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ANTIMICROBIAL BIODEGRADABLE PACKAGING OF SLICED BAKERY FOR RESTAURANTS

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Correspondence:

O. Shulga
E-mail: shulgaos@ukr.net

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O. Shulga[1]**,** Doctor of Technical Sciences, Professor
A. Chorna [1]**,** Candidate of Technical Sciences, Associate Professor
S. Shulga[2]**,** Candidate of Chemical Sciences, Professor
[1]Department of Food Expertise
[2]Department of Food Chemistry
National University of Food Technologies
Volodymyrska street, 68, Kyiv, Ukraine, 01033

Abstract. In the modern minds of the advanced ecology and safety of food products control, it is relevant the development of antimicrobial biodegradable packaging. The article presents the results of the antagonistic action of nanodispersed titanium dioxide powder (TiO_2) at the warehouse of biodegradable packaging for bakery products on the living of microorganisms (*Escherichia coli, Bacillus subtilis, Candida albicans, Aspergillus niger*). It is known there are developments on the use of antimicrobial substances of both organic and inorganic origin, the microbiological action of the substances used have an effect on pathogenic, opportunistic, fungi, gram-negative and gram-positive bacteria. We found that the introduction of 1% TiO_2 r into the molding solution allows to give the package antibacterial properties, as it inhibits the development of *Escherichia coli* and *Bacillus subtilis*, as there is a delay in the growth of their colonies compared to the sample without packaging with TiO_2. According to the results of provocative testing, biodegradable packaging with a content of 1% TiO_2 has an inhibitory effect on *Bacillus subtilis*. In addition to antimicrobial properties, the package under study must also have barrier properties, so the vapor permeability of the presented package was determined. The study results show that the addition of 1% TiO_2 slightly reduces the vapor permeability, but the increase in the concentration 2–5 % of TiO_2 causes an increase in vapor permeability from 4.7 to 5.2 mg / (m·h·kPa). The vapor permeability of the presented biodegradable antimicrobial packaging is due to the presence of pores, the number and size of which were determined experimentally. Thus, nanodispersed TiO_2 in the amount of 1% in the molding solution of the biodegradable coating is an effective antimicrobial component for antimicrobial coatings, which does not impair their barrier properties.

Key words: antimicrobial packaging, bakery products, titanium dioxide, vapor permeability, biodegradable packaging, microorganisms.

Introduction. Formulation of the problem

The problem of microbiological contamination of food products is now quite acute, especially in the context of the mandatory introduction of a safety system based on principles of HACCP for all market operators. Packaging, which will avoid the development of microorganisms, is necessary in modern conditions, so expanding the range of antimicrobial substances is appropriate and timely.

The meaning «antimicrobial packaging» covers any packaging technology used to control the reproduction of microorganisms in a food product [1-3]. Antibacterial packaging materials are a promising direction in the development of the packaging industry today [4].

The environmental safety of packaging materials and containers is very important. In April 2015 the European Parliament approved Directive 94/62 / EC on the reduction of light (thickness <50 μm) and ultralight (<15 μm) plastic bags, which are currently for a number of economic and technological reasons recyclable in very limited quantities. Until December 31, 2019, the annual consumption of light packages per capita should not exceed 90 units and 40 units until December 31, 2025. Labeling of biodegradable materials with composting conditions will remain mandatory. Given the active orientation of Ukraine to the European community, it is necessary to think now and actively implement the proposed approaches to this issue in the life of the country.

The Directive states that plastic bags, which manufacturers label as oxo-biodegradable and oxo-decomposable, are not in fact such. In these packages, oxy-additives are included in the composition of ordinary plastic. Due to the presence of these additives, plastics are destroyed over time, but only to small particles, which are not able to further biologically break down completely and therefore remain in the environment for a long time.

It is incorrect to call them «biodegradable». The Commission has decided to examine the impact of such decomposable plastics on the environment and to submit a report to the European Parliament outlining measures to reduce their consumption in order to minimize damage to the ecosphere and ensure the sustainable development of future generations.

Bread is a product of daily consumption, so ensuring its microbiological safety is an urgent problem for domestic producers. Restaurant establishments use sliced bread, which is stored for a certain period of time, so to ensure safe storage conditions it is necessary to protect it from microbiological spoilage.

Analysis of recent research and publications

Potential ways to use biodegradable edible films and coatings are to preserve the freshness of fruits and vegetables by controlling ripening, protecting meat and fish, and controlling the internal transfer of moisture in pizzas. In addition, biodegradable materials are used to create the barrier properties of cardboard.

