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DETERMINING THE EFFECT OF EDIBLE GELATIN, AGAR-AGAR, AND CHITOSAN COATINGS ON THE STORAGE OF CUCUMBER FRUITS

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This study examines the technology of pre-treating cucumber fruits using edible coatings based on gelatin, agar-agar of various concentrations, as well as chitosan with the addition of garlic essential oil. The task addressed is to identify safer and more effective post-harvest treatment technologies for cucumbers, which could reduce produce losses during storage and extend their shelf life.

The materials under investigation were cucumber fruits, gelatin, agar-agar, chitosan, as well as garlic essential oil. The ratio of gelatin to agar-agar in the coating matrix gelatin:agar-agar was 100%:0; 0:100; 75%:25%; 50%:50%; and 25%:75%, with chitosan at 1%. The influence of this coating on water-holding capacity, physicochemical, structural-mechanical, and microbiological parameters of cucumber fruits was evaluated.

It was established that treatment with edible compositions significantly (LSD 05 = 0.79) reduces natural weight loss of cucumbers during storage at a temperature of 15±1°C to a range of 3.1% to 3.6%. Weight loss in untreated fruits amounted to 4.7%. The agar-agar-based coating provided the lowest weight loss of 3.1%.

It was shown that daily weight loss of cucumbers ranged from 0.63% to 0.75% when treated with edible compositions. Untreated fruits lost up to 1.37% of their weight daily. The addition of 2% garlic essential oil to the coating inhibited the development of microorganisms by 1.5–1.7 times.

The study found that after 6 days of storage, the coated fruits exhibited 11.2% higher elasticity than the control group, and 18.5% higher at the end of the storage period. The effectiveness of the edible coating was confirmed by correlation coefficient r = 0.9317–0.9881

Keywords: cucumber, coated fruits, natural losses, fruit firmness, gelatin, agar-agar, chitosan, edible compositions

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1. Introduction

The main problem in the logistics supply chain of cucumber fruits after harvest is the rapid loss of freshness and deterioration of quality within 2–3 days under natural storage conditions. Refrigerated storage effectively maintains the quality and extends the post-harvest shelf life of various vegetables and fruits, making it a powerful tool for

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preserving fresh horticultural products throughout the supply chain. However, cucumber fruits are very susceptible to damage from cooling at storage temperatures below 4...6°C. Under such conditions, impaired primary metabolism and increased osmotic pressure affect the susceptibility of cucumber fruit skin to cooling, physiological diseases occur, the fruits become covered with watery spots and then darken. At temperatures above 6...10°C, the intensity of respiration increases, hydrolytic processes actively occur, the fruits become flabby, overripe, the skin becomes firm, the seeds become coarse, and the taste properties deteriorate [1]. It should be noted that this seriously limits the application of cucumber storage technology.

Various methods have been devised to reduce damage to cucumber fruits under such conditions. Individual use of physical treatments or addition of chemical elicitors or plant growth regulators, as well as their combined use, are applied. Such modern methods often emphasize the complex nature of cold injury and demonstrate the constant problems of its control. There is a critical need to devise more reliable and alternative strategies.

However, a limited number of studies have been conducted so far on the preservation of post-harvest quality of cucumber fruits under storage conditions in the retail chain. When selling fruits in the sales hall, it is not possible to create and maintain stable optimal conditions (temperature 6...8°C and relative humidity 90–95%) for cucumber storage. Therefore, the preservation of post-harvest quality is crucial for the presentation and nutritional value of cucumbers.

The food industry is increasingly focused on finding innovative, environmentally friendly alternatives for more rational use of packaging. Recently, the European Union introduced new regulations [2] as part of a strategy to reduce the use of plastic packaging from 2026, which could lead to a ban on packaging for fresh fruit and vegetables weighing less than 1.5 kg, including cucumbers in bags. The use of edible coatings has become a promising environmentally friendly method for reducing moisture loss, gas exchange, thereby preserving the quality and extending the shelf life of fruits and vegetables. Post-harvest treatment with edible coatings helps increase the yield of marketable products and preserve the organoleptic properties of vegetables to the fullest [3].

Edible coatings and films have differences: edible coatings can be applied directly to the surface of fruits and other foods, while edible film is used as a packaging material. Due to global environmental concerns and increased awareness of renewable green resources, much effort has been made to provide environmentally friendly and biodegradable materials for the next generation of composite products [4].

Edible materials are made from various types of biopolymer matrices, such as hydrocolloids, lipids, or their mixtures. In addition, antimicrobial agents can be added to inhibit microbial growth in the coated product [5, 6]. Another factor that is also important when choosing a coating material is the raw material that is sustainable, environmentally friendly, practical, and economical [7].

In view of this, designing environmentally friendly and simple coatings using biopolymeric substances such as gelatin, agar-agar, pectin, and chitosan is of significant importance and is relevant. Scientific research on this topic is important because the storage of perishable cucumber fruits with minimal weight loss and without deterioration in quality is an important issue of today. Growing concerns about food safety and public health increase the demand for environmentally friendly and intelligent packaging systems that offer functionality beyond physical protection.

