Jakub WIŚNIEWSKI
Kamil ZASADA
Mgr inż. Magdalena MIKUS
Dr hab. inż. Sabina GALUS
Department of Food Engineering and Process Management, Institute of Food Sciences Warsaw University of Life Science, Warsaw, Poland
Katedra Inżynierii Żywności i Organizacji Produkcji, Instytut Nauk o Żywności
Szkoła Główna Gospodarstwa Wiejskiego w Warszawie, Polska

AN ATTEMPT TO DEVELOP FAST DISSOLVING BIOPOLYMER-BASED POUCHES FOR INSTANT COFFEE®

Próba wytworzenia wysokorozpuszczalnych biopolimerowych opakowań jednostkowych do kawy rozpuszczalnej®

Key words: edible films, biopolymers, packaging, instant coffee.

The paper presents research on selected functional properties of edible films as a new type of fast-dissolving biopolymer-based packaging for instant coffee. The film production consisted of preparing aqueous film-forming solutions with biopolymers such as apple and citrus pectin, sodium alginate and soy protein isolate. The solutions were poured and dried at 50°C for 24 h. Water content, solubility in water, color and opacity, water vapor permeability and mechanical properties of analyzed films were investigated. The obtained results showed different film properties of which citrus pectin turned out to show the most desired functional properties for instant coffee, including transparency, good sealability and solubility in water.

Słowa kluczowe: folie jadalne, biopolimery, opakowanie, kawa rozpuszczalna.

W artykule przedstawiono badania wybranych właściwości użytkowych folii jadalnych jako nowego rodzaju szybko rozpuszczalnych biopolimerowych opakowań do kawy rozpuszczalnej. Produkcja folii polegała na przygotowaniu wodnych roztworów foliotwórczych z biopolimerami, takimi jak pektyna jabłkowa i cytrusowa, alginian sodu i izolat białka sojowego.

Roztwory wylano i suszono w temperaturze 50°C przez 24 h. Zbadano zawartość wody, rozpuszczalność w wodzie, barwę i nieprzezroczystość, przenikalność pary wodnej oraz właściwości mechaniczne analizowanych folii. Uzyskane wyniki wykazały różne parametry folii. Pektyna cytrusowa wykazywała najbardziej pożądane właściwości użytkowe dla kawy rozpuszczalnej, w tym przezroczystość, dobrą zgrzewalność i rozpuszczalność w wodzie.

INTRODUCTION

Biopolymer-based edible films have grown rapidly in recent times. This is due to changes in the awareness of society in the field of ecology and environmental protection, as well as for economic and health reasons. The use of packaging made of new, biodegradable, naturally occurring raw materials allows us to limit the use of packaging made of synthetic materials, which in turn reduces the amount of waste, including hazardous microplastics, mainly single-use plastic packaging [15]. Edible coatings are applied directly to the product, while the films are independent structures obtained outside the product in the form of a film [5]. The development of the technology of producing edible films allows for obtaining more and more diverse and better properties, with a simultaneous reduction in production costs. They depend mainly on the film-forming materials and the parameters in which they are formed. The film properties are influenced, among others, by material concentration and plasticizer used, solvent, film thickness, as well as pH and temperature [7, 18]. The main function of edible films is a selective barrier to water vapor, carbon dioxide, oxygen, aroma, and oils. In addition, they protect food products against the adverse effects of microorganisms, as a result extending their shelf life. They allow for the reduction of one the occurrence of mechanical damage and limit the influence of physical and chemical factors on the product [11]. They can also, by changing the color, inform about the expiry date of the product and thus effectively remind the consumer not to waste food [1]. Biodegradable materials also contribute to the improvement of the quality of the environment, as they are part of a modern

Corresponding author – Adres do korespondencji: Sabina Galus, Szkoła Główna Gospodarstwa Wiejskiego w Warszawie, Instytut Nauk o Żywności, Katedra Inżynierii Żywności i Organizacji Produkcji, ul. Nowoursynowska 159c, 02-776 Warszawa, e-mail: sabina_galus@sggw.edu.pl

approach to caring for a sustainable environment [17, 27] The possibility of using more and more new ingredients in the composition of films allows for innovative properties and better stability of edible packaging materials [6]. Packaging made of biopolymer films can, for example, be treated as active packaging, by using ingredients that prevent changes in the quality and freshness of food. It is also an alternative method of safer drug delivery [28]. The active properties of the films enable, among others, the release of antimicrobial substances, thanks to which the process of food degradation is delayed, substances that prevent browning and discoloration, improve the quality of the product, and carbon dioxide absorbing substances eliminate packaging swelling [16, 22], possible in the case of roasted coffee packaging.

