Edible coatings enriched with *Malva sylvestris* L. extract

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**Abstract.** Edible coatings can play a leading role in food storage. In baked goods, attention is focused on inhibiting the processes of mold development and moisture loss. Adding functional ingredients to coatings can slow the spoilage process thus increasing shelf-life. The purpose of this study was to prepare edible coatings with polysaccharides and coconut oil enriched with an ethanol extract of *Malva sylvestris* L. flowers (mallow) and to characterize its physico-chemical and antibacterial properties. A computerized method for analysis of the digital dispersions images was used to further describe the enriched coatings. The rheological characteristics of the coatings were determined by structural mechanical analysis. All developed model emulsion coatings demonstrated a polydisperse character - the diameter of the globules in the studied volume ranged from 1.5 µm to 12 µm. All enriched coatings with mallow extract had better dispersion characteristics. The results showed that the presence of a mallow extract had a positive effect on the antibacterial activity of the xanthan food coating by increasing the zone of inhibition against *Escherichia coli* ATCC 8739. The pectin coating with mallow extract exhibited antibacterial activity against *Salmonella* NCTC 6017, while a suppressive effect on tests pathogen did not characterize the control sample.

Keywords: edible coating, baked goods, polysaccharides, extract, antibacterial activity, *Malva sylvestris* L., rheology.

1. Introduction

The main function of an edible coating is not to completely replace the traditional packaging, but to rather give additional characteristics and generate functional advantages through natural additives used in food storage or helping to enrich them. Edible packaging can play a leading role in food storage, as it is considered a carrier of functional ingredients necessary for human health and well-being. Many plants synthesize substances that are beneficial to human health. The most common are nutraceuticals, phytochemicals (antioxidants and antimicrobials), flavorings, bacteriocins and probiotics [1]. In addition, edible packaging regulates moisture control and fat transport, the level of mechanical permeability, and the protection of packaged foodstuffs from gases. When functional ingredients are introduced into edible coatings and films to perform their functions, they become an undisputed plus both for the food itself, and for its consumers [2].

Introduction of antimicrobial agents in the edible coating also offers a number of advantages compared to traditional preservative, an antioxidant: natural ingredients can be applied directly onto the surface of the food without penetrating the food matrix, and thus to act directly on the designated locations [3]. The edible antimicrobial coatings allow food preservation by eliminating or at least limiting the development of pathogenic microorganisms (*Listeria monocytogenes, Salmonella,* and
In order to make the correct choice of the most appropriate antimicrobial agents, it is necessary to know their impact on the target microorganisms. In baked goods, attention is focused on slowing down the processes of mold and moisture. Microbial growth on the surface of foods is a major spoilage cause [4, 5].

Many plants synthesize substances that are beneficial to human health. Antioxidants are important components because they protect against free radicals. Free radicals are known to be a major factor in degenerative diseases and are recognized as major causes of cancer. Nowadays, there is a growing interest in both industry and research on medicinal plants and spices due to their antioxidant phytochemicals and antimicrobial properties [6].

The *Malva sylvestris* L. plant, known as common mallow, has been used as food and medicine in Europe since ancient Greece and Rome. It is a biennial plant of the *Malvaceae* family. Roots, leaves, flowers and seeds are used as infusions, decoctions, lotions and gargles [7, 8, 9, 10, 11, 12]. It is also used as a bronchodilator, expectorant, antitussive, antidiarrheal and highly recommended for the treatment of acne and skin care, as well as an antiseptic and sedative [9, 11, 12, 13].