The main film-forming agents of biodegradable packaging in the form of edible films and coatings are: polysaccharides (starch, cellulose esters, chitosan, pullulan, dextrins, alginate, carrageenan, pectin, gums, etc.), proteins (collagen, gelatin, zein, isolate casein, etc.), lipids (beeswax, beeswax, carnauba, etc.; acetoglycerides, glycerides, etc.) or combinations thereof.

A new generation of biodegradable films and coatings are specifically designed to increase their functionality by incorporating natural or chemical antimicrobial agents, antioxidants, enzymes, or functional ingredients such as probiotics, minerals, and vitamins. Antimicrobial and antioxidant packaging have advantages over their direct use because they slow down the diffusion of active substances from the surface of the food product. The use of functional components allows to create a group of packaging, which is called «active packaging».

Biodegradable edible packaging can improve the nutritional value of food products by transferring essential nutrients and/or food additives from the packaging matrix. Flavors and pigments can be added in packaging to improve the organoleptic characteristics [1,2].

Common chemical antimicrobial additives used in food systems, such as benzoic and propionic acids, sodium benzoate, sorbic acid and potassium sorbate, can be included in biodegradable packaging to inhibit the growth of both bacterial and fungal cells [2]. Antimicrobial compounds, when in contact with food, inhibit the growth of microorganisms present on the surface of the food product [1]. However, due to consumer health problems associated with chemical preservatives, the demand for natural foods has stimulated the search for natural biopreservatives. That is why edible films based on chitosan [5] are of particular interest due to their antifungal and antibacterial properties. The most commonly used bioresistive drugs for antimicrobial films are lysozyme [6] and nisin [7, 8].

Essential oils have a wide range of biological effects, including antimicrobial and antioxidant properties. In particular, demonstrate antibacterial activity against pathogens containing food. Phenolic components such as carvacrol, camphor, eugenol, linalool and thymol are the most active and act mainly as membrane cells [9].

A promising antimicrobial substance is titanium dioxide (titanium oxide IV, TiO_2), which is also a food additive E 171 and which has antibacterial properties [10,11].

The authors proposed gelatin films containing bergamot and lemongrass oil as substitutes for glycerin (plasticizer) [12]. Thus, films with essential oil of lemongrass showed an inhibitory effect on *Escherichia coli*, *Listeria monocytogenes*, *Staphylococcus aureus* and *Salmonella typhimurium*, while the addition of bergamot inhibits only *Listeria monocytogenes* and *Staphylococcus aureus*. Films containing bergamot and lemongrass essential oil do not inhibit the activity of *Pseudomonas aeruginosa*. Edible films based on milk proteins (calcium caseinate and whey protein isolate) and polysaccharides (agar, pectin) show bacterial resistance to *Streptococcus thermophilus* [13].

The authors proposed antibacterial film with potato starch, gelatin, pullulan as film-forming materials, glycerin (plasticizer), calcium chloride (crosslinking agent), made by casting and containing calcium propionate and brown aldehyde as antibacterial agents on *Staphylococcus aureus* and *Escherichia coli* [14].

A generalized classification of antimicrobial substances for biodegradable edible packaging, based on the analysis of literature sources, are in table 1.

The antimicrobial substance that deserves the attention of developers is titanium dioxide (TiO_2), which is a permitted food additive (E 171) in accordance with EU Regulation № 1333/2008 of the European Parliament Sand of the Council of 16 December 2008 on food additives without limitation of daily consumption [10, 11]. The antibacterial properties of TiO_2 are explained primarily by atomic oxygen, which is released during exposure to light, especially UV radiation [15]. In addition, most researchers suggest combining TiO_2 with other carriers of antibacterial properties [15-17].

Therefore, antimicrobial biodegradable packaging can contain antimicrobial substances, which will create packaging materials that prevent microbiological spoilage of food. The choice of antimicrobial substance will be determined by many factors, in particular, not for each product it will be appropriate to introduce essential oil, as this will change the organoleptic characteristics: the appearance of an inherent odor of this type of product. From a safety point of view, the use of triclosan should be avoided. The inert nature of the dioxide indicates its safety.

The purpose and objectives of the study. The aim of the work is to study the antibacterial properties of nanodispersed powder of TiO_2 in biodegradable packaging for sliced bakery products on the activity of microorganisms: *Escherichia coli, Bacillus subtilis, Candida albicans, Aspergillus niger*.

