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UTILIZAÇÃO DE EMBALAGENS DE BIOPOLÍMERO PARA PRESERVAÇÃO DE ALIMENTOS EM BAIXAS TEMPERATURAS

BIOPOLYMER PACKAGING APPLICATION FOR LOW-TEMPERATURE FOOD PRESERVATION

ПРИМЕНЕНИЕ БИОПОЛИМЕРНОЙ УПАКОВКИ ДЛЯ НИЗКОТЕМПЕРАТУРНОГО ХРАНЕНИЯ ПИЩЕВЫХ ПРОДУКТОВ

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RESUMO

Introdução: O uso de materiais de embalagem de biopolímero para congelamento e armazenamento em baixa temperatura proporciona a manutenção de alimentos com qualidade e segurança. Também reduz a poluição ambiental causada por materiais petrolíferos biopolímeros que têm um longo período de biodegradação. **Objetivo:** É necessário descobrir a possibilidade de usar o filme de biopolímero "CornBag" na preservação de alimentos em baixa temperatura. **Métodos:** O congelamento e armazenamento em baixa temperatura dos filmes poliméricos foram realizados em freezer horizontal Liebherr LGT 2325 Mediline e VESTFROST Solutions VT 078. As propriedades físicas e mecânicas foram medidas por meio da máquina de ensaio de tração Labthink XLW (M). **Resultados e Discussão:** O artigo aborda os resultados da pesquisa dos efeitos de baixa temperatura nas propriedades físicas e mecânicas (resistência à tração e resistência à tração na ruptura) do filme de biopolímero "CornBag" derivado da polimerização do amido de milho e batata-doce, tendo sido realizada ação em baixa temperatura no faixa de -60ºC a -20ºC por 90 dias. Verificou-se que durante o período de armazenamento a ação de baixas temperaturas não reduz significativamente as propriedades de resistência do filme de biopolímero. Alterações nas propriedades de resistência do filme de biopolímero e do filme de polipropileno biaxialmente orientado sob efeitos de longo prazo de baixas temperaturas foram analisados diferencialmente. Analisadas as mudanças na resistência à tração à ruptura, foram obtidos diagramas de estiramento do biopolímero e dos filmes orientados biaxialmente. Concluiu-se que as propriedades de resistência do filme de biopolímero "CornBag" diminuem para não mais que 12,5% após 90 dias de armazenamento sob -60º C. **Conclusões:** O filme de biopolímero é igual ao filme de polipropileno orientado biaxialmente e pode ser recomendado para congelamento e armazenamento em baixa temperatura de alimentos.

Palavras-chave: *filme de biopolímero, embalagem, efeitos de baixa temperatura, propriedades físicas e mecânicas, itens alimentícios.*

ABSTRACT

Background: The use of biopolymer packaging materials for freezing and low-temperature storage keeps food items qualitative and safe. It also reduces environmental pollution caused by biopolymer petrolic materials that have a long biodegradation period. **Aim:** It is necessary to find out the possibility of using biopolymer film "CornBag" in the low-temperature preservation of food items. **Methods:** Freezing and low-temperature storage of polymer films were carried out in chest freezers Liebherr LGT 2325 Mediline and VESTFROST Solutions VT 078. The tensile testing machine Labthink XLW (M) measured physical and mechanical properties. **Results and Discussion**: The article covers the results of researching low-temperature effects on physical and mechanical

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properties (tensile strength and tensile strength at break) of biopolymer film “CornBag” derived by polymerizing starch from corn and sweet potato, low-temperature action having been performed in the range of -60 ºC to -20 ºC for 90 days. It has been found that during the storage period, the action of low temperatures does not reduce the strength properties of the biopolymer film significantly. Changes in the strength properties of the biopolymer film and the biaxially oriented polypropylene film under long-term effects of low temperatures have been differentially analyzed. Changes in tensile strength at the break having been analyzed, stretch diagrams of the biopolymer and biaxially oriented films were obtained. It has been concluded that the strength properties of biopolymer film “CornBag” decline to no more than 12.5 % after 90-day storage under -60 ºC. **Conclusions:** The biopolymer film is equal to the biaxially oriented polypropylene film and can be recommended for freezing and low-temperature storage of food items.