*M. sylvestris* is well known in the field of pharmacology, and cosmetics. There are applications of mallow in the culinary practice as well [9, 14]. The young leaves are eaten raw in salads, soups, and as cooked vegetables. Immature flowers are sucked or chewed by children, shepherds and hunters [9, 12]. The biological activity of this plant may be due to antioxidants such as polyphenols, vitamin C, vitamin E, β-carotene and other important phytochemicals. The leaves and flowers also contain large amounts of carbohydrates. Petkova et al. [15] proved a richer carbohydrate content of the flowers compared to the leaves. Similar results were reported by Barros et al. [16]. Carbohydrates give the mallow most of its calming activity, although flavonoids and anthocyanidins can also contribute to it. The active ingredients found in flowers and leaves, are rich in mucus, which is used for their expectorant properties [17]. The plant is widely used to soothe mucosal inflammation. *M. sylvestris* plant extract is able to strengthen the immune system and reduce the effect of *Candida* infection [18]. Mihaylova et al. [19] found that the flowers are more active against pathogenic microorganisms. The maximum inhibitory zone is observed in the infusion of flowers against *Penicillium* sp. The same antimicrobial activity of *M. sylvestris* seed oil was reported by Fatima et al. [20].

The purpose of this study was to develop a technology for enriched with an ethanol extract of *M. sylvestris* flowers multicomponent biopolymer coatings with polysaccharides and coconut oil. The current investigation aslo aimed at evaluating the effect the added extract had on target properties that characterize edible coatings i.e. moisture, water activity, pH, rheological characteristics, dispersion characteristics and antibacterial activity and to compare it to and identical coating without extract.

2. Material and Methods

2.1. Materials

Edible coatings include biopolimers: plant polysaccharides - apple pectin and carboxymethylcellulose (CMC), as well as bacterial polysaccharide - xanthan. Apple pectin is highly esterified with a degree of esterification of 63% (62% purity, 125,000 molecular weight). CMC is manufactured by Noviant (Nijmegen, Netherlands) under the trade name Cekol®. The bacterial polysaccharide xanthan has been obtained during the fermentation of the bacterial culture *Xanthomonas campestris*. Each polysaccharide introduced in an aqueous solution (1-2% w/v) is used as a stabilizer in the edible coating in an emulsion form. Coconut oil is added 1% to the emulsion in order to increase the hydrophobicity of the coating. Glycerol is used as a plasticizer (0.5 ml/g biopolymer). All reagents and chemicals are classified as "pure for analysis". Distilled water is used. The corresponding multicomponent biopolymer coatings based on polysaccharides and coconut oil without included plant extract are used as control samples. The recipe and technology of the coatings are presented in previously published work [21].
2.1.1. Plant extract /tincture/
The flowers of *M. sylvestris* plant were gathered from the Sliven region, Bulgaria in spring-summer 2019. The flowers were sent for further identification at the Botany faculty of Plovdiv University “Paisii Hilendarski”. The starting plant flowers were pre-dried (moisture content 15.82 ± 0.84%) and milled. The moisture content of air-dried flowers of *M. sylvestris* was determined by drying to constant weight at 105°C [22]. Ethyl alcohol with a concentration of 70% was used to obtain an extract (tincture) from the dried flowers of *M. sylvestris*. A quantity of the raw material (air-dried plant flowers) is subjected to solid-liquid extraction with ethyl alcohol at a hydromodule of 1:20 (product to alcohol) for 30 min in a glass reflux. The resulting extracts are filtered and stored at 4°C.

2.2. Physico-chemical analyzes of the obtained biopolymer coatings without and with plant extract

2.2.1. Moisture content
Moisture content is measured by express weight method by an electronic scale with infrared heating (KERN MLB50-3/Version 1.1 09/2004).

2.2.2. Water activity (a_w)
The water activity (a_w) of the biopolymer coating is measured with an apparatus Novasina AG Neuheimstrasse 12 CH-8853 Lachen, Switzerland, at a temperature of 30 ± 0.5°C. The sample put in a plastic cylinder with a height of 1 cm and a diameter of 4 cm is placed in the measuring chamber of the apparatus, the sensor is calibrated, after which the readings are taken.

2.2.3. Active acidity
The active acidity of the biopolymer coating is measured by a pH meter (model inoLab pH 7110, Weilheim).