Objectives:

1. Determine the concentration of TiO_2 in the coating to give it antibacterial properties.
2. Analyze the effect of different concentrations of TiO_2 on the vapor permeability of packaging.
3. To determine the effect of TiO_2 in the coating on the microbiological parameters of bakery products.
4. Determine the effect of TiO_2 on the size of the packing pores.

Table 1 – Classification of antimicrobial substances for biodegradable packaging

Originally:							
	acides and their derivatives	***essential oils***	***enzymes***	***peptides***	***aminocarbohydrates***	***aldehydes***	***derivatives of phenols***
Organic	benzoin; gallic, lemon; propionic; sorbic; sodium benzoate; calcium propionate; potassium sorbate; sodium salts of sulfamine derivatives; succinic anhydride	bergamot; carnations; eugenol; cinnamon; lemon grass; oregano; rosemary; garlic; thyme; *Mentha pulegium; Myrcia ovata Cambessedes; Zataria multiflora Boiss*	glucose oxidase; lactoper oxidase; lysozyme and catechin-lysozyme; chitinase	nisin; lactocin; pediocin	chitosan	brown	triclosan
Inorganic	modifications of Ag, TiO_2						
By microbiological action on:							
pathogenic	conditionally pathogenic	molds	gram-negative bacteria	gram-positive bacteria			

Research materials and methods

Potato starch was used to prepare biodegradable packaging (producer – PBP «Vimal», Ukraine); instant food gelatin, brand P-11 (producer – PSC «Ecotechnics», Ukraine); plasticizer urea (E 927b); linseed oil (producer – Agrosilprom LLC, Ukraine); nanodispersed powder of TiO_2 (particle size 20–50 nm, specific surface area – 50 ± 5 m^2/g, patent PCT/US2007/025504, 06.09.2011); water as a solvent.

The film-forming solution for packaging was prepared by mixing the components with water and heating at 85-90 °C during 30 min., then plasticizer and TiO_2 were added until completely dissolved. The solution was cooled to 40 °C. Linseed oil was added and emulsification was performed to obtain a packaging solution emulsion. Biodegradable packaging was obtained by casting a film-forming solution (91 cm^3) on a teflon surface (293 cm^2).

Complete drying of the package was in 10–12 h. in room conditions. Packaging was obtained by applying a molding solution to the surface of the sliced bakery product. Samples of bakery products were prepared by steamless method. The weight of the bread was 250±3 g. The control sample of wheat bread was stored wrapped in polyethylene stretch film.

Determination of the inhibitory effect of nanodispersed powder of TiO_2 on test cultures of microorganisms was determined by seeding on dense media. Pure cultures were used as research objects: *Escherichia coli* IEM-1 ($1{,}6\times10^6$ CFU/g), *Bacillus subtilis* BTT-2 ($5{,}7\times10^6$ CFU/g), *Candida albicans* D-6 ($1{,}8\times10^7$ CFU/g), *Aspergillus niger* P-3 ($2{,}3\times10^5$ CFU/g) from the collection of pure cultures of the Department of Biotechnology and Microbiology of NUFT. In a test tube with a suspension of TiO_2 (2.5; 5; 10; 20%) under sterile conditions was placed 1 cm^3 of a suspension of a certain culture of microorganisms, mixed thoroughly, pipetted with 0.1 cm^3 (drop) and introduced into the center of the solidified medium. Carefully rubbed with a sterile spatula over the entire surface of the medium in the cup. The plates were placed in a thermostat (28 °C for fungi and 37 °C for bacteria) and incubated for 72 h (bacteria) and 5-7 days (fungi). Studies of the inhibitory effect of solution of TiO_2 on bacterial and fungal cultures were also performed under daylight and in a thermostat with UV irradiation. According to the literature, UV rays cause the release of atomic oxygen, which has an antagonistic effect on microorganisms. Atomic oxygen is released during the action of light, but UV rays are a catalyst. UV radiation is not used in the production of bakery products, so it will require additional investment. The number of microorganisms in 1 cm^3 of solution was determined by multiplying the number of colonies to dilute the sample and dividing by the amount of inoculated seed. In the absence of cell growth, it was concluded that the activity of a certain microorganism was inhibited [18].