Thus, the area of research into a new technology for post-harvest processing of vegetables with a short shelf life is extremely relevant. Further evolution of safe methods and technologies for post-harvest processing to preserve the quality of vegetable produce will make it possible to extend the consumption of fresh products for a long time with minimal losses [8].

2. Literature review and problem statement

One of the biopolymers for edible food coatings is gelatin. Gelatin has good mechanical and optical properties, as well as a barrier effect on gas flow. It is a fibrillar protein of animal connective tissue [9]. An alternative source of gelatin that can be used is waste from the fishing industry. In [10], the physicochemical, antioxidant, and antibacterial characteristics of edible films based on tuna skin gelatin containing plasticizers based on glycerin or sorbitol with essential oils of turmeric or eucalyptus, which can extend the shelf life of food products, were established. Tuna skin gelatin has the ability to form a good film, has a transparent color, and a good barrier against oxygen, CO_2, and lipids. The disadvantage of the cited study is the need to modify the edible film of gelatin from tuna skin by adding hydrophobic materials and surfactants to improve its physical and functional properties [11]. In addition, the use of gelatin has limitations: it has a rather high vapor permeability value due to its hydrophilic nature; therefore, this property needs to be improved [12].

An option to overcome the difficulties could be to mix it with polysaccharides such as pectin or agar-agar, which can correct these shortcomings. This is the approach used in [13], which found that pectin has good mechanical properties and is a good barrier to oxygen and oil. In [14], it was proven that the use of an edible coating of gelatin-pectin composite with garlic essential oil incorporated for gelatinating coating of red chili peppers extends its shelf life. However, the relationship between weight loss and elasticity of pepper fruits treated with edible coatings based on gelatin, of different concentrations, and chitosan remains unresolved.

However, to our knowledge, there is no data yet on the combined effect of this composite on increasing the shelf life and preserving the quality of cucumber fruits.

It is possible to improve the mechanical and functional properties of edible coatings by adding antimicrobial agents, such as essential oils, to slow down spoilage. In [15], it was found that the use of common essential oils, including rosemary, in fish gelatin reduces vapor permeability by up to 54%, since essential oils are hydrophobic. The addition of 1% garlic essential oil, which is an antifungal agent, reduces the damage and development of fungal microorganisms. However, the effect of higher concentrations of garlic essential oil on the damage of *Botrytis cinerea* was not investigated in the work. It should be noted that the presence of garlic essential oil in an edible composition at a concentration of more than 2% gives the product a persistent garlic odor.

Chitosan when applied to fruits exhibits triple activity: activation of the fruit's defense system, antimicrobial activity, and film formation on the treated surface. In [16], it was found that chitosan in combination with *Mentha piperita L.* essential oil at a concentration of 0.6 or 1.25 mg/ml serves as an effective protection against diseases caused by *Colle-*

totrichum gloeosporioides. The disadvantage of the study is the use of high concentrations of chitosan of 5 and 7.5 g/l. In studies [17] conducted on avocados, a 1% solution of chitosan was used in combination with 1% thyme oil. But it should be noted that chitosan in combination with *Mentha piperita L* essential oil has a bactericidal mono effect on *Colletotrichum gloeosporioides*.

From the reported results, it can be stated that the antimicrobial activity of chitosan and its derivatives depends mainly on the degree of deacetylation, pH of the medium, and temperature. It should be noted that this has a better effect on yeast than on bacteria.

In [18], a reduction in the weight loss of eggplant fruits and their sugar content was proven by post-harvest treatment with chitosan coating. The composition of such a coating is as follows: concentration of high-molecular chitosan 1.5%, acetic acid – 10%, Tween-20 – 0.03%, and propylene glycol – 3%. It should be noted that the disadvantage of this analog is the use of high-molecular chitosan in the film composition, which affects the antibacterial properties of the coating and limited microbiological activity. The disadvantage of the developed composition is the content of Tween-20. This is an extremely active artificial surfactant that exhibits dangerous properties: the ability to accumulate in the human body; toxicity. Long-term use of products containing this additive can provoke the development of gastritis, inflammatory processes in the liver and kidneys, and obesity. Tween-20 cannot be used in infant and medical food products. However, the use of this coating is not recommended for use on other fruits and vegetables.

In [19], the effective effect on the preservation of sweet pepper after post-harvest treatment with various coatings of chitosan, gelatin, and chitosan-gelatin was proven. Sweet pepper was stored for three weeks at a temperature of 1…5°C and 7°C. After the cold storage period, the fruits were stored under market conditions at a temperature of 21°C for another 3 days. Edible chitosan coating (2%) effectively reduced chilling damage and the degree of decay and also preserved the nutritional value of sweet pepper. The disadvantage of the work is the study of the effect of the coating based on a separate substance. Therefore, the development of a coating matrix in different ratios of the test substances remained an unresolved issue. It should be noted that all three types of coating preserved the organoleptic characteristics of the fruits compared to the uncoated control fruits. However, the study did not determine the relationship between weight loss and elasticity of sweet pepper fruits when treated with edible coatings based on gelatin and chitosan.

