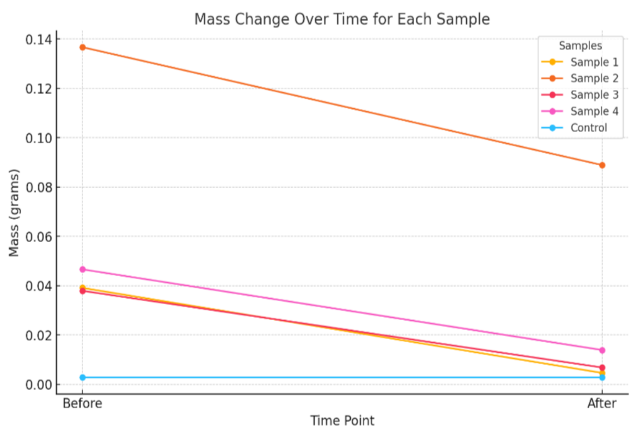


Figure 16. The curve of the change in the mass of the samples

The work continued with the development of design concepts, logo and designs for future eco-packaging for various products.

The packaging material used was a biopolymer produced in a laboratory using the above methodology from plant-based, renewable sources such as starch, algae and gelatine. Such packaging is considered to be more environmentally friendly and biodegradable, which is important for products that do not require long term storage.

Shape and volume of eco-packaging: the packaging should have a convenient shape that makes it easy to grab and use the contents, as well as providing protection from damage. Environmental message: the packaging design can include the message that the use of biopolymer in packaging helps to reduce negative environmental impact and supports sustainable production.

Based on this concept and the input received, 3D packaging designs were developed in a 3D graphics and animation editor and a logo in graphic editors. Analogues of logos of companies in this field were compared. There are several companies that produce biodegradable films, offering them as an environmentally friendly alternative to traditional plastic packaging.

Analogues: NatureWorks - produces biodegradable film based on PLA polymer, which is broken down by bacteria under industrial composting conditions. Their logo is designed in a minimalist style and the NatureWorks logo combines a graphic symbol and text to emphasise the company's environmental focus. The circular symbol with a sprout inside symbolises nature and environmental sustainability, while the division of the circle hints at balance and cyclicality. The text is in a modern font where "Nature" is associated with the environment and "Works" with activity. The green and blue colours reinforce associations with cleanliness, ecology and trust (Figure 17).

Figure 17. "Nature Works" logo

BASF (ecovio) - produces a biodegradable film based on a blend of PLA and PBAT.

These materials degrade both in composting conditions and outdoors. The BASF logo features a minimalist design on a green background, symbolising sustainability and innovation. The geometric shapes - one square and a second square with a smaller painted surface - symbolise precision and structure. The bold text "BASF" emphasises the strength of the brand and the slogan "The Chemical Company" underlines its status as a leader in the chemical industry. The overall design reflects reliability, modernity and respect for the environment (Figure 18).

Figure 18. "BASF" logo

Novamont (Mater-Bi) is an Italian company producing starch-based biodegradable film. Their products are used for product packaging and in agriculture. The NOVAMONT logo features a dynamic symbol in the shape of a globe with green and blue ribbons, symbolising sustainability, innovation and the integration of nature and technology. The bold, modern font "NOVAMONT" underlines the brand's commitment to sustainable solutions, while the gradient colours emphasise growth, harmony and care for the environment. The overall design reflects the company's focus on creating a sustainable future (Figure 19).

Figure 19. "NOVAMONT" logo

Based on the analysis of the logo analogues presented above, a unique and improved author's logo design for eco-packaging was developed. The logo shown in Figure 20 is a harmonious combination of images and text that reinforces and complements the main message. Its design takes into account the psychological aspect of colour: the gradient from light green to dark green symbolises balance, tranquility and a deep connection with nature. These colours evoke trust and security, which is particularly important for creating a positive perception in consumers.