2.2.4. Structural-mechanical analysis for determination of the rheological characteristics
According to their rheological properties, liquids are divided into two groups - Newtonian and non-Newtonian. The rheological characteristics of non-Newtonian fluids are usually taken by setting different shear rates \(D\) and measuring the shear stress \(\tau\). The dependence between the two quantities (in coordinates \(\tau/D\) or \(D/\tau\)) is constructed. The resulting curve is called the flow curve or rheogram. The rheological type of the dispersed system is determined by the type of flow curve [23].

The rheological characteristics are determined by a rotary viscometer Fungilab Premium-L (Spain). Structural viscosity (\(\eta\)) is measured at various shear rates (\(D\)) and at a temperature of 19-20°C, using cylinders TL-5 (at coating with pectin) and TL-6 (at coating with CMC and xanthan). Shear stress (\(\tau\)), ultimate shear stress (\(\theta_u\)), plastic viscosity (\(\mu_p\)), flow index (\(n\)) - characterizing the degree of product anomaly with respect to viscosity, consistency coefficient (\(k\)) - are determined to characterize consistency.

2.2.5. Method for computer analysis of digital images
The method for analysis of digital images - Image Analysis [24] is used to determine the dispersion characteristics of the colloidal particles (oil globules) in the studied samples. The computer processing is performed with a software program for microscopic image analysis, "UTHSCSA ImageTool - Version 3.0" developed by The University of Texas Health Science Center - USA. UTHSCSA ImageTool is free and open source software and does not require a license.

2.2.5.1. Sauter Diameter method
The Sauter diameter - \(d_{32}\) is one of the indicators by which the dispersed characteristic of the oil globules in the samples is evaluated. It takes into account both the volume and the total surface area of the colloidal particles in a given sample volume. Sauter diameter is inversely proportional to a specific surface in the studied colloidal particles. Thus, the smaller \(d_{32}\) means a large number of smaller particles,
because their total specific surface area is larger and vice versa - larger values of $d_{32}$ means a large number of larger colloidal particles having a smaller total specific surface. Sauter diameter is used to estimate and characterize the fineness of the dispersion of colloidal particles [25]. The formula by which the Sauter diameter is calculated:

$$d_{32} = \frac{\sum_{i=1}^{k} n_i d_i^3}{\sum_{i=1}^{k} n_i d_i^2}$$  \hspace{1cm} (1)$$

where: $n_i$ is the number of colloidal particles (oil globules) which have a diameter $d_i$.

2.3. Microbiological analyzes

2.3.1. Test microorganisms

Strains of foodborne pathogenic bacteria are used as test microorganisms. Antibacterial activity was tested against Gram-positive bacteria - *Listeria monocytogenes* NCTC 11994 and *Staphylococcus aureus* ATCC 25093, and Gram-negative bacteria – *Escherichia coli* ATCC 8739 and *Salmonella enterica* subsp. *enterica* serovar Abony NCTC 6017. The strains are supplied by the National Bank for Industrial Microorganisms and Cell Cultures. Selective media used for the microbiological testing were Listeria Oxford Agar Base with an additive containing cycloheximide /Biolife/; ENDO agar /Merck/; LEIFSON Agar /Merck/; Baird Parker Agar Base /Biolife/ with yolk-tellurite supplement and Plate Mount Agar /Merck/, respectively.

2.3.2. Determination of the antibacterial activity of biopolymer coatings with plant extract

Antibacterial activity is determined by modifying the agar diffusion method by measuring the zones of growth inhibition of pathogens around metal rings in which a certain amount of food coating is applied. Selective media for *Listeria monocytogenes* NCTC 11994, *Escherichia coli* ATCC 8739, *Salmonella enterica* NCTC 6017 are inoculated with pathogen suspensions prepared from a 24-hour culture on PCA. From a suitable ten-fold dilution ($10^{-3}$) of the suspension, the melted and cooled to 45-50°C selective media are inoculated. The effective concentration of the cells in the agar is equated to the concentration of the suspension from a dilution of $1.10^{-5}$, since 1 ml of suspension is inoculated into 99 ml medium. After solidifying the media, sterilized metal rings with a diameter of Ø = 6 mm are placed on their surface, in which 0.10 and 0.15 ml of food coating have been applied. The plates are incubated at 37°C. The diameter [mm] of the growth inhibition zones of *Listeria monocytogenes* NCTC 11994, *Escherichia coli* ATCC 8739, *Salmonella enterica* NCTC 6017 and *Staphylococcus aureus* ATCC 25093 is measured at 24 and 48 hours and a comparative assessment of their antibacterial activity is made.