All this gives grounds to argue that it is advisable to conduct a study aimed at determining the safety of cucumber fruits depending on the treatment before storage with edible coatings based on high-molecular gelatin, agar-agar and chitosan, which would reduce product losses during storage and extend the duration of its consumption.

It is advisable to conduct a study on the selection of concentrations and assortment of components of the protective composition. Such processing of vegetables is aimed at reducing mass loss due to inhibition of negative microbiological and physiological processes during product storage. The use of edible coatings requires almost no changes in the technology of product storage.

Edible coatings based on biopolymers can be a promising measure that reduces losses and offers an ecological alternative to traditional methods. Polysaccharide-based coatings are considered edible and biologically safe for many fruits and vegetables. A wide range of bioactive components (essential oils/plant extracts) can be blended with biopolymers to further enhance their antioxidant and antimicrobial properties. Thus, these bio coatings can extend the shelf life of vegetables and fruits.

However, there is not enough scientific information on the effect of edible coatings based on gelatin and agar-agar on the safety and quality of cucumber fruits. This is explained by the fact that most studies consider the use of edible coatings based on sodium alginate. It is a very cheap and affordable gelling agent, but alginate coatings cannot be used without saturating them with $CaCl_2$. In this case, calcium chloride can migrate to the surface tissues of the fruit and give it a bitter-salty taste, bind the pectin of the cell walls, and thereby worsen the taste properties of the fruit. In addition, a slight excess of the concentration of calcium chloride in the alginate mixture leads to brittleness of the coating. It should be noted that when using gelatin and agar-agar, such difficulties do not arise.

The above allows us to argue that it is advisable to conduct a study on the selection of concentrations of the components of the protective composition for coating cucumber fruits.

3. The aim and objectives of the study

The aim of our work is to determine the effect of processing with edible coatings based on high-molecular gelatin, agar-agar, and chitosan on the safety of cucumber fruits before storage. This will reduce product losses during storage and extend the duration of its consumption.

To achieve the goal, it is necessary to solve the following tasks:

– to determine the natural weight loss of cucumber fruits during storage when treated with compositions based on gelatin, agar-agar of different concentrations, and chitosan;

– to establish the average level of daily weight loss of cucumber fruits during storage when treated with compositions based on gelatin, agar-agar of different concentrations, and chitosan;

– to identify the relationship between weight loss and elasticity of cucumber fruits when treated with edible coatings based on gelatin, agar-agar of different concentrations, and chitosan.

4. The study materials and methods

The object of our study is the technology of pre-treatment of cucumber fruits using edible coatings based on gelatin, agar-agar of different concentrations, and chitosan with the addition of garlic essential oil.

The subject of the study is the influence of the matrix of edible coatings on the weight loss and change in elasticity of cucumber fruits during storage.

The materials of the study were cucumber fruits, gelatin, agar-agar, chitosan, and garlic essential oil. The ratio of gelatin, agar-agar, and chitosan in the coating matrix gelatin: agar-agar: 100%:0; 0:100%; 75%:25%; 50%:50%; 25%:75% and chitosan 1%.

The principal hypothesis assumes that the treatment of fruit and vegetable products with film-forming substances with antimicrobial drugs after harvesting could reduce product losses during storage, would help preserve nutritional value, reduce damage by microorganisms and physiological disorders. Storage of products in a modified gas environment increases the yield of marketable products and the duration of storage.

Assumption: the use of an edible coating of gelatin-pectin composite with the inclusion of garlic essential oil improves the preservation of sweet pepper and chili pepper compared to mono-coating. Therefore, there is a possibility of obtaining similar results when processing cucumber fruits.

In the process of the study, simplification was adopted: only one commercially available cucumber variety (*Cucumis sativus L.*) was used; the possibility of changing the chemical composition of cucumber fruits during storage was not taken into account.

The research used the cucumber variety Samorodok. Short-fruited cucumber fruits of group I (fruit length no more than 10–11 cm) of commercial maturity were studied.

The fruits were grown in Kharkiv district, Ukraine. The fruits selected for the study were free from physical and pest damage and were uniform in size and shape.

The edible coating is made of a gelatin composite of fish skin, which has a transparent color and good barrier properties against O_2, CO_2, and lipids. To improve its physicochemical and functional properties, it must be modified by adding composite elements such as agar-agar, as well as hydrophobic ingredients such as garlic essential oil.

Edible gelatin is produced in the form of colorless or light yellow thin transparent plates, or small shapeless grains. Gelatin forms light jelly (trembling) at the rate of 10–15 g per 1 liter of water, which barely holds its shape; medium density (elastic but not stiff): 20–25 g – classic version and dense jelly: 30–40 g/l – such jelly holds its shape very well [20].

Agar-agar is made from red algae and has a thickening speed and quality 10 times higher than gelatin. It is resistant to temperatures and does not lose its gelling ability when cooled.