Figure 20. Author's logo for eco packaging

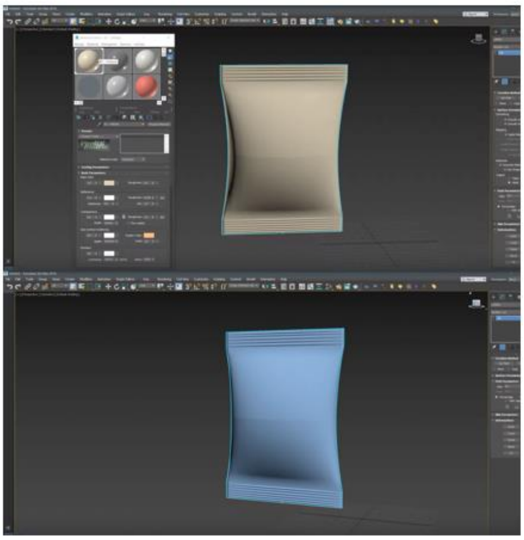


Figure 21. 3D design drawing

The leaf symbol in the logo represents environmental friendliness and sustainability, highlighting the commitment to natural values. The circle can symbolize unity, wholeness and cyclicality, which is particularly relevant to the concept of recycling. The recycling symbol indicates a commitment to environmentalism and sustainable consumption, emphasizing the importance of reusing resources and minimizing waste. The inclusion of a biodegradability element in the logo emphasizes the commitment to developing packaging that is environmentally friendly. This is very important for customers who are keen to make eco-friendly choices. Therefore, the logo is not only aesthetically pleasing but also deeply symbolic, conveying essential values and ideals related to environmental protection, sustainable development and the biodegradability of eco-packaging.

For the study, a three-dimensional drawing was created in the Autodesk 3ds Max program, which is a pillow bag type packaging model (Figure 21). This drawing includes a realistic visualization of the shape of the package, taking into account the physical and geometric parameters.

Parallel to the 3D model, a conceptual drawing (Figure 22) was developed containing the exact dimensions of the package. This drawing is made using standard projections and annotations, which allows for further design analysis.

Both drawings provide the basis for evaluating the design and can be used to optimize the shape, study materials, or create prototypes.

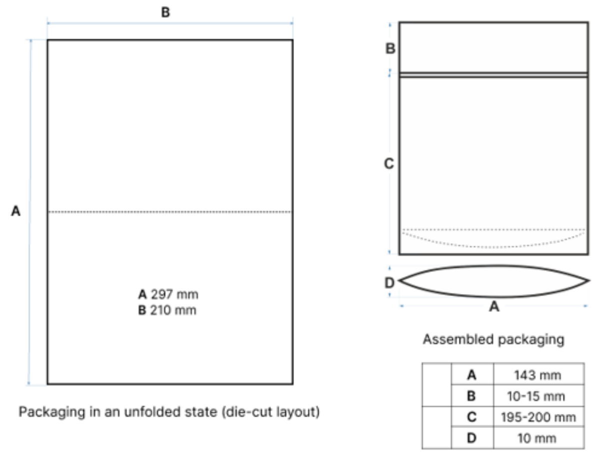


Figure 22. Conceptual drawing

The drawing is a technical representation of a pillow bag type package in two states: open (unfolding) and assembled. In the open state, a flat scan of the package with the fold line required for assembly is shown. The assembled form shows the final shape of the package with an oval base, upper and lower parts, as well as vertical lines indicating the connection points. The drawing demonstrates the transition from a flat shape to a three-dimensional design, which allows it to be used for analysis, design and preparation for production.

(a) Design variations of eco-packages with logo

(b) Different design variations of eco-packages from the received samples

Figure 23. Packaging designs

Figure 23 shows graphic representations of eco-packaging. These variants can be designed as eco-packages for various consumer goods. At the same time, the design and colours of the eco-packaging materials themselves can be different, either with a clasp or with convenient handles, coloured or transparent.