Keywords: *biopolymer film, packaging, low-temperature effects, physical and mechanical properties, food items.*

АННОТАЦИЯ

Бекграунд: Использование биополимерных упаковочных материалов для замораживания и хранения при низких температурах обеспечивает качество и безопасность пищевых продуктов. Это также снижает загрязнение окружающей среды, вызванное биополимерными нефтяными материалами, которые имеют длительный период биоразложения. **Цель**: необходимо выяснить возможность использования биополимерной пленки «CornBag» в консервировании пищевых продуктов при низкой температуре. **Методы:** Замораживание и хранение полимерных пленок при низкой температуре осуществляли в горизонтальном морозильном аппарате Liebherr LGT 2325 Mediline и VESTFROST Solutions VT 078. Физические и механические свойства калибровали с использованием разрывной машины Labthink XLW (M). **Результаты и обсуждение**: В статье представлены результаты исследования низкотемпературного воздействия на физико-механические свойства (прочность при растяжении и предел прочности при разрыве) биополимерной пленки «CornBag», полученной путем полимеризации крахмала из кукурузы и батата, низкотемпературное воздействие проводилось в условиях диапазоне от -60ºC до -20ºC в течение 90 дней. Установлено, что в период хранения воздействие низких температур не приводит к существенному снижению прочностных свойств биополимерной пленки. Проведен дифференциальный анализ изменения прочностных свойств биополимерной пленки и биаксиально-ориентированной полипропиленовой пленки при длительном воздействии низких температур. Проанализированы изменения предела прочности при разрыве, получены диаграммы растяжения биополимерных и биаксиально ориентированных пленок. Сделан вывод, что прочностные свойства биополимерной пленки «КорнБэг» снижаются не более чем на 12,5 % после 90-суточного хранения при температуре -60°C. **Выводы**: Биополимерная пленка аналогична биаксиально-ориентированной полипропиленовой пленке и может быть рекомендована для замораживания и низкотемпературного хранения пищевых продуктов.

Ключевые слова*:* *биополимерная пленка, упаковка, низкотемпературное воздействие, физико-механические свойства, продукты питания.*

1. INTRODUCTION:

The Russian frozen food market is developing dynamically due to the growing pace of life, especially in cities, and the desire to diversify the diet by consuming vegetables, fruit, and berries regardless of the season. The quality of frozen products directly depends on the modes and methods of freezing, storage, and transportation conditions; a significant role is played by correctly selected packaging. Packaged products are less susceptible to changes caused by exposure to light and air oxygen, desorption of moisture from the surface, and other factors that reduce the quality of food items (Holman, Kerry and Hopkins, 2018; Motelica, Ficai, Ficai, Oprea, Kaya, Andronescu, 2020; Lai, Zhao, Chiou, 2021; Kasperski, Grabowska, 2016).

The most commonly used material for packaging frozen food is biaxially oriented polypropylene film (BOPP). It has high barrier properties, mechanical strength, and a relatively low price which is very important when used in the food industry (Lai, Zhao, Chiou, 2021; Chang, Kang, Park, Choic, Kimc, Hana, 2019; Gutierrez, Mendieta, Ortega-Toro, 2021; ARRIETA, A., 2021). However, according to many researchers, the significant drawback of this packaging material is the lack of the possibility of recycling and a long period of biodegradation (Holman, Kerry, and Hopkins, 2018; Lai, Zhao, Chiou, 2021; Gutierrez, Mendieta, Ortega-Toro, 2021) leading to significant environmental problems. In