Fast-dissolving sealable packaging is a subject of great interest in the last decade. One of the most favorable applications of edible films that dissolve quickly upon water contact is in individually portioned dry food, instant beverages or dry ingredients, including breakfast cereal, instant coffee or tea, and powders. In the literature, there are some examples of a new type of single-use packaging for oils and powders. Biopolymer-based single packaging from corn zein was also investigated to improve the shelf-life of sliced cheese [25] and in combination with soy protein isolate can be used as packaging for olive oil [3]. Different kinds of water-soluble pouches for oil protection were previously investigated also by others [9, 12, 14, 24]. Quilez-Molina et al. [21] analyzed vegetable-based bioplastic materials, obtained from the upscaling of food byproduct materials derived from the orange peel that showed a good potential for replacing plastics in single-use applications. Similar research was conducted by Sharma et al. [26] on chemically modified cellulose from rice husk blended with polyvinyl alcohol. The authors developed a heat-sealed packet, which exhibits comparable properties to commercially used flexible polyvinyl chloride films with optimized water barrier and biodegradable nature [2, 23]. Nawab et al. [19] also showed the potential of biopolymers from waste sources (mango kernel) as heat-sealable pouches for the packing of red chili powder. Janjarasskul et al. [13] developed edible, fast-dissolving sealable whey protein isolate-based films for packaging premeasured dry foods that are completely water-soluble, visually clear and glossy, and release their contents upon contact with water. Liu et al. [15] investigated heat-sealable soybean polysaccharide/gelatin blend films intended to be used as edible food packaging materials for instant coffee and coconut powder pouches. A similar combination of animal and plant-based biopolymers (pectin–sodium alginate/casein) as edible pouches was presented by Bora and Mishra [10]. Those examples show that the studies on sealable biopolymer-based single-use packaging are promising to minimize the use of petroleum-based materials. Therefore, this study aimed to try to produce fast-dissolving sachets based on various biopolymers, compare their properties to each other, determine the characteristic features of given biopolymers and evaluate the films as a new type of pouch packaging for instant coffee.

MATERIALS AND METHODS

Sodium alginate and low-methylated apple pectin were purchased from Agnex (Białystok, Poland). Citrus pectin was purchased from Hortimex (Konin, Poland). Soy protein isolate (Exelsoy 933EX, ~90% protein) was purchased from Exeller Polska Sp. Z o.o. (Piaseczno, Poland). Glycerol (Avantor Performance Materials Poland S.A.Gliwice, Poland) was used as a plasticizer. Instant coffee was purchased in the local market.

Film preparation

The film-forming solutions were prepared by casting method using distilled water as a solvent and sodium alginate, apple and citrus pectin at the concentration of 1.5%, whereas soy protein isolate was used at the concentration of 3% since lower amounts were unable to create a continuous film structure. The film-forming solutions were heated and stirred for 20 minutes using an RCT basic IKAMAG magnetic stirrer (IKA Poland, Warsaw) at the level of 250 rpm at a temperature of 60°C. After cooling, glycerol was added to the solutions, representing 50% of each biopolymer. The film-forming solutions were poured on Petri dishes in different amounts to control the similar film thickness. The samples were dried format 50°C in a laboratory dryer SUP-65W (WAMED, Warsaw, Poland). The dried films were conditioned in a climate chamber model KBF 240 (Binder GmbH, Tuttlingen, Germany) at 25°C and relative humidity of 50% for 48 h before testing.