Transparent biodegradable eco-packaging is designed for various products and combines functionality, environmental friendliness and attractive appearance. Here are some characteristics of such packaging:

Material: The packaging is made of biofilm and eco-friendly materials that decompose naturally. These materials do not contain harmful chemicals and are safe for the environment. In bio-packaging, glycerin is used to increase flexibility and improve the strength characteristics of the material. It acts as a plasticizer, reducing the rigidity and brittleness of biopolymers such as starch or polysaccharides. This allows the packaging to remain flexible, elastic and more resistant to mechanical damage such as tears and cracks, as well as improves its processing and shaping.

Transparency: The transparent design allows consumers to see the contents, increasing confidence in the product. It also makes the packaging more attractive on shop shelves. The transparency of the packaging does not affect the strength of the material.

Shape and size: Packaging can come in a variety of shapes and sizes, adapting to different products such as food, cosmetics, clothing, and more. For example, it can be in the form of pouches or blisters. The packaging can be equipped with secure and convenient closure systems such as snap buttons, Velcro or special locks to ensure product protection.

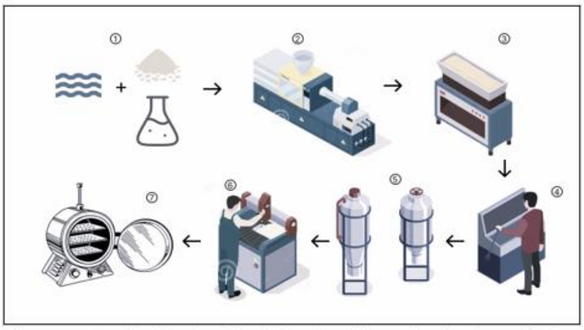
Information labelling: The packaging can be labelled with environmentally friendly labels that provide information on biodegradability, recycling methods and the benefits of using the packaging. This helps consumers make informed choices.

Durability: Although packaging is biodegradable, it should provide the necessary protection for products, preventing damage and extending shelf life.

Aesthetics: Packaging can have a minimalistic and modern design using neutral colours and simple shapes, in line with sustainable consumption trends.

Transparent biodegradable eco-packaging thus not only attracts consumers with its appearance, but also emphasises the brand's environmental responsibility, contributing to the protection of the planet.

4.1 Technological scheme and visualisation of potential production



1-raw material; 2-extruder; 3-heater; 4-mechanical panel; 5-filling machine; 6-forming moulding machine; 7-drying plant

Figure 24. Graphic visualisation of biofilm production technology for eco-packages

In order to identify the production efficiency of biodegradable film materials, a graphical visualisation of the production of these materials in mass production was also developed. Figure 24 summarises the steps involved in the production of the biofilm materials.

Figures 12 and 24 show the basic technological scheme of biofilms for eco-packaging and its graphic visualization. The scheme is quite simple: the production of biofilms involves straightforward processes that do not require high temperatures or expensive equipment.

5. CONCLUSIONS

Although packaging films composed of polysaccharides have been approved for use in many countries, they are still not widely used.

The compositions and methods of production of materials for eco-packaging proposed in this paper have been tested in the ENU-Lab. The compositions with higher gelatin content give the samples a harder structure, suitable for the creation of stronger, rapidly degradable eco-packaging. All samples tested are characterized by the unique properties of the biopolymers, allowing the most suitable to be selected depending on the specific task and purpose of their use.

Sample No.2 showed the best results, providing the biopolymer with a high degree of strength and elasticity, which makes it suitable for industrial applications, such as packaging dry products.

This research provides data to support the industrial production of biodegradable materials and can promote sustainable development.

In addition to protecting goods from the external environment and ensuring fast degradability, the appearance of the packaging material also plays an important role as an effective marketing tool for eco-packages and in promoting environmental education among the population.