2.4. Statistical analysis

Statistical analysis of the results is performed using ANOVA at a level of significance 0.05 and triplicate sample.

3. Results and Discussion

3.1. Technology for production of multicomponent biopolymer coatings based on polysaccharides and coconut oil with plant extract

After analysis of the experimental data and the results of preliminary technological experiments [21], three stages turn out to be critical for the quality of the final products: 1) dissolution; 2) inclusion of plasticizers; 3) homogenization. Based on the experimental data, a generalized technological scheme for obtaining multicomponent biopolymer coatings with plant extract is prepared (Fig. 1). The plant extract is directly incorporated into the emulsion coating. The mallow extract (*M. sylvestris*) used in the present work was added in a concentration of 8% of the emulsion coating.
Polysaccharide (1-2% w/v) + water

- **Homogenisation:**
  - speed 400-500 rpm

- **Storage:**
  - 18-20°C for 10-12 h

- **Plasticizer and (glycerol, coconut oil):**
  - Homogenization at speed 400-500 rpm

- **Antimicrobial/antioxidant substances (plant extract):**
  - Homogenization at speed 400-500 rpm

- **Coating application:**
  - Spraying/immersion of the food product for 0.5-3 min

**Figure 1.** Technological scheme of food biopolymer coatings based on polysaccharides with plant extract.

### 3.2. Physico-chemical characteristics of multicomponent food coatings based on polysaccharides without and with plant extract

The studied physico-chemical characteristics of multicomponent food coatings without and with plant extract (*M. sylvestris*) are given in Table 1.

| Type of edible coating* | Physico-chemical characteristics |
|-------------------------|----------------------------------|
|                         | Moisture, [%] ±SD | a_w, [%] ±SD | pH          |
| P                       | 97.24 ± 0.50       | 0.990 ± 0.000 | 3.45 ± 0.06 |
| C                       | 97.96 ± 0.28       | 0.992 ± 0.001 | 6.52 ± 0.08 |
| X                       | 98.76 ± 0.21       | 0.993 ± 0.001 | 5.49 ± 0.07 |
| P₁                      | 97.22 ± 0.01       | 0.982 ± 0.001 | 3.58 ± 0.09 |
| C₁                      | 97.88 ± 0.47       | 0.984 ± 0.000 | 6.57 ± 0.07 |
| X₁                      | 98.54 ± 0.02       | 0.985 ± 0.000 | 5.30 ± 0.05 |

* P - pectin; C - CMC; X - xanthan

Index 1 indicates coatings in which mallow extract (*M. sylvestris*) has been added

The moisture content of multicomponent food coatings based on polysaccharides was over 97%. It does not change significantly when mallow extract is added. A decrease in the water activity of all types of multicomponent edible coatings was found when applying the *M. sylvestris* extract. The pectin coating had the lowest pH values. The plant extract had no significant effect on the pH values of the coatings.

### 3.3. Rheological characteristics of multicomponent biopolymer coatings without and with plant extract

Table 2 shows the viscosity values of the emulsion coatings with pectin, without and with plant extract at shear rates in the range of $D = 26.4$ s⁻¹ and $D = 132.0$ s⁻¹. As the shear rate increased, the structural viscosity, although weak, decreased, which indicated the non-Newtonian character of the studied fluids. The values of the structural viscosity of the two emulsion coatings were very close for all shear rates.
Table 2. Structural viscosity (η) of emulsion coatings with pectin, with CMC, with xanthan - without and with plant extract, at different shear rates (D).