Thickness

The thickness of the films was determined using an electronic gauge Thwing-Albert Instrument Company (Klimatest, Warsaw, Poland) with a precision of 1 μm. The results were obtained by measuring the thickness at ten random points, and then the mean and the standard deviation were calculated.

Water content

The water content of the films was determined by the drying method at 105°C for 24 h using a laboratory dryer SUP 65 W/G (WAMED, Warsaw, Poland) and expressed in percentages. The measurement was performed in triplicate.

Solubility in water

The prepared samples of edible films were cut into squares (20 x 20 mm). The samples were then dried at 105°C for 24 h and then cooled in a desiccator containing silica gel. The samples were reweighed and placed in 25 mL of distilled water. After 24 h of storage, occasionally shaken, the excess water was removed using filter paper. The samples were dried at 105°C for 24 h and reweighed. The water solubility of the edible films was determined in three repetitions and was calculated based on the method described by Rhim et al. [4].

Color

The color test was performed using the CR-400 model colorimeter (Minolta, Japan) in the CIE L^* a^* b^* system (L^* - lightness, a^* - green to red color, b^* - blue to yellow color). The measurement was performed in ten repetitions. For a better interpretation, the total color difference (ΔE) between the film and the white standard (L^*=92.36; a^*=-0.47; b^*=0.70) was calculated according to the method described by Mikus et al. [17]:

$$\Delta E = \sqrt{(L*-L)^2 + (a*-a)^2 + (b*-b)^2}$$

where: ΔE – total color difference;
$L*$, $a*$, $b*$ – parameters for white standard;
L, a, b – parameters for films.

Film opacity

Opacity was determined according to the spectrophotometric method using the EVOLUTION 220 UV-Visible spectrometer (Thermo Electron Corporation, Waltham, MA, USA) and Thermo INSIGHT software. The absorbance was measured at 600 nm in ten repetitions, and an empty test cell was used as a reference. The opacity of the prepared material was calculated according to the method described by Han and Floros [10].

Water vapor permeability

The water vapor permeability was determined by the gravimetric method described by Debeaufort et al. [4]. The relative humidity difference was 50 and 100% at a temperature of 25°C. At least three replicates were performed for each film type, and the water vapor permeability was determined at a steady state and from the change in the cell mass as a function of time.

Mechanical properties

The ASTM standard method D882-02 [8] was used to determine tensile strength and elongation at the break of the analyzed films with at least six repetitions. The Texture Analyzer TA-XT2i (Stable Micro Systems, Haslemere, UK) with the Texture Expert software was used to process the results.

Pouch preparation and solubility in water

To obtain pouches, films were heat-sealed on four sides with an impulse laboratory heat-sealer PFS/FS-200B (Kegel Machines, Poznań, Poland) and approximately 2 g of instant coffee was placed inside the pouches. The samples were prepared according to the labeled instructions without removing the edible pouches. The pouches with instant coffee were stirred in approximately 200 ml of hot water (95°C) using an RCT basic IKAMAG magnetic stirrer (IKA Poland, Warsaw) at the level of 500 rpm. Visual observations were done and the time of solubility was measured.

Statistical analysis

Statistica 13 (StatSoft Inc., Tulsa, OK, USA) was used to analyze the obtained results. The analysis of variance (ANOVA) at a significance level of 0.05 was performed with Tukey's post hoc test to detect significant differences in film properties.

RESULTS AND DISCUSSION

Edible films were prepared by casting method from aqueous film-forming solutions using plant-based biopolymers such as apple and citrus pectin, sodium alginate, and soy protein concentrate and were developed and analyzed to use them as single-use pouch packaging for instant coffee. The photographs of the films were presented in Fig. 1. All films showed homogeneous and continuous structure, without pores and crack. Films based on citrus pectin and sodium alginate were visible and transparent, whereas films based on apple pectin and soy protein isolate were more opaque with beige color, which is due to the character of the origin powders used in the study.