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addition, artificial antioxidants are used in the manufacture of polypropylene films. Under certain conditions, they can migrate into food products and thereby cause harm to health (Chang, Kang, Park, Choic, Kimc, Hana, 2019). These factors and the growing consumer demand for organic food motivate manufacturers to use biopolymers for food packaging. Currently, biopolymers based on gluten, chitosan, methylcellulose and its derivatives, starch, gelatin are used for packaging food products (Gutierrez, Mendieta, Ortega-Toro, 2021; Filipini, Romani, Guimaraes, 2020; Giro, Kulikovsky, Andreeva, Gorlov, Giro, 2020; Mostafavi, Zaeimb, 2020; Luo, Hossen, Zeng, Dai, Li, Qin, Liu, 2022; Korotkiy, Korotkaya, Rasshchepkin, Sahabutdinova, 2021). The film "CornBag" was obtained by the reaction of polymerizing corn and sweet potato starch. The status of the biomaterial is confirmed by documents and certificates, including conformity certificate № POCC SG AB51.H00197 [13].

At the same time, the behavior of biopolymers under low-temperature exposure has not been studied enough. Biopolymer films used for freezing and low-temperature storage of food products must retain their physical and mechanical properties, both during technological operations and the entire storage period. In this regard, studying the physical and mechanical properties of biopolymer films under the influence of low temperatures is of undoubted interest.

The study aimed to establish the possibility of using the biopolymer film "CornBag" for the low-temperature preservation of food products. The objectives of the study were as follows: to determine the physical properties of a biopolymer film according to the national standards of the Russian Federation – GOST R 58061-2018 "Modified synthetic films. Types and basic parameters" and GOST 14236-81 "Polymer films. Tensile test method" (tensile strength at break, relative tensile elongation) when exposed to low temperatures in the range from -60 °C to -20 °C during long term storage (90 days); comparison with the properties of a polypropylene film.

2. MATERIALS AND METHODS:

2.1. Materials

The objects of the study were the biopolymer film "CornBag" (company "Olive Green Pte Ltd", Singapore) (www.olivegreen.com.sg) and a three-layer biaxially oriented polypropylene (BOPP) film (OOO Interbeg, Novosibirsk, Russia) (https://interbag.ru/katalog/pljonka/plenka-bopp). The physical properties of the films are shown in table 1. According to the manufacturer's statistics, the three-layer BOPP film consists of a main polypropylene layer surrounded by two heat-sealed ones. It withstands low temperatures well without becoming brittle during polymer crystallization. Therefore it is used for packaging ice cream and other food products that require low-temperature storage (https://interbag.ru/katalog/pljonka/plenka-bopp).

Table 1. *Physical properties of the polymer films at 20°C*

Indicator	film "CornBag"	BOPP film
relative tensile strain, ξ, %	415	250
tensile strength at break, σ, MPa	475	300

2.2. Methods or Experimental procedures

The machines used for the study were as follows: Laboratory chest freezer Liebherr LGT 2325 Mediline (maintained temperature range -10° -45 °C with an accuracy of 0.1 °C); low-temperature chest freezer VESTFROST Solutions VT 078 (Denmark) with temperature range -60 °C -86 °C.

Based on the tasks set, the biopolymer film was frozen at temperatures of -60°C, - 40°C, and - 20°C. Frozen samples were stored at freezing temperatures for 90 days.

Freezing and low-temperature storage of the studied film samples were carried out in a Liebherr LGT 2325 Mediline chest freezer (at temperatures of -20 °C and -40 °C) and in a VESTFROST Solutions VT 078 low-temperature chest (at a temperature of -60 °C).

Physical and mechanical properties of the polymer films were calibrated according to the national standards of the Russian Federation – GOST R 58061-2018 "Modified synthetic films. Types and basic parameters" and GOST 14236-81 "Polymer films. Tensile test method". Tests to determine the physical and mechanical properties

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of the biopolymer and biaxially oriented polypropylene films were carried out on a Labthink XLW (M) (Fig. 1) tensile testing machine (manufacturer OOO Labthink Instruments Co).