| D, [s⁻¹] | η, [mPa.s] | D, [s⁻¹] | η, [mPa.s] | D, [s⁻¹] | η, [mPa.s] |
|---------|-----------|---------|-----------|---------|-----------|
|         | P*        | P₁      | C         | C₁      | X         | X₁       |
| 26.4    | 20.1      | 21.7    | 1.02      | 2069    | 1880      | 0.17     | 20910    | 17967    |
| 33.0    | 18.5      | 19.3    | 1.36      | 1936    | 1785      | 0.34     | 12298    | 10743    |
| 39.6    | 17.2      | 18.2    | 2.04      | 1762    | 1630      | 0.68     | 6981     | 6196     |
| 46.2    | 16.6      | 17.6    | 3.40      | 1564    | 1450      | 1.02     | 5046     | 4458     |
| 52.8    | 16.2      | 17.2    | 5.10      | 1373    | 1290      | 1.36     | 3963     | 3546     |
| 66.0    | 15.8      | 16.7    | 6.80      | 1268    | 1190      | 2.04     | 2832     | 2543     |
| 92.4    | 15.4      | 16.1    | 3.40      | 1846    | 1669      |          |          |          |
| 105.6   | 15.1      | 15.8    | 5.10      | 1320    | 1184      |          |          |          |
| 132.0   | 15.1      | 15.7    | 6.80      | 1036    | 924       |          |          |          |
| 8.50    |            |         |           |         | 860       |          | 771      |

* P - pectin; C - CMC; X - xanthan
Index 1 indicates coatings in which mallow extract (M. sylvestris) has been added.

The graphs plotted in D-τ coordinates (Fig. 2) for both fluids were close to straight lines, and when approximated did not pass through the beginning of the coordinate system. This suggested that the studied emulsion coatings had the behavior of an ideal plastic body and an equation of the form [23] could be used to describe the rheological lines:

\[ τ = θ_d + μ_{pl}D \]

(2)

where \( μ_{pl} \) is the plastic viscosity, and \( θ_d \) is the flow stress.

Figure 2. Rheological curves of emulsion coatings with pectin, without (- ▲ -) and with (- ■ -) plant extract.

Figure 3. Rheological curves of emulsion coatings with CMC, without (- ▲ -) and with plant extract (- ■ -).

Figure 4. Rheological curves of emulsion coatings with xanthan, without (- ▲ -) and with plant extract (- ■ -).

The values of \( μ_{pl} \) and \( θ_d \) and the correlation coefficient are presented in Table 3.

Table 3. Values of plastic viscosity (\( μ_{pl} \)), ultimate shear stress (\( θ_d \)) and correlation coefficient (\( R^2 \)) of emulsion coatings with pectin, without (P) and with plant extract (P₁).

| Rheological characteristics | P*  | P₁  |
|----------------------------|-----|-----|
| \( μ_{pl} \), [Pa.s]       | 0.1372 | 0.1618 |
| \( θ_d \), [Pa]            | 0.0139 | 0.0144 |
| \( R^2 \)                  | 0.9990 | 0.9992 |

* P - pectin

Index 1 indicates coatings in which mallow extract (M. sylvestris) has been added.
The emulsion coating’s structural viscosity with CMC and xanthan, without and with the plant extract at various shear rates is shown in Table 2. As the shear rate increased, the viscosity of all four emulsion coatings decreased, indicating that the emulsion coatings were non-Newtonian liquids. Figures 3 and 4 show the rheological curves of the emulsion coatings with CMC and xanthan, respectively. Rheologically, all four emulsion coatings behaved like pseudoplastic fluids. The graphical dependencies \( D\text{-}\tau \) were curves convex to the axis \( \tau \) and when approximated, they passed through the beginning of the coordinate system. This finding showed that the rheological curves could be described empirically by the power law of Oswald-de-Villa:

\[
\tau = kD^n,
\]

where \( k \) is the consistency coefficient (Pa.s\(^n\)) and \( n \) is the flow index.