The analyzed edible film films had a water content of 11.00–19.69%. Moisture is an important parameter influencing physical properties, including flexibility and organization of the film structure and barrier properties of the film [29]. The apple pectin film achieved the highest level of water content, while the soy protein isolate film had the lowest value. The differences may be due to the origin and the characteristic of the hydrophilic biopolymers. Substances containing a lot of components that easily absorb water, such as carbohydrates, protein, or fiber, interact with water molecules, retaining more water [20]. Low water content in soy protein-based films may be the result of using the same amount of glycerol as in the case of other biopolymers, but increasing the percentage of protein in the film-forming solutions to 3% affects the lower water retention capacity of the films. Glycerol is a hydrophilic plasticizer that has water-retaining properties [7].

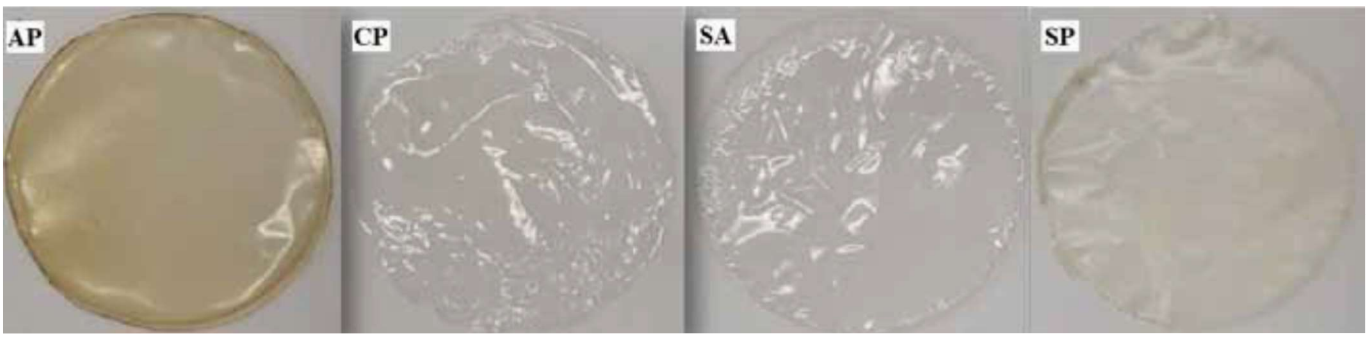

Fig. 1. Photographs of analyzed films based on apple pectin (AP), citrus pectin (CP), sodium alginate (SA) and soy protein isolate (SP).

Rys. 1. Fotografie analizowanych folii jadalnych z pektyny jabłkowej (AP), pektyny cytrusowej (CP), alginianu sodu (SA) i izolatu białka sojowego (SP).

Source: The own study

Źródło: Badania własne

Table 1. Water content and solubility in water of films based on apple pectin (AP), citrus pectin (CP), sodium alginate (SA) and soy protein isolate (SP)

Tabela 1. Zawartość wody i rozpuszczalność w wodzie folii wytworzonych z pektyny jabłkowej (AP), pektyny cytrusowej (CP), alginianu sodu (SA) i izolatu białka sojowego (SP)

Film/ Folia	Water content/ Zawartość wody [%]	Solubility in water/ Rozpuszczalność w wodzie [%]
AP	19.69 ± 0.03 ^{b}	99.94 ± 0.00 ^{b}
CP	13.67 ± 0.72 ^{a}	99.93 ± 0.02 ^{b}
SA	14.56 ± 1.33 ^{ab}	99.98 ± 0.00 ^{b}
SP	11.00 ± 0.95 ^{a}	99.83 ± 0.02 ^{a}

Mean values ± standard deviations. Different superscript letters ($^{a-b}$) within the same column indicate significant differences between the films ($p < 0.05$). Wartości średnie ± odchylenia standardowe. Różne litery indeksu górnego ($^{a-b}$) w tej samej kolumnie wskazują na istotne różnice między foliami (p <0,05).