Preparation of edible coatings. First, the dissolution of gelatin and agar-agar in distilled water was tested separately with a concentration of 3% (w/v) at 50°C for 120 min. After that, mixtures of gelatin and agar-agar solutions were prepared. In 1 liter of water at 40°C, gelatin 40, 30, 20 g and agar-agar 1.5, 3.75, 7.5 g were dissolved. Coating solutions were made with the ratio of gelatin/agar-agar: 100%:0%; 0%:100%; 75%:25%; 50%:50%; 25%:75%. The mixture was homogenized by stirring with a stirrer for 3 hours. Chitosan was dissolved in water in the same way as gelatin, creating a 1% solution. After that, 7% glycerin was added to the chitosan and gelatin solutions as a plasticizer and stirred at 40°C for 20 min. Garlic oil at 2% concentration was added to the solutions and stirred. The edible coating solution was ready for use.

Cucumber fruits were immersed in the solution for 3–5 min. They were dried by blowing with a fan at 25°C.

Research options:

1. Control.
2. Gelatin 100%.
3. Agar-agar 100%.
4. Gelatin 75% + Agar-agar 25% + Garlic essential oil 2%.
5. Gelatin 50% + Agar-agar 50% + Garlic essential oil 2%.
6. Gelatin 25% + Agar-agar 75% + Garlic essential oil 2%.
7. Chitosan 1% + Garlic essential oil 2%.

The effectiveness of treatments in extending the shelf life of fruits was assessed by weight loss, *Botrytis cinerea* elimination, and qualitative signs of visual appearance. The criterion for the end of fruit storage is weight loss of no more than 10%. The selection of samples for analysis was carried out according to DSTU ISO 874–2002, mass losses were determined by the fixed sample method.

The number of fixed samples of each variant was 3. Mass losses (B) were calculated as a percentage of the initial mass using the following formula (1)

$$B = \frac{(a-b)\times 100}{a}, \quad (1)$$

where a is the mass of products placed for storage, g;

b – mass of products after storage, g.

During storage of cucumbers, natural mass losses, changes in the content of dry matter and dry soluble substances in fruits were determined, taking into account mass losses. The effectiveness of the impact of different concentrations of the composition was determined by the average level of daily fruit losses during storage, which consist of the sum of mass losses and losses caused by microbiological diseases and physiological disorders, attributed to the number of days of storage (2)

$$P = \frac{L_W + TL_W}{\tau}, \quad (2)$$

where P – average daily loss rate, % per day;

L_w – mass loss, %;

TL_w – total mass loss caused by microbiological diseases and physiological disorders, %;

τ – storage duration, days.

The density of the pulp (hardness) of the fruits during storage was estimated using a penetrometer (density tester) GY-3, which measures the force required to penetrate the fruit. A cylindrical steel probe with a diameter of 8 mm was used. The fruit punctures were made at three equidistant points along the length (at a distance of ¼ of the fruit). The density of the pulp was measured in the center of the fruit diameter in three repetitions. The depth of penetration of the probe was 10 mm. The result was taken as the arithmetic mean of measurements from 5 fruits. The marketable quality of the products after storage was determined according to DSTU 8320:2015, the content of dry soluble substances was determined by a refractometer RPL-3M according to DSTU 8402:2015. The percentage of natural weight loss was determined every 3 days of storage.

Botrytis cinerea damage was visually determined. The first signs of gray mold are spots on the surface of the fruit. The spots rapidly increase in size, and at high humidity, a fluffy gray coating appears on the surface of these brown necrosis, consisting of spores and mycelium. First of all, the stalk is affected, and then gray mold covers the entire fruit.

The coefficient of variation is a relative value that serves to characterize the variability of the trait. The coefficient of variation V is determined by entering a numerical series of data into special calculators (MiniWebtool), in which the ratio of the standard deviation (σ sigma) to the arithmetic mean ($\bar{x}$) is automatically calculated.

The data reported in the work are the average value between three measurements. Statistical analysis was performed using Microsoft Excel 2007 (USA). Differences were considered statistically reliable at a significance level of $\alpha = 0.05$.

5. Results of the study to determine the effect of edible coatings on the preservation of cucumber fruits

5. 1. Determining natural weight loss of cucumber fruits when treated with edible coatings

Treatment with compositions based on gelatin, agar-agar of different concentrations, and chitosan reduces the natural weight loss of cucumber fruits during storage at a temperature of 15 ± 1°C. Depending on the ratio of the composition components, weight loss ranges from 3.6 to 3.1%, while in untreated fruits (1c) it is 4.7% (Fig. 1).