Figure 1*. Automatic tensile testing machine Labthink XLW (M).*

2.3. Data Collection

The temperature conditions in the freezers were maintained automatically. The controller set them with an accuracy of 0.1 °C. The set temperature was shown on the external display.

The Labthink XLW(M) tensile testing machine has 7 modes of operation and is controlled by a microcontroller. The professional personal software supports statistical analysis of a group of samples, superposition of test curves, and functions of data-to-history comparison, as well as the functions of parameter setting, printing, cleaning, and calibration.

Samples of the film 200 mm long, 20 mm wide, and 20 μm thick were investigated (Figure 2). The clamps of the tensile testing machine were located at a distance of 110 mm, and the speed of the upper clamp was 500 mm/min.

Figure 2. *Samples of polymers: 1 - biopolymer film; 2 - biaxially oriented polypropylene film.*

The pre-prepared sample was placed between two jaws of the tensile testing machine, the jaws moving in the respective direction during the test. Changes in force signals and changes in sample position were automatically recorded with a dynamometer mounted on a movable gripper and a built-in displacement sensor. In addition, tensile strength, relative elongation in tension, and strain rate were calculated using automatic tensile testing machine software.

The tensile strength (σ, MPa) and relative elongation in tension (ξ, %) were determined for all film samples at a temperature of 20 °C.

2.4. Statistical Analysis

The studies were carried out with five-time replication. Table 2 presents the results of determining the physical and mechanical properties of the biopolymer film (samples 1 – 5) and BOPP (samples 6 – 10) at 20 °C, as well as after 30-day storage under -20 °C, -40 °C, and -60 °C. Statistical processing of the results was based on using the Statistica 8 software package.

Table 2. Physical and mechanical properties of the films according to temperature conditions

Sample	**Relative tensile strain, ξ, %**			**Tensile strength at break, σ, MPa**		
	-20 °C	**-40 °C**	**-60 °C**	**-20 °C**	**-40 °C**	**-60 °C**
1.	410	394	404	469	467	463
2.	407	417	399	472	471	464
3.	412	400	397	463	461	457
4.	414	417	408	468	465	470
5.	405	406	402	478	473	475
6.	239	237	237	289	287	277
7.	240	242	243	288	282	281
8.	246	243	241	300	297	298
9.	238	245	239	299	300	287
10.	243	249	250	292	291	280

3. RESULTS AND DISCUSSION:

3.1. Results

The results of studying the strength characteristics of biopolymer film “CornBag” – relative tensile strain (ξ, %) and tensile strength at break (σ, MPa) at freezing and low-temperature storage are shown in figures 3 and 4.

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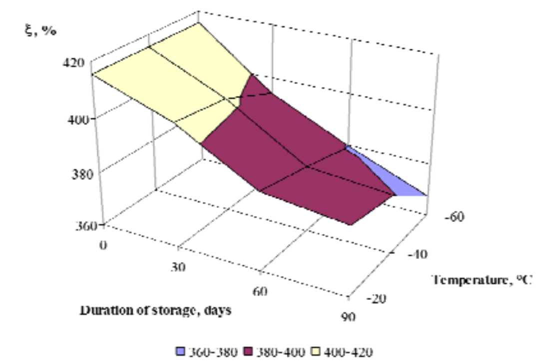

Figure 3. *Change in the relative tensile strain of the biopolymer film depending on the temperature and duration of storage.*

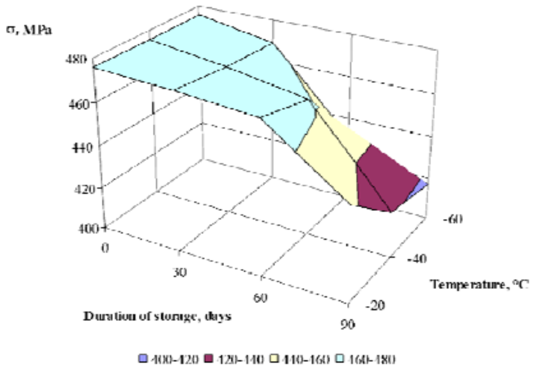

Figure 4. *Change in the tensile strength at break of the biopolymer film depending on the temperature and duration of storage.*

A stretch diagram was plotted to compare the strength at break values of the heat-shrinkable BOPP film and biopolymer film “CornBag”. In addition, the measurements of the actual tensile elongation of the film depending on the longitudinal force were carried out. The diagram is shown in Figure 5.