For pseudoplastic fluids, the rheological properties could be expressed by these two coefficients. The consistency coefficient was an expression of the viscosity - the higher \( k \), the higher the viscosity [23, 26]. The flow index indicated how much the liquid differs from the Newtonian one, assumed values lower than 1.0 and the lower they are, the more pronounced is the non-Newtonian character of the liquid [27, 28, 29]. Values of \( k \) and \( n \) for the studied systems are presented in Table 4.

**Table 4.** Values of consistency coefficient \( k \), flow index \( n \) and correlation coefficient \( R^2 \) of emulsion coatings with CMC, without (C) and with plant extract (C\(_1\)), and of emulsion coatings with xanthan, without (X) and with plant extract (X\(_1\)) at different shear rates.

| Rheological characteristics | C*  | C\(_1\) | X  | X\(_1\) |
|----------------------------|-----|--------|----|--------|
| \( k \), [Pa.s\(^n\)]      | 2.1002 | 1.9259 | 5.0382 | 4.4561 |
| \( n \)                     | 0.7425 | 0.7501 | 0.1799 | 0.1897 |
| \( R^2 \)                   | 0.9995 | 0.9994 | 0.9962 | 0.9929 |

* C - CMC; X - xanthan
Index 1 indicates coatings in which mallow extract (M. sylvestris) has been added

The consistency coefficients of the coatings without extract were slightly higher than those with plant extract - by 8.3% and 11.6%, respectively, for the emulsion coatings with CMC and xanthan. Lower values of the flow indices of liquids without extract indicated an increase in their non-Newtonian behavior.

A comparison could be made between the rheological behavior of CMC and xanthan coatings at shear rate values between \( D = 1.02 \text{ s}^{-1} \) and \( D = 6.80 \text{ s}^{-1} \). Considering the results in Table 2 it was seen that the structural viscosity of the emulsion coating with xanthan gum is significantly higher than the ones of the emulsion coating with CMC, at all values of \( D \) within the said interval. The values of the consistency coefficient were also significantly higher (Table 4). The non-Newtonian character of the xanthan emulsion coatings was even more pronounced, which was evident from the lower values of the flow index.

3.4. **Dispersive characteristics of model emulsion multicomponent food coatings based on polysaccharides and coconut oil without and with plant extract**

The dispersion characteristics of food M/V emulsions are an important indicator related to the structural mechanical and stability characteristics of each dispersed system. The amount and distribution of the oil globules in the emulsion affects their various properties such as physical stability of the process of flocculation, coalescence and cremation; rheological behaviors such as fluids; sensory indicators - texture, color and rate of release of various volatile components that determine aroma and taste.

One of the main functional roles of food hydrocolloids is to be included in the composition of emulsions as agents that stabilize the aqueous medium of the dispersed system. Hydrocolloids can also affect the shelf life of the emulsion. They are especially suitable when applied in emulsion disperse systems, in which the concentration of the oil phase is very low - beverages, food coatings, etc. The
selected hydrocolloids (pectin, xanthan, and CMC) included in the developed model emulsion food coatings have besides stabilizing and emulsifying properties.

The experimental data from the microphotographic analysis are presented in Table 5, and examples of the microphotograms are given in Figure 5.

**Table 5.** Dispersive characteristics of model emulsion food coatings without and with plant extract (*M. sylvestris*).

| Disperse characteristic | Type of edible coating |
|-------------------------|------------------------|
|                         | P          | C          | X          | P₁        | C₁        | X₁        |
| Average diameter, \(\bar{d}\) [\(\mu m\)] | 2.55 ± 0.01 | 3.02 ± 0.003 | 3.38 ± 0.005 | 2.62 ± 0.004 | 2.60 ± 0.003 | 2.63 ± 0.004 |
| Median diameter, \(Md\) [\(\mu m\)] | 2.05 a | 2.77 b | 3.01 b | 2.36 a | 2.32 a | 2.35 a |
| S₃₂ - Sauter diameter, \(d₃₂\) [\(\mu m\)] | 9.69 a | 4.32 b | 5.05 c | 3.97 a | 3.78 a | 3.97 a |
| Average volume, \(V\) | 55.86 ± 0.97 | 24.74 ± 0.14 | 36.59 ± 0.28 | 17.25 ± 0.13 | 15.80 ± 0.11 | 17.39 ± 0.13 |
| Average surface, \(S\) | 34.58 ± 0.42 | 34.39 ± 0.11 | 43.49 ± 0.16 | 26.07 ± 0.10 | 25.06 ± 0.09 | 26.31 ± 0.10 |
| Dispersion, \(D\) [\(\mu m\)] | 0.39 a | 0.33 b | 0.3 b | 0.38 a | 0.39 a | 0.38 a |