Source: Own study

Źródło: Badania własne

Water solubility is a parameter that has two crucial aspects. Low solubility is useful to obtain a water-resistant film or coating, thereby rendering the package a moisture barrier. When designing instant coffee packages, high water solubility values are the most important parameter. The films made of sodium alginate were characterized by the highest solubility in water (99.98%), while films made of soy protein isolate had the lowest solubility (99.83%). However, all values were near 100% and the films retained their physical integrity during the analysis, which is attributed to the methodology and using high temperature (105°C). The differences in the obtained water solubility values may result from the different thicknesses of the individual films and the heterogeneous and porous structure. Nevertheless, the obtained values were similar to other biopolymer-based edible films [17].

Color is a crucial parameter influencing the consumer's choices as the most remarkable food quality attribute. Thus, it is expected for edible films to be transparent without the effect of coated or protected products. The color results for the analyzed films are shown in Table 2.

The results indicate that the lowest lightness of 88.66 (parameter L^*) was found for apple pectin, whereas all other films had significantly higher lightness from the range of 90.48–90.94. Values for the parameter a^* ranged from -1.36 for soy protein isolate to -0.50 for sodium alginate. Positive values of the parameter a^* indicate a greater proportion of red, while negative values indicate a greater proportion of green. For all the films tested, a tendency toward green color was observed more than the red one. The parameter b^*values ranged from 2.02 for sodium alginate to 8.87 for apple pectin. Positive values of the b* parameter indicate a greater proportion of yellow, while negative values indicate a greater proportion of blue. For all tested films, a tendency toward yellow color was observed, including films from apple pectin and soy protein isolate, which were characterized by a typical yellowish color. The obtained values of the total color difference (ΔE) were in the range of 2.57–8.99. According to the criterion adopted by the International Commission on Illumination, values in the range of 0–2 are unrecognizable for humans. An inexperienced observer will notice differences in color deviations in the range of 2–3.5, while clear differences are visible at values greater than 3.5 [17]. In the case of the tested samples, a clear difference can be observed only for films prepared from apple pectin and soy protein isolate.

Opacity is an important parameter from the consumer's point of view as it determines the visibility of the product. The analyzed films had opacity values in the range of 1.90–2.84 A/mm (Table 2), with the highest value for films from soy protein isolate. Such a high level of opacity may make it impossible to correctly identify the product contained in such packaging. The lowest values were recorded for films made of citrus pectin (1.90 A/mm). These films were highly transparent and easy to assess the product quality. However, more opaque packaging is better for minimizing UV radiation, thus creating a barrier to light and allowing some products to have improved shelf life.

Table 2. L^*, a^*, b^* color parameters, the total color difference (ΔE), and opacity (O) of films based on apple pectin (AP), citrus pectin (CP), sodium alginate (SA), and soy protein isolate (SP)

Tabela 2. Parametry barwy L^*, a^*, b^*, bezwzględna różnica barwy i nieprzezroczystosć (O) folii wytworzonych z pektyny jabłkowej (AP), pektyny cytrusowej (CP), alginianu sodu (SA) i izolatu białka sojowego (SP)

Film / Folia	L^*	a^*	b^*	ΔE	O [A/mm]
AP	88.66 ± 0.65 ^{a}	-0.85 ± 0.11 ^{b}	8.87 ± 1.47 ^{c}	8.99 ± 1.55 ^{c}	2.15 ± 0.34 ^{ab}
CP	90.70 ± 0.67 ^{b}	-0.59 ± 0.08 ^{c}	2.60 ± 0.79 ^{a}	2.57 ± 0.95 ^{a}	1.90 ± 0.22 ^{a}
SA	90.94 ± 0.46 ^{b}	-0.50 ± 0.08 ^{c}	2.02 ± 0.59 ^{a}	1.97 ± 0.66 ^{a}	1.98 ± 0.56 ^{ab}
SPI	90.48 ± 0.64 ^{b}	-1.36 ± 0.20 ^{a}	6.38 ± 0.96 ^{b}	6.07 ± 1.06 ^{b}	2.84 ± 0.87 ^{b}

Mean values ± standard deviations. Different superscript letters ($^{a-c}$) within the same column indicate significant differences between the films ($p < 0.05$). Wartości średnie ± odchylenia standardowe. Różne litery indeksu górnego ($^{a-c}$) w tej samej kolumnie wskazują na istotne różnice między foliami (p <0,05).