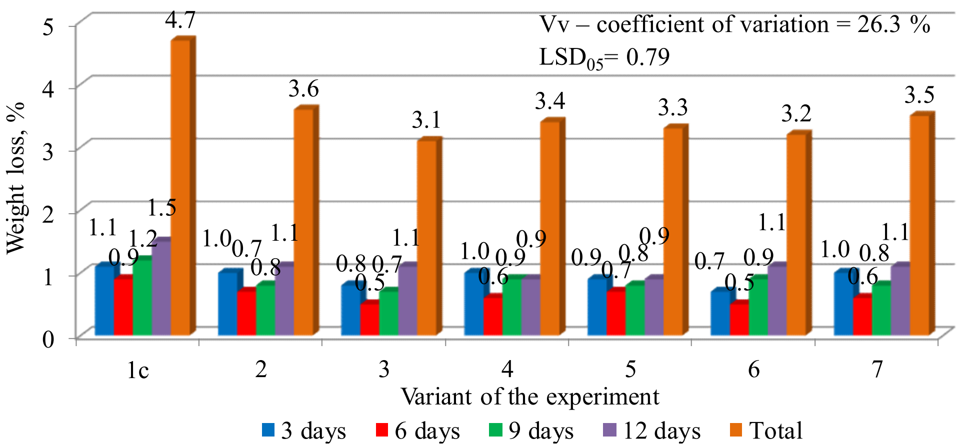

Fig. 1. Dynamics of weight loss of cucumber fruits: 1k – Control; 2 – Gelatin 100%; 3 – Agar-agar 100%; 4 – Gelatin 75% + Agar-agar 25%; 5 – Gelatin 50% + Agar-agar 50%; 6 – Gelatin 25% + Agar-agar 75%; 7 – Chitosan 1%

Agar-agar-based coating (3b), which was mixed with garlic essential oil, provided the lowest weight loss of cucumber fruits – 3.1%. It is worth noting that gelatin and chitosan coatings reduced fruit weight loss only relative to the control.

The coefficient of variation *Vv* – 26.3% – measures the degree of variability of the data relative to their mean values and shows the homogeneity of the population and the reliability of the mean values. It is considered that if the coefficient of variation is more than 25%, then the variation is significant, and LSD_{05} = 0.79 confirms that there is a significant difference between the variants.

It should be noted that increasing the content of agar-agar to gelatin reduced weight loss by 2.9–5.9%. During fruit storage, the dynamics of weight loss were uneven. At the beginning of storage, losses were high in all variants of the experiment: 0.7–1.1% depending on the coating. The next three days of storage, the losses decreased to 0.5–0.9% and then increased again. During the period from 9 to 12 days of storage, the appearance of the control cucumber fruits significantly deteriorated, so after the 9th day of storage it was inappropriate.

5. 2. Average daily weight loss of cucumber fruits during storage

An important criterion for the effectiveness of impact of different edible coating compositions is the average daily weight loss of cucumber fruits during storage. They consist of the sum of weight loss and losses caused by microbiological diseases and physiological disorders, divided by the number of days of storage (Table 1).

Natural weight losses of coated cucumber fruits were adequate with respect to the significant difference between the variants. These losses were significantly (LSD_{05} = 0.79) less than the losses of uncoated fruits by 1.3–1.5 times. A significant positive effect of the studied edible coatings was observed on reducing losses of cucumber fruits from physiological disorders and diseases. Losses of coated products from physiological disorders were 3–4 times less than in the control, from diseases – 1.5–1.7 times. This also significantly (LSD_{05} = 0.81) affected the level of total losses: in coated cucumber fruits they were 2 times less. Analysis of variance established that the strength of the coating's influence on the above-mentioned indicators of cucumber fruits was from 52.0 to 97.2%.

Daily losses of cucumber fruits during storage ranged from 0.63 to 0.75% when treated with edible compositions. Untreated fruits lost up to 1.37% of mass daily, which is significantly (LSD_{05} = 0.78), almost 2 times, more than when treated with edible coatings. Analysis of variance established that the coating (coating) of cucumber fruits affects the level of total fruit mass losses by 72.1%.

Table 1

Average daily weight loss of cucumber fruits during storage depending on treatment with compositions based on gelatin, agar-agar of different concentrations, and chitosan, %

Variant	Natural mass loss, %	Losses from physiological disorders, %	Losses from disease damage, %	Average level of total losses, %	Average level of daily mass loss, %
1c	4.7	8.3	3.4	16.4	1.37
2	3.6	3.1	2.2	8.9	0.75
3	3.1	2.7	2.0	7.8	0.65
4	3.4	2.9	2.1	8.4	0.70
5	3.3	2.3	2.1	7.7	0.64
6	3.2	2.8	2.1	8.1	0.68
7	3.5	2.0	2.1	7.6	0.63
LSD_{05}	0.79	0.56	0.56	0.81	0.78
Coating impact, %	66.1	97.2	52.0	72.1	72.0

In the structure of losses, it is worth noting the infection of fruits with *Botrytis cinerea* microorganisms, the presence of a plush gray coating on the affected parts. Adding garlic essential oil to the edible coating suppressed their development by 1.5–1.7 times. Correlation analysis revealed the relationship between the average level of daily weight losses of cucumber fruits and the components of the coating matrix (Table 2).

Table 2

Pairwise correlation coefficients of cucumber fruit weight loss during storage depending on treatment with compositions based on gelatin, agar-agar of different concentrations, and chitosan

Factor	X_1	X_2	X_3	X_4	У
X_1	1	Absent	Absent	Absent	Absent
X_2	0.961540	1	Absent	Absent	Absent
X_3	0.996471	0.93568	1	Absent	Absent
X_4	0.994704	0.97311	0.984664	1	Absent
У	0.999892	0.96076	0.996693	0.993883	1

Note: X_1 – average daily mass loss, %; X_2 – natural mass loss, %; X_3 – losses from physiological disorders, %; X_4 – losses from disease, %; Y – average total loss, %.