Determination of antagonistic properties of antimicrobial biodegradable packaging with nanodispersed powder of TiO_2 was performed by the method of agar disks. Under sterile conditions, cut discs of film with TiO_2 were applied to the culture medium (during the determination of bacteria – MPA, during the determination of fungi and yeast – Saburo). Transferred to a thermostat (30 °C) and after 24 h measured the diameter of the zone of growth retardation of microorganisms [18].

Provocative testing to detect the antagonistic effect of TiO_2 on *Bacillus subtilis* was performed. White wheat bread was cut into 2 cm thick pieces. The density of 17-h broth culture of *Bacillus subtilis* (DSM 10AG 276351, Korea) was adjusted to 0.5 according to the Mc-Farland turbidity standard. Control samples were prepared as follows: a suspension of *Bacillus subtilis* in the amount of 0.1 cm^3 was evenly distributed on the surface of pieces of bread with an area of 10 cm^2.

The test samples were prepared as follows: a suspension of *Bacillus subtilis* in the amount of 0.1 cm^3 was evenly distributed on the surface of pieces of bread with an area of 10 cm^2. Then the surface of a piece of bread was covered with antimicrobial biodegradable packaging. All samples (control and experimental) were placed in a thermostat and kept at a temperature of 25 ºC. Samples were examined for the content of *Bacillus subtilis* immediately, after 24 h, 48 h.

The vapor permeability of the film was determined according to BS EN 12086:1997. Vapor permeability – a value numerically equal to the amount of water vapor in milligrams, passing for 1 h through a layer of material with an area of 1 m^2 and a thickness of 1 m, provided that the air temperature of opposite sides is the same and the difference of partial pressures of water vapor is 1 Pa according to ASTM E96/E96M-16.

The size of the packing pores is determined on Quantachrome ASiQwin – Automated Gas Sorption Data Acquisition and Reduction.

Statistical data processing was performed using Statistica and MS Office. The description of the features having a normal distribution is given in the form M±m, where M is the arithmetic mean, m is the error of the mean. In the case of comparing the two groups with the normal nature of the distribution used a parametric method of research, for abnormal distribution – non-parametric. Differences were considered statistically significant in the case of $p < 0.05$, in the case of non-parametric comparison method – $p < 0.000$.

Results of the research and their discussion

A series of model studies was performed to determine the effect of a suspension of nanodispersed powder of TiO_2 with a concentration of 0 to 20 % in the composition of the prescription composition of antimicrobial biodegradable packaging on test cultures of microorganisms. Studies of the effect of suspension with TiO_2 on bacterial and fungal cultures were performed under daylight and in a thermostat with UV irradiation. In the absence of cell growth, it was concluded that the activity of a certain microorganism was inhibited. Suspensions with TiO_2 of different concentrations in different conditions (in daylight, in a thermostat at a temperature of 30 °C without lighting, under UV irradiation) do not show an inhibitory effect on *Candida albicans* D-6, *Aspergillus niger* P-3, because compared to their initial concentrations (1.8×10^7 and 2.3×10^5, respectively) no significant difference in CFU/g values was observed [19]. This may be due to the uneven distribution of particles of TiO_2 in the molding solution of antimicrobial biodegradable packaging.

It is established that the introduction of antimicrobial biodegradable packaging with TiO_2 in the amount of 1 % into the molding solution allows to give the developed material antibacterial properties, as it inhibits the activity of some microorganisms. The results of the study by the method of agar disks are given in Table 2.

The results of Table 2 show that TiO_2 in the packaging really inhibits the development of bacteria *Escherichia coli* IEM-1, *Bacillus subtilis* БТ-2 because there is a delay in the growth of their colonies.

The results of provocative testing are given in Table 3.

Table 2 – Zone of growth retardation of microorganisms (*n=3, p≤0,05*)

Test-culture	QMA and OAMO without packaging, CFU/g	Zone of growth retardation, mm		
		Antimicrobial biodegradable packaging, % TiO_2		
		0	0,5	1,0
Escherichia coli IEM-1	$(3.5\pm0.02)\times10^3$	0	9±1	15±2
Bacillus subtilis БТ-2	$(2.7\pm0.02)\times10^3$	0	6±1	7±1
Candida albicans Д-6	$(1.4\pm0.01)\times10^3$	0	0	0
Aspergillus niger P-3	$(1.3\pm0.06)\times10^3$	0	0	0

Table 3 – Provocative testing of sliced bread (*n=3, p≤0,05*)