1 Results marked with the same letters are statistically indistinguishable, with a confidence level of 0.05
2 P - pectin; C - CMC; X - xanthan

Index 1 indicates coatings in which mallow extract (*M. sylvestris*) has been added.

**Figure 5.** Microphotograms of model emulsion food coatings *without and with plant extract (*M. sylvestris*).

*P* - pectin; *C* - CMC; *X* - xanthan

Index 1 indicates coatings in which mallow extract (*M. sylvestris*) has been added.

When food-grade edible emulsion coatings are used, the distribution and size of the globules can affect the uniformity of application, but also the degree of release of the antimicrobial ingredients included in the coating compositions.

The results presented in Table 5 show that all samples of model emulsions to which mallow extract (*M. sylvestris*) has been added have better dispersion characteristics. This trend is best demonstrated by the Sauter diameter indicator.
Figure 6. Experimental histograms of model emulsion food coatings * without and with plant extract (M. sylvestris).

*P - pectin; C - CMC; X - xanthan; Index 1 indicates coatings in which mallow extract (M. sylvestris) has been added.
The Sauter diameter index reflected the ratio of the total volume of the oil globules to the total surface area of the dispersed particles in the sample volume studied. Sauter diameter was a volume, boron-proportional to the specific surface area of the test colloidal particles and was used to evaluate and characterize the fineness of dispersion of colloidal particles in the developed emulsion food coatings. In the model emulsions, in which the extract of mallow was added, the value of the Sauter diameter was reduced. In the emulsions containing the hydrocolloid pectin, the Sauter diameter was reduced approximately 3 times - from 9.69 μm to 3.97 μm. In emulsions with xanthan and mallow extract, the Sauter diameter decreased by 27%, and in those with CMC it decreased by 14%.

All developed model emulsion coatings demonstrated polydisperse character - the diameter of the globules in the studied volume varied from 1.5 μm to 12 μm. The average values of the diameter of the measured oil globules were from 2.55 μm to 3.38 μm. The change in the degree of dispersion when adding mallow extract could be traced from the values of the "dispersion" indicator and the experimental histograms - fig. 6.

The distribution of oil globules in model emulsion systems was also represented by experimental histograms. In all model systems with xanthan, pectin and CMC, monomodal distribution peaks with a diameter of oil globules varying about 3 μm were observed before the addition of mallow extract. After the addition of mallow extract, bimodal peaks were observed, one remained at about 3 μm, but a new one at about 2 μm appeared. The total number of oil globules with a large diameter (12 μm) decreased in all model systems with mallow extract, and the number of globules with a smaller size increased.

3.5. Antibacterial activity of food coatings with plant extract

Table 6 presents the results concerning the zones of growth inhibition of the pathogenic bacteria in the selective growth media of various samples of food coatings involving the plant extract (M. sylvestris).

**Table 6. Zones of inhibition of the growth of pathogenic bacteria (mm) in selective media of different types of food coatings without and with plant extract (at the 48th hour).**

| Pathogenic microorganism | Type of food coating* | P | P₁ | C | C₁ | X | X₁ |
|--------------------------|-----------------------|---|----|---|----|---|----|
| **Escherichia coli**     |                       | 6 | 6  | 6  | 6  | 17| 15 |
| ATCC 8739                |                       | 10| 10 | 10 | 10 | 15| 15 |
| **Salmonella**           |                       | 6 | 6  | 36 | 10 | 12| 6  |
| NCTC 6017                |                       | 12| 6  | 6  | 6  | 6 | 6  |
| **Listeria monocytogenes** |                      | 19| 6  | 6  | 6  | 6 | 6  |
| NCTC 11994               |                       | 6 | 6  | 6  | 6  | 6 | 6  |
| **Staphylococcus aureus** |                      | 6 | 6  | 6  | 6  | 6 | 6  |
| ATCC 25093               |                       | 6 | 6  | 6  | 6  | 6 | 6  |