It should be noted that the higher correlation coefficient ($r = 0.9947$) was between the average daily weight loss and losses from damage by microorganisms. The effectiveness of the coating was based on a dual mechanism: physical – a barrier based on film-forming substances minimized water loss and oxygen penetration, synergistic – garlic oil inhibited the development of microorganisms. The fruits were stored until the first signs of wilting, yellowing, or damage to individual specimens by diseases at the initial stage up to 10% weight loss. As can be seen from the data in Table 3, relative weight loss depends on the type of coating.

Table 3

Structure of natural losses of cucumber fruits depending on film-forming coating, %

Coating	Natural mass loss	Dry matter content		Relative mass loss due to:	
		Before storage	After storage	Dry matter	Humidity
Fruits without coating (*c*)	4.7	5.8	4.6	30.2	69.8
Gelatin-agar-agar	3.3	5.8	5.5	14.5	85.5
Chitosan	3.5	5.8	5.3	20.0	80.0

As shown in Table 1, edible coating has a significant positive effect on product preservation, while fruits without coating breathe more intensively due to sufficient aeration. As a result, they consume more dry matter (Table 3). The study found that relative mass losses due to dry matter of 30.2% occurred during storage of cucumber fruits without edible coating. Fruit coating with gelatin-agar-agar coating and chitosan reduced this ratio to 14.5 and 20.0%, respectively.

5. 3. Relationship between weight loss and elasticity of cucumber fruits after treatment with edible coatings

According to the requirements of standards, up to 10% of fruits with light abrasions, with slight darkening of the skin from pressure, with scratches and slightly limp are allowed in cucumber batches. However, after storage, practical criteria for assessing the quality of most vegetables are the absence of color defects and elasticity (hardness or density). Loss of elasticity and signs of wilting are associated with changes in the state of tissue moisture, the threshold for loss of which for cucumbers is 7% [21].

During storage, the elasticity of the fruits gradually decreases in the experimental cucumber varieties. The hardness (elasticity) of the fruits is significantly affected by natural weight loss. Over the years of research, the average daily natural weight loss of cucumber fruits in the control reaches 0.35–0.35% (Table 1). The elasticity of the fruits was 10.5 ± 0.3 kg/cm^2, the pulp – 5.6 ± 0.1 kg/cm^2.

The dynamics of natural weight loss show that in the first three days of storage, weight loss is somewhat higher in all variants, although statistically the values are the same. Further, in the experimental variants of cucumbers, losses increase evenly until the end of storage (Fig. 1).

Our study found that the elasticity of cucumber fruits depends on the duration of storage and processed with an edible coating (Fig. 2).

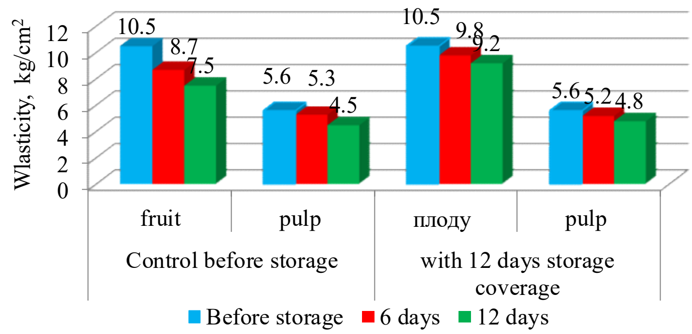

Fig. 2. Cucumber fruit elasticity during storage, kg/cm^2

As can be seen from Fig. 2, during storage of cucumbers, the firmness of the pulp remains practically unchanged in both the control and experimental variants. This phenomenon can be logically explained by the parallel course of the processes of enzymatic tissue decay and lignification of the seed coat during aging.

6. Discussion of results of the possibility to improve consumer quality of cucumber fruits during storage

Quality changes occurring in harvested cucumber fruits are a rapid loss of moisture and ripening, which is associated with the loss of green color, texture, yellowing, hardening of seeds, loss of turgor, lignification and a decrease in nutritional value [22]. Thus, our study was aimed at increasing the safety of cucumber fruits depending on the treatment with an edible coating based on high-molecular gelatin, agar-agar and chitosan with the addition of garlic essential oil before storage. This will reduce product losses during storage and extend the duration of its consumption. Mass loss is due to the process of metabolism in tissue cells and water evaporation. It is possible to slow down these processes by limiting the degree of aeration of the fruits. Edible shells cover the surface layer of the fruit, preventing respiration, transpiration, and syneresis [23].