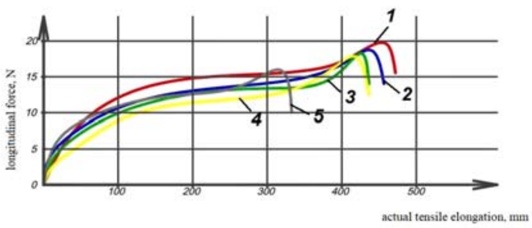

Figure. 5. *Stretch diagram: 1 – “CornBag” film at 20 °C; 2 - film “CornBag” exposed to -20 °C for three months; 3 – film “CornBag” exposed to -40 °C for three months; 4 – film “CornBag” exposed to -60 °C for three months; 5 – BOPP at 20 °C*

A comparative analysis of the physical and mechanical properties of the heat-shrinkable BOPP and biopolymer film “CornBag” (BioP) was carried out before freezing at room temperature (20°C), as well as after freezing and 90-day storage at -60 °C. Generalized comparative characteristics of the films under study are shown in Figure 6.

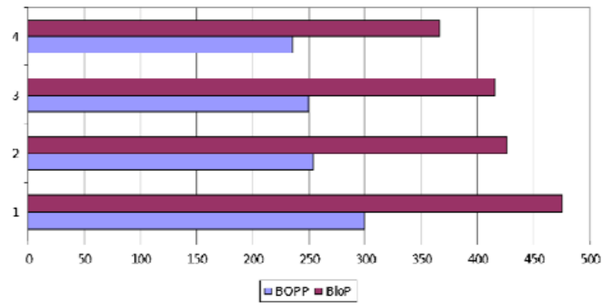

Figure 6. *Physical and mechanical characteristics of the films. Before freezing: tensile strength at the break – 1, relative tensile strain – 3; after freezing and 90-day storage at a temperature of -60 °C: tensile strength at the break – 2, relative tensile strain – 4*

3.2. Discussion

As noted above, biopolymer films used for packaging food items are made based on natural polymers of chitosan, gluten, gelatin, starch, soy protein isolate, and whey protein (Gutierrez, Mendieta, Ortega-Toro, 2021; Filipini, Romani, Guimaraes, 2020; Giro, Kulikovsky, Andreeva, Gorlov, Giro, 2020; Mostafavi, Zaeimb, 2020; Korotkiy, Korotkaya, Rasshchepkin, Sahabutdinova, 2021; Soazo, Pérez, Rubiolo, Verdinib, 2013; Liu, Xu, Liu, Liu, Zhao, Ma, Zhang, 2021; Liu, Xue, Li, Adhikari, 2022). A significant part of investigations is devoted to studying the physical properties of biopolymers under standard conditions or high-temperature exposure (Lai, Zhao, Chiou, 2021; Kasperski, Grabowska, 2016; Chang, Kang, Park, Choic, Kimc, Hana, 2019; Gutierrez, Mendieta, Ortega-Toro, 2021; Mostafavi, Zaeimb, 2020; Liu, Xu, Liu, Liu, Zhao, Ma, Zhang, 2021; Liu, Xue, Li, Adhikari, 2022; Nandi, Guha, 2021). However, it was found just a few references about the properties of biofilms under low-temperature exposure (Chang, Kang, Park, Choic, Kimc, Hana, 2019; Korotkiy, Korotkaya, Rasshchepkin, Sahabutdinova, 2021; Soazo, Pérez, Rubiolo, Verdinib, 2013). Chang *et al*. (2019) studied the migration of artificial antioxidants from polypropylene films stored at -30 °C for 1 hour (Chang, Kang, Park, Choic, Kimc, Hana, 2019). These antioxidants were butylated hydroxytoluene (BHT) and pentaerythritol tetrakismethylene-(3,5-di-tert-butyl-4-hydroxyhydrocinnamate (Irganox 1010).