*P - pectin; C - CMC; X - xanthan
Index 1 indicates coatings in which mallow extract (M. sylvestris) has been added
b diameter of the zone equal to the diameter of the metal ring (6 mm) is considered a negative result

From the studied edible coatings, that of apple pectin with the participation of mallow extract, in an amount of 0.15 ml, was characterized by the strongest antibacterial activity, with a zone of inhibition of 36 mm against S. enterica. The strain of E. coli was the most sensitive to edible coatings involving plant extract. The most pronounced antibacterial activity against the pathogen was characterized by the xanthan coating with the participation of plant extract (16 mm/0.15 ml and 11 mm/0.10 ml), followed by the coating with carboxymethylcellulose with the participation of mallow extract - 15 mm/0.15 ml.
The edible coatings did not exhibit antibacterial activity against pathogenic microorganisms *L. monocytogenes* and *S. aureus* (Table 6).

The results obtained in this study showed that the presence of the extract had a positive impact on the antibacterial activity of food coated with xanthan by increasing the zone of inhibition from 14 mm (the sample without the presence of the plant extract) to 16 mm (sample with the mallow extract) against *E. coli*. Pectin coating with the extract exhibited antibacterial activity against *S. enterica* with a zone of growth inhibition of 36 mm/15 ml and 10 mm/10 ml, while the control sample was not characterized by inhibitory activity against the tested pathogen.

According to literature, Gram (+) bacteria were more sensitive than Gram (-) to herbal and spice extracts. This sensitivity was due to the outer membrane, which acts as a barrier for the penetration of a number of antimicrobial substances and the unique periplasmic space possessed by Gram (-) microorganisms [30]. Some plant extracts did not fully follow this trend. This discrepancy is explained by the difference in the plant extracts’ chemical composition and the climatic and geographical features that characterize them.

4. Conclusion
Technology for application of antimicrobial and antioxidant substances of plant origin in multicomponent biopolymer coatings has been developed.

The moisture content of multicomponent food coatings based on polysaccharides was over 97%. It does not change significantly mallow extract is added. A decrease in the water activity of all types of multicomponent food coatings was found when applying mallow (*Malva sylvestris* L.) plant extract.

The results showed that bioactive substances of vegetable origin in the composite matrix significantly affected the rheological properties of the coatings of carboxymethylcellulose and xanthan gum. For all shear rates, the viscosity of emulsion coatings with plant extract was lower than that without extract. Higher values of the flow indices of the coatings with plant extract indicated a weakening of their non-Newtonian behavior.

The study of the dispersion of model emulsion food coatings with polysaccharides showed that the addition of mallow extract reduced the degree of polydispersity. In all model systems – it significantly increased the number of oil globules with a smaller diameter. More than 30% of the oil globules had a diameter of 1.5 µm in the emulsions with carboxymethylcellulose and about 25% of the globules in the model systems with xanthan. Reducing the size of the oil globules led to a general stabilization of the dispersed system and can affect both the uniformity of applying food coatings and the degree of release of antimicrobial components included in their composition.

The results showed that the presence of a mallow extract had a positive effect on the antibacterial activity of the xanthan food coating by increasing the zone of inhibition from 14 mm (sample without plant extract) to 16 mm (sample involving mallow extract) against *Escherichia coli* ATCC 8739. The pectin coating with mallow extract exhibited antibacterial activity against *Salmonella* NCTC 6017 with an inhibition zone of 36 mm/15 ml and 10 mm/10 ml, while the control sample is not characterized by a suppressive effect on pathogen tests.

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