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REFERENCES

[1] Kolibaba, M., Stabil, L., Panigrahi, S., Crerar, W., Powell, T., Wang, B. (2006). Biodegradable polymers: Past, present, and future. In ASABE/CSBE north central intersectional meeting. American Society of Agricultural and Biological Engineers. Joseph, Michigan, USA. https://doi.org/10.13031/2013.41300

[2] Bazarbayeva, S.M., Erkin, A., Sadykova, Z.M., Baizhanova, Z.B., Shmygol, N.N. (2023). Ethnic multifunctional furniture: A design approach to the use of waste plastic. International Journal of Design & Nature and Ecodynamics, 18(1): 21-28. https://doi.org/10.18280/ijdne.180103

[3] Sorrentino, A., Gorrasi, G., Vitoria, V. (2007). Potential prospects for the use of bionanocomposites for food packaging. Trends in Food Science & Technology, 18: 84-95. https://doi.org/10.1016/j.tifs.2006.09.004

[4] Sadeghizadeh-Yazdi, J., Habibi, M., Kamali, A.A., Banaei, M. (2019). Application of edible and biodegradable starch-based films in food packaging: A systematic review and meta-analysis. Current Research in Nutrition and Food Science, 7(3): 624-637. http://dx.doi.org/10.12944/CRNFSJ.7.3.03

[5] Jiménez, A., Fabra, M. J., Talens, P., Chiralt, A. (2012). Edible and biodegradable starch films: A review. Food and Bioprocess Technology, 5: 2058-2076. https://doi.org/10.1007/s11947-012-0835-4

[6] Kumar, Y., Roy, S., Sharma, A., Yadav, D.K., Kishore, A., Kumar, N., Meghwal, M. (2022). Edible packaging: Mechanical properties and testing methods. In Edible Food Packaging: Applications, Innovations and Sustainability, Singapore: Springer Nature Singapore, pp. 331-352. https://doi.org/10.1007/978-981-16-2383-7_17

[7] Hallez, L., Vansteenbeeck, H. (2023). Persuasive packaging? The impact of packaging color and claims on young consumers' perceptions of product healthiness, sustainability and tastiness. Appetite, 182: 2-10. https://doi.org/10.1016/j.appet.106433

[8] Galati, A., Alaimo, L.S., Ciaccio, T., Vrontis, D., Fiore, M. (2022). Plastic or not plastic? That's the problem: Analysing the Italian students purchasing behavior of mineral water bottles made with eco-friendly packaging. Resources, Conservation and Recycling, 179: 106060. https://doi.org/10.1016/j.resconrec.2021.106060

[9] Cui, Y.M., Ren, X.G. (2016). The innovative application studty on eco-packaging design and materials. In MATEC Web of Conferences, EDP Sciences, 63: 03002. https://doi.org/10.1051/matecconf/20166303002

[10] Zhang, P.X. (2023). Analysis of the visual language of design of sustainable packaging manufactured from biomaterials. Journal of Print and Media Technology Research, 12(3): 139-146. https://doi.org/10.14622/JPMTR-2305

[11] Wang, Y.X., Liu, K., Zhang, M. (2023). Sustainable polysaccharide-based materials for intelligent packaging. Carbohydrate Polymers, 313: 120851. https://doi.org/10.1016/j.carbpol.2023.120851

[12] Ningsih, P., Rahmawati, S., Santi, N.M.N., Suherman, Diah, A.W.M. (2021). Making edible film from jackfruit seed starch (Artocarpus heterophyllus) with the addition of rosella flower extract (Hibiscus sabdariffa L.) as antioxidant. International Journal of Design & Nature and Ecodynamics, 16(6): 691-699. https://doi.org/10.18280/ijdne.160611

[13] Rahmawati, S., Aulia, A., Hasfah, N., Nuryanti, S., Abram, P.H., Ningsih, P. (2021). The utilization of durian seeds (Durio zibethinus Murr) as a base for making edible film. International Journal of Design & Nature and Ecodynamics, 16(1): 77-84. https://doi.org/10.18280/ijdne.160110

[14] Nešić, A., Cabrera-Barjas, G., Dimitrijević-Branković, S., Davidović, S., Radovanović, N., Delattre, C. (2020). Prospect of polysaccharide-based materials as advanced food packaging. Molecules, 25(1): 135. https://doi.org/10.3390/molecules25010135

[15] Issa, A., Ibrahim, S.A., Takhergorabi, R. (2016). Sweet potato starch and clay nanocomposite: A new material for emerging biodegradable food packaging. Technology of Food Processes of the Ministry of Justice, 3(33): 313-315. https://doi.org/10.15406/mojfpt.2016.03.00073