Source: Own study

Źródło: Badania własne

Table 3. Water vapor permeability of films based on apple pectin (AP), citrus pectin (CP), sodium alginate (SA), and soy protein isolate (SP)

Tabela 3. Przenikalność pary wodnej folii wytworzonych z pektyny jabłkowej (AP), pektyny cytrusowej (CP), alginianiu sodu (SA) i izolatu białka sojowego (SP)

Film/ Folia	Water vapor permability/ Przenikalność pary wodnej [·10-11g/m·s·Pa]
AP	1.65 ± 0.26 [a]
CP	1.17 ± 0.25 [a]
SA	1.20 ± 0.28 [a]
SP	5.75 ± 0.13 [b]

Mean values ± standard deviations. Different superscript letters ([a-b]) within the same column indicate significant differences between the films ($p<0.05$). Wartości średnie ± odchylenia standardowe. Różne litery indeksu górnego ([a-b]) w tej samej kolumnie wskazują na istotne różnice między foliami ($p <0,05$).

Source: Own study

Źródło: Badania własne

Table 4. Tensile strength and elongation at break of films based on apple pectin (AP), citrus pectin (CP), sodium alginate (SA), and soy protein isolate (SP)

Tabela 4. Wytrzymałość na zerwanie i wydłużenie względne folii wytworzonych z pektyny jabłkowej (AP), pektyny cytrusowej (CP), alginianiu sodu (SA) i izolatu białka sojowego (SP)

Film/ Folia	Tensile strength/ Wytrzymałość na zerwanie [MPa]	Elongation at break/ Wydłużenie względne [%]
AP	1.26 ± 0.54 [a]	8.64 ± 1.92 [a]
CP	0.9 ± 0.05 [a]	4.83 ± 1.22 [a]
SA	5.16 ± 0.00 [b]	7.06 ± 0.02 [a]
SPI	4.40 ± 1.29 [b]	39.37 ± 4.61 [b]

Mean values ± standard deviations. Different superscript letters ([a-b]) within the same column indicate significant differences between the films ($p < 0.05$). Wartości średnie ± odchylenia standardowe. Różne litery indeksu górnego ([a-b]) w tej samej kolumnie wskazują na istotne różnice między foliami ($p <0,05$).

Source: Own study

Źródło: Badania własne

One of the main purposes of using edible films is to control water vapor migration between the coated food product and the surrounding atmosphere, which is also crucial for the present study due to the hygroscopic character of instant coffee. Therefore, water vapor permeability for analyzed films was evaluated and the results are presented in Table 3. The films had a water vapor permeability in the range of 1.17 to 5.75 10^{-11} g/m·s·Pa, which is rather similar to other biopolymer-based films plasticized with glycerol. Films with the addition of glycerol are usually characterized by higher hygroscopicity [7]. The films made of soy protein isolate were characterized by highest values of water vapor permeability, whereas other films had significantly lower values.

Mechanical strength and flexibility are important film features that help maintain the integrity and impermeability of food packaging [8]. Many different factors affect strength, the main ones are the type of biopolymer, the structural organization of the biopolymer chain, processing technology, and the degree of cross-linking [6]. Table 4 presents the results of the mechanical properties of analyzed edible films. The tensile strength of the film ranged from 0.9 to 5.16 MPa, and the most resistant films were those prepared from sodium alginate whereas the lowest ones were those prepared from citrus pectin. The ability to film elongate is a water humidity-dependent factor since moisture can play a role as a plasticizer in the film structure. The elongation at break for analyzed films ranged from 4.83 to 39.37%. The lowest elongation showed films from citrus pectin and the highest films from soy protein isolate. Molecular interactions enhanced by heat denaturation could be accountable for the differences in mechanical properties of analyzed films. The addition of a plasticizer, which was glycerol, may cause a decrease in the affinity between the biopolymer chains in the film matrix. As a result, the formation of hydrogen bonds between the plasticizer and biopolymers (polysaccharides or proteins) resulted in greater flexibility of the film [13].