It was established that the application of edible gelatin-agar-agar and chitosan coating supplemented with garlic essential oil reduces the weight loss of cucumber fruits by 1.3–1.5 times (Fig. 1) depending on the ratio of the composition components. The proportion of weight loss of fruits without coating (control) was much greater than in the coated samples and was 4.7%. Agar-agar-based coating provided the lowest weight loss of cucumber fruits – 3.1%. A similar pattern of the ratio in the gelatin: agar-agar mixture. Increasing the amount of agar-agar from 25 to 75% reduced weight loss from 3.2 to 3.4%. The difference between the minimum loss values is 1.65%. The results are explained statistically significantly: $LSD_{05} = 0.79$.

The surface coating of cucumber fruits preserves chlorophyll pigments and slows down the degradation of carotenoid pigments. The content of soluble solids was better preserved in processed (coated) fruits, and the coating with chitosan showed the maximum retention.

It should be noted that the weight loss of fruits depends on the duration of storage. Similar results were reported in studies with sweet peppers and mangoes [19]. It has been proven that the application of an edible gelatin-pectin coating supplemented with garlic essential oil reduces the percentage of weight loss of red peppers stored at room temperature for 14 days. Gelatin coating with the addition of ginger essential oil reduces the loss of weight, color, texture, microstructure, taste, volatile flavors and flavor ingredients [24].

Due to the loss of water, fruits are not able to actively protect against microbes. The decomposition of organic substances in them increases. Coating fruits with edible coating inhibits the development of microorganisms (Table 1). Cucumber fruits of the control variant were affected by microorganisms by 35.2–41.1% more than coated ones. Correlation analysis established (Table 2) the relationship between the average daily weight loss of cucumber fruits and the components of the coating matrix. A direct strong relationship ($r = 0.9947$) was confirmed between the average daily weight loss and losses from damage by microorganisms. Coating affects the level of total fruit weight loss by 72.1%. It should be noted that coating cucumbers with a composition based on agar-agar inhibited the development of *Botrytis cinerea* to a greater extent. This is probably due to the fact that agar-agar is one of the strongest gelling substances; its presence in the coating matrix contributes to the formation of a denser film. It is appropriate to investigate this issue in further studies. In addition, studies by Taiwanese scientists have shown that essential oil isolated from pomelo and citrus fruits showed antifungal activity against a wide range of food or plant pathogens [7].

Weight loss is usually associated with water loss, but loss of other components can also contribute to this problem (Table 3). However, in addition to water loss, losses of other components are considered minimal. Water evaporation reduces the turgor and firmness of the fruit. This can lead to accelerated surface depression and product deformation. Water loss is associated with several other changes occurring in the fruit and can act as a trigger for the initiation of these changes. Transpiration of moisture from the surface of vegetables is accompanied by an imbalance in the metabolic process, as a result of which the state of enzymes and their functions change and the decomposition of biological substances is significantly enhanced, which is accompanied by an increase in the intensity of respiration, and the energy balance is disturbed [25]. These data confirm the advantages of applying an edible coating to fresh vegetables. Due to the formation of a polymer barrier, water loss from fresh samples is significantly reduced.

Gelatinizing cucumber fruits with the studied coatings reduces the ratio of dry matter to water loss (Table 3). The ratio of dry matter consumption to water in the relative mass loss of 9–11 cm long greens is 1:2.3, gelatin-agar-agar coating increases this ratio to 1:5.9, and chitosan coating increases this ratio to 1:4. The rate of water loss depends on the area, surface density, and degree of skin lignification. Water loss occurs mainly through the fruit cuticle, physical properties of vegetables, or both. The loss of a carbon atom during each respiration cycle can also lead to weight loss [26]. Similar results were obtained for the storage of Brussels sprouts and radishes. In the structure of natural mass losses of Brussels sprouts, the share of water evaporation falls from 20.7 to 89.5% [27]. In the structure of natural mass losses of radishes, on average, 27.5% falls on dry matter, and 72.5% on water [28].

Essential oils with antimicrobial and antioxidant properties (e.g., basil essential oil) can be added to the gelatin film to reduce water vapor permeability, but due to the high price of the essential oil and its strong odor, its use is limited.

When treated with an edible coating, there is a significant inhibition of the decrease in the firmness of cucumbers. After 6 days of storage, the coated fruits demonstrate elasticity 11.2% higher than the control variant. At the end of storage – 18.5% (Fig. 2). Such a high efficiency of the complex film coating (correlation coefficient $r = 0.9317–0.9881$) is due to the inhibition of respiration under conditions of limited oxygen access. Anaerobic respiration inhibits metabolic processes in relation to the structural organization of the lipid matrix of cell membranes, the integrity of which is directly related to the elasticity of the fruits. This treatment also helped preserve chlorophyll pigments. The content of soluble solids was better preserved in the coated fruits.

The strength of fruit tissues, and therefore their preservation and transportability, depends on the density of cell adhesion to each other. The more tightly they adhere, the stronger the tissue, and the strength of tissues to mechanical damage often depends on the size and thickness of the cell walls. Therefore, the obtained solutions indicate a relationship between mass loss and elasticity of pepper fruits when treated with edible coatings based on gelatin, of different concentrations and chitosan.