[16] Nath, P. C., Sharma, R., Debnath, S., Sharma, M., et al. (2023). Recent trends in cellulose-based biodegradable polymers for smart food packaging industry. International Journal of Biological Macromolecules, 127524. https://doi.org/10.1016/j.ijbiomac.2023.127524

[17] Jiang, T., Duan, K., Zhu, J., Liu, H., Yu, L. (2020). Starch-based biodegradable materials: Challenges and opportunities. Advanced Industrial and Engineering Polymer Research, 3(1): 8-18. https://doi.org/10.1016/j.aiepr.2019.11.003

[18] Bangar, S.P., Purewal, S.S. (2021). Functionality and applicability of starch-based films: An eco-friendly approach. Foods, 10(9): 2181. https://doi.org/10.3390/foods10092181

[19] Cui, Y., Zhang, R., Cheng, M. (2024). Development and application of mathematical modeling of thymol release from environmental-responsive potato starch active packaging films. International Journal of Biological Macromolecules, 271(132353): 132353. https://doi.org/10.1016/j.ijbiomac.2024.132353

[20] Samsudin, H., Hani, N.M. (2017). Use of starch in food packaging. In Starch-Based Materials in Food Packaging: Processing, Characterization and Applications, Academic Press, pp. 229-256. https://doi.org/10.1016/B978-0-12-809439-6.00008-X

[21] Agama-Acevedo, E., Flores-Silva, P.C., Bello-Perez, L.A. (2018). Cereal starch production for food applications. In Starches for Food Application: Chemical, Technological and Health Properties, Academic Press, pp. 71-102. https://doi.org/10.1016/B978-0-12-809440-2.00003-4

[22] Ferreira, A.R.V., Alves, V.D., Coelhoso, I.M. (2016). Polysaccharide-based membranes in food packaging applications. Membranes, 6(2): art.no.22. https://doi.org/10.3390/membranes6020022

[23] Primožič, M., Knez, Ž., Leitgeb, M. (2021). (Bio) Nanotechnology in food science-food packaging. Nanomaterials, 11(2): 292. https://doi.org/10.3390/nano11020292

[24] Huang, Y.K., Mei, L., Chen, H., Wang, K. (2018). Recent developments in the field of food packaging based on nanomaterials. Nanomaterials, 8(10): 830. https://doi.org/10.3390/nano8100830

[25] Malati, A.N., Santosh, K.S., Gidoni, U. (2014). Recent trends in the field of biodegradable polymers: Biodegradable films for food packaging and the use of nanoparticles in biodegradable food packaging. Course. Technological trends. Science, 3: 73-79.

[26] Plastics in Europe. (2015). Plastics: Facts. Analysis of data on plastics production in Europe, demand and waste. Plastics in Europe: Brussels, Belgium.

[27] Agyepong, J.K., Barima, J. (2018). Physico-chemical properties of starches extracted from local cassava varieties using crude pectolytic enzymes of saccharomyces (ATCC 52712). African Journal of Food Science, 12(7): 151-164. https://doi.org/10.5897/AJFS2018.1701

[28] Altemimi, A.B. (2018). Extraction and optimization of potato starch and its application as a stabilizer in yogurt manufacturing. Foods, 7(2): 14. https://doi.org/10.3390/foods7020014

[29] Cornejo-Ramirez, Y.I., Martinez-Cruz, O., Del Toro-Sanchez, K.L., Wong-Corral, F.J., Borboa-Flores, J., Cinco-Moroiki, F.J. (2018). The structural characteristics of starches and their functional properties. Journal of

Food, 16: 1003-1017. https://doi.org/10.1080/19476337.2018.1518343
[30] Potapova, E.V. (2018). The problem of plastic waste disposal. Proceedings of the Baikal State University, 28(4): 535-544. https://doi.org/10.17150/2500-2759

NOMENCLATURE

Logo	Logotype
g	mass/weight, grams
PLA	Poly lactic acid
PBAT	Polybutylene adipate terephthalate