Term, h.	Content of *Bacillus subtilis*, CFU/g	
	Control	Experiment
0	$(9.7\pm0,01)\times10^4$	$(1.0\pm0.01)\times10^5$
24	$(7.9\pm0,02)\times10^5$	$(1.5\pm0.01)\times10^5$
48	$(5.1\pm0,02)\times10^6$	$(2.9\pm0.02)\times10^5$

Notes. 1. Control – a piece of wheat bread 20 mm thick packed with polyethylene stretch film, 20 μm thick and previously infected with *Bacillus subtilis*. 2. Experiment – a piece of wheat bread 20 mm thick on the surface of which is applied antimicrobial biodegradable packaging with 1 % TiO_2 and previously infected with *Bacillus subtilis*.

According to the results of provocative testing (see Table 3), antimicrobial biodegradable packaging containing 1% TiO_2 has an inhibitory effect on *Bacillus subtilis*, because the increase in the number of microorganisms is less intense compared to the sample without biodegradable packaging with TiO_2.

Therefore, the results of the study make it possible to recommend TiO_2 as an effective means of combating potato disease. Biodegradable packaging with 1 % TiO_2 in the molding solution, provided it is applied to sliced bread, will be in direct contact with the site of disease development of wheat bakery products, which is most relevant in summer. The antibacterial properties of TiO_2 are due to the release of atomic oxygen [15], which acts on *Bacillus subtilis* on the surface of a slice of bread and due to the small thickness of the slice penetrates into its middle. In restaurants and mass catering establishments, bakery products are sold in different forms, so the presence of biodegradable packaging with TiO_2 will keep them fresh [19] and prevent the development of potato disease.

The addition of TiO_2 in the amount of 1 % does not have a negative effect on the organoleptic properties of biodegradable packaging.

The maximum inhibitory effect of TiO_2 on the vital activity of the studied microflora is observed in the case of UV use. Without treatment with UV solution, it is advisable to use a suspension of TiO_2 with a concentration above 10% [19]. More intense growth retardation occurs when the TiO_2 content of 1 % in the molding solution of the film. Probably, titanium dioxide in the film contributes to the destruction of the cell membrane of bacteria and their death [15]. The activity of *Candida albican* s D-6 and *Aspergillus niger* P-3 TiO_2 is not affected, it is likely that TiO_2 has no effect on the surface structures of eukaryotic cells.

Vapor permeability is important for the characterization of the proposed biodegradable packaging, because in addition to its antibacterial properties, the packaging should help preserve the freshness of the product. Controlling the movement of moisture inside or between food and the environment remains a major challenge today during food storage. Currently, a wide range of film-forming compounds is available, which facilitates the adaptation of barriers to moisture with optimized functional properties. Vapor permeability can hardly be considered as one of the main characteristics of packaging that has barrier properties. However, a comprehensive approach to the development of food barriers to moisture will regulate the organoleptic and physicochemical characteristics of products.

The study results of the antimicrobial component (TiO_2) adding on the vapor permeability of the material are shown in Fig. 1.

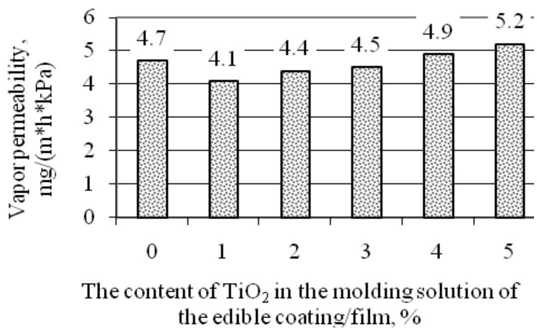

Fig. 1. The effect of different concentrations of TiO_2 on the vapor permeability of packaging (n = 5, p≤0,05)

The results of the study (see Fig. 1) show that the addition of TiO_2 slightly reduces the vapor permeability, but the increase in the concentration of TiO_2 causes an increase in vapor permeability from 4.7 to 5.2 mg/(m·h·kPa). This increase is not significant and falls within the error of the experiment. This effect of TiO_2 can be explained by the fact that the used TiO_2 has a particle size in the range of 20-50 nm, resulting in a specific surface area of 50±5 m^2/g.

The contact surface of the titanium dioxide powder with the components of the packaging matrix is quite large, as a result of which the powder is firmly mechanically adhered to the matrix without forming pores. However, with increasing TiO_2 concentration, the specific surface area of the powder increases accordingly, due to which it does not come into full contact with the packaging matrix, which is why pores are formed, which slightly increases the vapor permeability.