Soazo *et al*. (2013) investigated the physical properties of emulsion films under low-temperature exposure. The films were made with

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whey protein and beeswax having been added. The authors noted that freezing did not cause external changes in the films (cracks, perforations) and did not affect their relative elongation. Instead, it increased the puncture strength but decreased the elastic modulus (Soazo, Pérez, Rubiolo, Verdinib, 2013).

Polymer films used for freezing and low-temperature storage of food items must retain their strength characteristics during the entire storage period of food products. The analysis of the low-temperature influence on such characteristics of biopolymer film “CornBag” as relative tensile strain and tensile strength at break presented in figures 3 and 4 showed that both indicators slightly decreased with temperature reduction and increasing shelf life. Thus, when being stretched, the biopolymer film had the relative tensile elongation decreased by slightly more than 1 time at all freezing and storage temperature regimes. After 90 days of storage, it was reduced on average by 1.1 times and became 11.8% of the initial value. After 90 days of storage at temperatures of -20 °C, -40 °C, and -60 °C, the decrease in the tensile strength at break amounted to 6.7%, 11.3%, and 12.4%, respectively. So, the strength characteristics of the biopolymer film did not decline to more than 12.5% for the entire storage period under all investigated low-temperature conditions.

The analysis of the stretch diagram shown in Figure 5 for the films under study at room temperature and low-temperature exposure allows us to conclude that biopolymer film “CornBag” (dependences 1-4) in its strength characteristics is not inferior to the heat-shrinkable biaxially oriented propylene film (dependence 5).

These changes in the physical characteristics of the films investigated can be considered insignificant. Therefore, the results of this research agree with the data of M. Soazo and co-authors (Soazo, Pérez, Rubiolo, Verdinib, 2013).

The comparative analysis of the physical and mechanical characteristics of the BOPP and “CornBag” films at room temperature revealed that the relative tensile strain and tensile strength at break of the biopolymer film were 1.6 times and 1.7 times higher, respectively, than those of the biaxially oriented polypropylene film. A similar relationship was observed after freezing and 90-day storage at a temperature of -60 °C. The strength characteristics of the biopolymer film were higher than those of the polypropylene film. After 90 days of storage, the tensile strength at the break for the BOPP film decreased by 1.2 times and for the biopolymer film by 1.1 times. The decrease in the relative tensile strain for the polymer film was 5.6%, and for the biopolymer film, 11.8%.

4. CONCLUSIONS:

According to the study, 90-day low-temperature exposure in the range from -60 °C to -20 °C did not materially change the physical and mechanical properties of biopolymer film “CornBag”. When being stretched, the biopolymer film had the relative tensile elongation decreased by 1.1 times at all temperature regimes. Lowering the temperature had a greater effect on the tensile strength at break. At temperatures of -20 °C, -40 °C and -60 °C it amounted to 6.7%, 11.3% and 12.4% respectively.

The comparative analysis of the physical and mechanical characteristics of the films revealed that tensile strength at break changed approximately the same for both BOPP and “CornBag” films. However, the relative elongation of the BOPP film declined two times less than that of the biopolymer one.

Based on the studies performed, it can be concluded that the biopolymer film “CornBag” in its strength characteristics is not inferior to the biaxially oriented polypropylene film and can be used for freezing and low-temperature storage of food items.

5. DECLARATIONS

5.1. Study Limitations

The study is limited to the samples analyzed.

5.3. Funding source

The authors funded this study.

5.4. Competing Interests

There were no conflicts of interest.

5.5. Open Access

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