All films showed very good sealability, however, pouches from sodium alginate were not stable and started to open after a few seconds. The ability to be hermetically sealed is very important for integral packaging to extend shelf life and protect its content through the product lifecycle [13]. Therefore, pouches prepared from apple or citrus pectin and soy protein isolate were taken into account to access the solubility in contact with water. All pouches prepared from the films based on citrus pectin dissolved totally and instantly (within less than 30 s), which is beneficial in many applications such as quick-dissolvable pouches or oral strips for the delivery of active compounds. Similar observations were for films from apple pectin, however, films from soy protein isolate needed more time to dissolve, especially for sealable areas of the films. This is likely due to thermal denaturation occurring during the heat-sealing process, causing soy proteins to crosslink and become water-insoluble. Although completely safe to eat, the insoluble heat-sealing area can potentially confuse and turn off consumers. Nevertheless, all analyzed films can be further investigated to improve their capacity to dissolve instantaneously upon contact with water.

SUMMARY

Edible films can be used as soluble sachets, bags, packets, or sachets containing powdered substances such as seasoning and flavoring additives for instant food, instant coffee, powdered milk, pasta, beverage mixes, tea leaves, and other food additives. In this context, films made of biopolymers including apple or citrus pectin, sodium alginate, and soy protein isolate were investigated. The tests showed different properties of edible films depending on the biopolymer used. Soy protein films were rejected despite having the best mechanical tensile strength because they did not dissolve in

Fig. 2. Photographs of edible pouches based on apple pectin (AP), citrus pectin (CP) and soy protein isolate (SP) with instant coffee and beverage prepared from citrus pectin pouch.
Rys. 2. Fotografie jadalnych saszetek z pektyny jabłkowej (AP), pektyny cytrusowej (CP) i izolatu białka sojowego (SP) z kawą rozpuszczalną oraz napój przygotowany z saszetki z pektyną cytrusową.
Source: The own study
Źródło: Badania własne

water due to heat denaturation at the seal. Apple pectin and sodium alginate showed the best properties, but the low seal strength of the sodium alginate film and the yellow color of the apple pectin film reduced the functionality of these films. The research confirms the possibility of using edible films made of citrus pectin as a unit packaging for instant coffee, which showed the desired physical properties and complete solubility of coffee sachets in water. Further research is needed to improve the functional properties of the film in terms of stability and performance of citrus pectin packaging with instant coffee.

PODSUMOWANIE

Folie jadalne mogą znaleźć zastosowanie jako rozpuszczalne saszetki, torby, paczki lub saszetki zawierające sproszkowane substancje, takie jak dodatki przyprawowe i smakowe do żywności typu instant, kawy rozpuszczalnej, mleka w proszku, makaronu, mieszanek napojów, herbat liści i innych dodatków do żywności. W tym kontekście zbadano folie wytworzone z biopolimerów, w tym z pektyny jabłkowej lub cytrusowej, alginianu sodu i izolatu białka sojowego. Przeprowadzone badania wykazały różne właściwości folii jadalnych zależne od zastosowanego biopolimeru. Folie z izolatu białka sojowego zostały odrzucone pomimo najlepszej wytrzymałości mechanicznej na rozciąganie, gdyż nie rozpuszczały się w wodzie z uwagi na denaturację cieplną przy zgrzewie. Pektyna jabłkowa oraz alginian sodu wykazywały najlepsze właściwości, lecz niska wytrzymałość zgrzewu folii z alginiatu sodu i żółte zabarwienie folii z pektyny jabłkowej obniżyły ich funkcjonalność. Badania potwierdzają możliwość wykorzystania folii jadalnych z pektyny cytrusowej jako opakowanie jednostkowe do kawy rozpuszczalnej, ponieważ wykazują pożądane właściwości fizyczne i całkowitą rozpuszczalność saszetek z kawą w wodzie. Niezbędne są dalsze badania w celu ulepszenia właściwości funkcjonalnych folii pod kątem stabilności i właściwości użytkowych opakowań z pektyny cytrusowej zawierających kawę rozpuszczalną.

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