The vapor permeability of the presented biodegradable antimicrobial packaging with 1% TiO_2 is due to the presence of pores, the number and size of which were determined experimentally (Fig. 2).

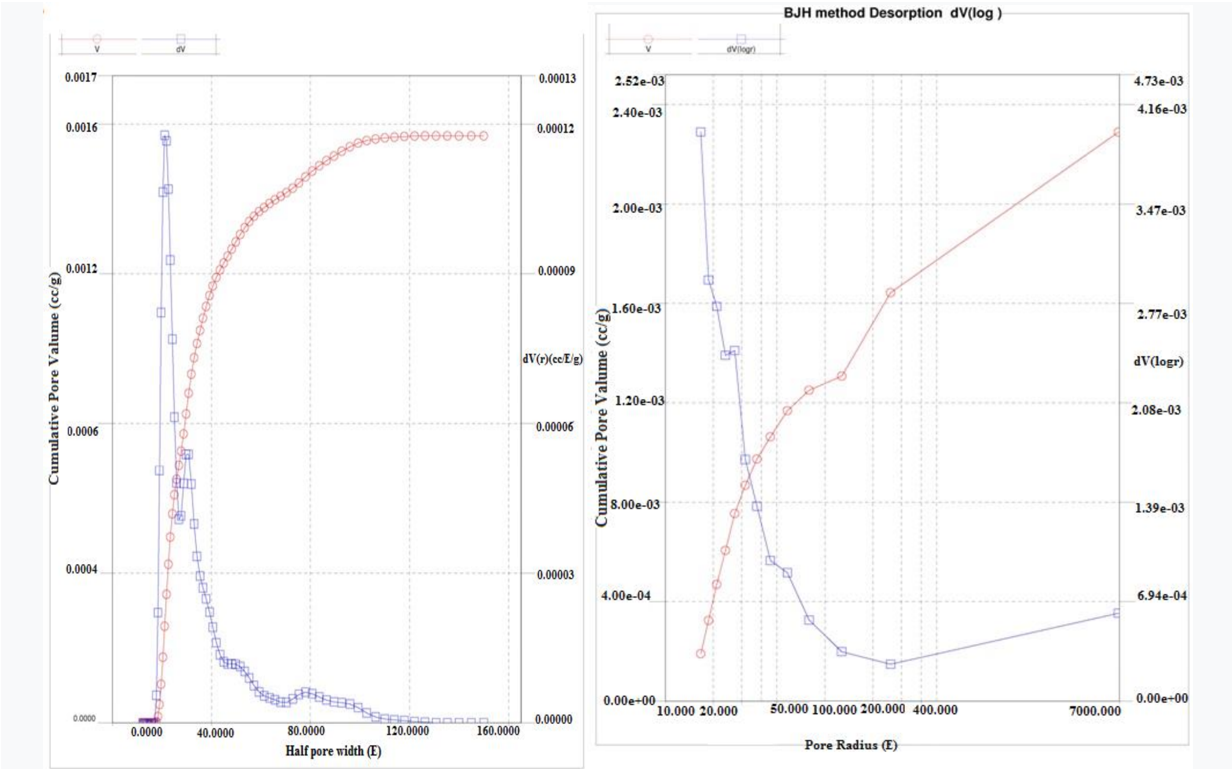

Fig. 2. Experimental results for determining the pore size in antimicrobial biodegradable packaging

Depending on the size of the pores are classified into macropores (more than 50 nm), mesopores (2–50 nm), micropores (less than 2 nm). After processing the obtained experimental studies (see Fig. 2), it was determined that the package contains the largest micropores with a radius of 0.156–1.668 nm. Fewer mesopores with radii of 2.110 and 4.432 nm are present.

Approbation of research results. The presented antimicrobial biodegradable packaging was tested in industrial conditions. Production tests of edible coating on bakery products were carried out at TAK LTD (Kyiv).