The use of chitosan-gelatin composite material as an edible coating of red sweet pepper demonstrated excellent hardness retention compared to disposable coatings (non-composite coating) and untreated fruits [14, 19].

Our studies on the preservation of cucumber fruits are aimed at finding alternative ecological technologies for the use of edible coatings to reduce weight loss, control diseases, and extend the shelf life of cucumbers. As a result of the studies, post-harvest treatment of cucumber fruits with protective organic edible coatings based on gelatin, agar-agar of various concentrations, and chitosan was proposed to predict shelf life and preserve the consumer value of cucumbers.

Despite the fact that the treatment of cucumber fruits with edible coatings based on gelatin, agar-agar of various concentrations, and chitosan contributed to the reduction of weight loss and the preservation of organoleptic qualities, our study could be expanded. Taking into account the varietal characteristics and size of the fruits, as well as the combination of gelatin and chitosan, agar-agar, and chitosan when creating compositions could allow for a more accurate interpretation of the results. In the future, it would be advisable to expand the study of organoleptic, biochemical indicators and their preservation under various research factors. Future development of our study may involve testing the effectiveness of pretreatment with the above compositions.

Among the limitations of this study, one should note its relevance mainly to cucumber fruits. Also, it should be taken into account that the effect of a protective organic film at different storage temperatures may be limited and requires additional investigation under other temperature regimes. In addition, the varietal characteristics of the cucumber and the size of the fruits were not taken into account.

It is necessary to note the drawback of the study: 7% glycerin with a 1% concentration was added to solutions of gelatin, agar-agar of different concentrations, and chitosan as a plasticizer to form a plastic, soft film on the surface of the fruits. Such glycerin with a 1% concentration is used in food production. It should be noted that glycerin has the ability to absorb moisture from the air and retain it. In the air, it can absorb up to 40% of water by its mass, which can contribute to the formation of condensate on the surface of the fruit during storage. Further studies of film-forming mixtures will include the addition of other plasticizers.

7. Conclusions

1. Treatment with edible coatings with the addition of garlic essential oil reduces the natural weight loss of cucumber fruits during storage at a temperature of 15 ± 1°C from 3.1 to 3.6% depending on the ratio of the matrix components of the compositions. Weight loss in untreated fruits is 4.7%. Agar-agar-based coating provided the lowest weight loss of cucumber fruits – 3.1%. A similar pattern is for the gelatin:agar-agar ratio in the mixture. Increasing the amount of agar-agar from 25 to 75% reduced weight loss from 3.2 to 3.4%. The difference between the minimum loss values is statistically significant and is 1.65 at LSD_{05} = 0.79.

2. Daily losses of cucumber fruits during storage ranged from 0.63 to 0.75% when treated with edible compositions. Untreated fruits lost up to 1.37% of their mass daily. Adding 2% garlic essential oil to the edible coating inhibited the development of *Botrytis cinerea* microorganisms by 1.5–1.7 times, which affected the daily losses of cucumber fruits. Correlation analysis established a relationship between the average daily mass losses of cucumber fruits and the components of the coating matrix. A direct strong relationship (r = 0.9947) was confirmed between the average daily mass losses and losses from damage by microorganisms. Analysis of variance revealed that the coating of cucumber fruits affects the level of total fruit mass losses by 72.1%.

3. When treated with an edible coating, the decrease in the hardness of cucumbers is inhibited. After 6 days of storage, coated fruits have an elasticity that is 11.2% higher than untreated ones; at the end of storage – 18.5%. Such high efficiency of complex film coating is confirmed by the correlation coefficient: r = 0.9317–0.9881. It was also established that the loss of dry matter content during storage of cucumber fruits ranged from 0.3 to 0.8%. Gelatin-agar-agar coating reduced the loss of dry matter by 0.3%, chitosan coating – by 0.5%, while uncoated fruits lost up to 0.8% (2.7–1.6 times more). Relative mass losses due to dry matter (30.2%) occurred during storage of cucumber fruits without edible coating. Coating of fruits with gelatin-agar-agar coating and chitosan reduced this ratio to 14.5 and 20.0%, respectively. A similar pattern was observed for the content of dry soluble substances.

Conflicts of interest

The authors declare that they have no conflicts of interest in relation to the current study, including financial, personal, authorship, or any other, that could affect the study, as well as the results reported in this paper.

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Data availability

The manuscript has associated data in the data warehouse.

Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technologies when creating the current work.

Authors' contributions

Ludmila Pusik: Formal analysis, Conceptualization, Investigation, Writing – original draft; **Veronika Bondarenko:** Data curation, Project administration, Writing – review & editing; **Vladimir Pusik:** Formal analysis, Methodology, Validation; **Oksana Serhiienko:** Resources, Software, Validation; **Liudmyla Terokhina:** Visualization, Resources, Software; **Maxim Gurin:** Visualization, Resources, Software; **Oleksii Soldatenko:** Visualization, Resources, Software; **Volodymyr Voitsekhivskyi:** Visualization, Resources, Software; **Oksana Muliarchuk:** Visualization, Resources, Software; **Mykola Orlovsky:** Visualization, Resources, Software.

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