Biodegradable packaging is applied to bakery products from the molding film-forming solution. This solution can be applied manually (with a brush), spraying, dipping or by glazing. Manual method and method of immersion should be used in small businesses or catering establishments. The spray method should not be used for the studied packaging compositions, as they have a fairly high viscosity. In procurement factories, it is advisable to use the method of glazing. The advantage of the proposed method of packaging is the use of existing technological equipment for glazing. Confectionery companies, as a rule, already have similar equipment that does not require additional investment. If the company does not have such equipment, you can offer to install a glazing line L-250 or glazing machine MAG-250 or any other that is designed for glazing with chocolate or confectionery glaze. However, for procurement companies or cafes-bakeries you can also offer equipment for glazing – Choko-Line R400, Impex EM-300 with cooling conveyor Impex ST-400.4 whose working area is only 4 m. It all depends on the production area and capacity of the procurement factory. The developed antimicrobial biodegradable packaging, similar to chocolate glaze, requires maintaining the temperature at 35-37 ^{o}C during application to the surface of the products. Packaging equipment (dispensers, cooking vessels, mixer), as a rule, is already available at the procurement factory and can be used for its production.

Conclusion

Therefore, nanodispersed TiO_2 in the molding solution in the amount of 1% allows to give the developed material antibacterial properties, is an effective antimicrobial component for antimicrobial packaging, as it inhibits the development of bacteria *Escherichia coli*, *Bacillus subtilis*. The addition of 1 % TiO_2 to the antibacterial coating reduces the vapor permeability, but increasing the concentration of TiO_2 in the amount of 2–5 % causes an increase in vapor permeability from 4.7 to 5.2 mg/(m·h·kPa). The use of 1% TiO_2 in the molding solution of biodegradable packaging will allow to produce antimicrobial biodegradable packaging for bakery products, as it has an inhibitory effect on *Bacillus subtilis*.

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АНТИМІКРОБНЕ БІОДЕГРАДАБЕЛЬНЕ ПАКУВАННЯ НАРІЗНИХ ХЛІБОБУЛОЧНИХ ВИРОБІВ

Шульга О. С., доктор технічних наук, професор, *E-mail*: shulgaos@ukr.net
Чорна А. І., кандидат технічних наук, доцент[1], *E-mail*: anastasia_chernaya@ukr.net
Шульга С. І., кандидат хімічних наук, професор[2], *E-mail*: shulgasi2015@gmail.com
[1]Кафедра експертизи харчових продуктів
[2]Кафедра харчової хімії
Національний університет харчових технологій, вул. Володимирська, 68, м. Київ, Україна, 01033

Анотація. У сучасних умовах підвищеного контролю екологічності та безпечності харчових продуктів актуальним є розроблення антимікробного біодеградабельного пакування. У статті представлено результати дослідження антагоністичної дії нанодисперсного порошку діоксиду титану (TiO_2) у складі біодеградабельного пакування для хлібобулочних виробів на життєдіяльність деяких мікроорганізмів (*Escherichia coli, Bacillus subtilis, Candida albicans, Aspergillus niger)*. З літературних джерел відомо, що нині є розробки щодо використання антимікробних речовин як органічного, так і неорганічного походження, за мікробіологічною дією використовувані речовини проявляють дію на патогенні, умовно патогенні, плісняві гриби, грамнегативні та грампозитивні бактерії. Нами встановлено, що введення до складу формувального розчину пакування порошку TiO_2 у кількості 1 % дозволяє надавати пакуванню антибактеріальних властивостей, оскільки пригнічує розвиток бактерій *Escherichia coli* і *Bacillus subtilis*, оскільки спостерігається затримка росту їх колоній, порівняно зі зразком без їстівного покриття з TiO_2. Відповідно до отриманих результатів провокаційного тестування біодеградабельне пакування з вмістом 1 % TiO_2 здійснює пригнічувальну дію на *Bacillus subtilis*. Крім антимікробних властивостей досліджуване пакування повинно також володіти і бар’єрними властивостями, тому був визначений показник паропроникність представленого пакування. Результати дослідження показують, що додавання 1% TiO_2 дещо зменшує показник паропроникність, проте збільшення концентрації TiO_2 у кількості 2–5% зумовлює зростання паропроникності з 4,7 до 5,2 мг/(м·год·кПа). Паропроникність представленого біодеградабельного антимікробного пакування обумовлено наявністю пор кількість і розмір яких було визначено експериментально. Отже, нанодисперсний TiO_2 у кількості 1% у складі формувального розчину біодеградабельного покриття є дієвою антимікробною складовою для антимікробних покриттів, який при цьому не погіршує їх бар’єрні властивості.

Ключові слова: антимікробне пакування, хлібобулочні вироби, діоксид титану, паропроникність, біодеградабельне пакування, мікроорганізми.

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