The study of the preservation of the quality of berry raw materials is becoming relevant due to the value of berries as a food product for dessert and technological purposes in the processing industry. The solution to this issue is the use of edible films and coatings. The problem being solved is to determine safer and more effective technologies for post-harvest treatment of mulberry fruit with chitosan solutions, which will reduce product losses during storage and extend the duration of its consumption.

The object of the study is the technology of pre-treatment of mulberry fruit using edible coatings based on chitosan.

The subject of the study is mulberry fruit and protective coatings with 0.2 % 0.4 % 0.6 % concentration of chitosan and 0.5 % ascorbic acid. The minimum weight loss of mulberry fruit (2.72 %) and daily losses (0.84 %) during storage were observed after pretreatment with 0.6 % chitosan dissolved in 0.5 % ascorbic acid. The addition of ascorbic acid inhibited the development of Botrytis cinerea by 1.5–2.1 times. There is a close inverse relationship between the yield of marketable products and the concentration of the chitosan solution. An increase in the concentration of chitosan from 0.2 % to 0.6 % reduces natural weight loss, physiological disorders of fruit, and absolute shortage of products. The yield of marketable products increases from 91.7 to 95.1 %. The dry matter content during the storage period decreased by 3.0–6.6 % when treated with an aqueous solution of chitosan and a 2.0–3.5 % solution with ascorbic acid. The lowest losses were observed when treated with 0.6 % chitosan solution and 0.5 % ascorbic acid. A similar pattern was observed for the content of dry soluble substances

Keywords: mulberry fruit, natural losses, microbiological diseases, physiological disorders, chitosan

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DETERMINATION OF THE EFFECT OF CHITOSAN TREATMENT BEFORE STORAGE ON THE STORAGE OF MULBERRY FRUITS

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1. Introduction

Healthy eating, which involves increasing the consumption of fresh berries, the development of various vegetarian practices, where berries are widely used, has led to a 9-fold increase in the volume of trade in berries in the world over the past 20 years. One of the factors increasing the consumption of fresh berry products is the growth of incomes in leading countries, which can buy berries, primarily organic ones, as well as their widespread use in the food industry. The world market for berries is becoming complex, more competitive, even global, which requires improving the quality and safety of products, increasing its diversity [1]. Mulberry has long been the number one berry crop in Central Asia in terms of consumption. Its demand is due to its relatively low price and a large number of offers, because mulberry trees are very common in this region. In Europe, mulberry has long unjustifiably remained a rare, niche crop. Due to its medicinal properties, harmonious taste, aroma and attractiveness of berries, it is gaining popularity. It is in the berries that a significant amount of substances valuable to the human body, especially essential oils, are contained. Mulberry fruit is a valuable resource that has found its use in the food, pharmaceutical, textile and other industries, as well as in cosmetology. Mulberry contains a large number of useful and nutritious components that have a positive effect on most vital organs. Mulberry contains vitamins, minerals, antioxidants, phytonutrients [2].

Currently, agricultural producers sell a significant part of their grown products through supermarket chains. Previously, retail expanded its positions in relation to fruits with a long shelf life. Retail chains are actively expanding sales of fresh raspberries, mulberries, blackberries, strawberries and other berry crops, which were previously considered quite "complex" products.

With the constant improvement of the logistics chains of chain supermarkets, one can expect a further increase in their role in the sale of berries [3].

However, mulberry fruits are very delicate and prone to rapid aging. One of the features of berries is their high metabolic activity and short shelf life, which shortens their supply chain. Due to physiological processes that are accompanied by losses throughout the post-harvest stage, from harvesting to transportation, storage, and retail, up to 40 % of fresh fruits and berries are lost [4]. Violation of the post-harvest processing technology or individual elements of the technology can lead to significant post-harvest losses on a large scale.

In the current conditions, when the ecology has deteriorated and the human body is exposed to various negative environmental factors, there is a need to search for new protective substances of natural origin. Increasing the yield of marketable products and maximally preserving the taste, nutritional and medicinal properties of berry products provides processing of fruit and berry products with edible coatings. In view of this, the development of environmentally friendly and simple-to-implement technology for storing mulberry fruits using chitosan is of significant importance and is relevant.

Scientific research on this topic is important, because storing berries with minimal weight loss and without deterioration in quality is a pressing issue of today. A new technology for post-harvest processing of fruit and berry products is being introduced. Edible coatings and films are the object of a new research direction.

The results of such research are needed in practice, because further development of safe methods and technologies for post-harvest processing to preserve the quality of berry products will allow extending the consumption of fresh vitamin products for a long time with minimal losses.

2. Literature review and problem statement

Mulberry fruits (Morus sp.) are known for their high yield during the fruiting season and their long-term use as an edible berry combined with medicinal properties, especially in Asia. However, the rapid decay of the fruits after harvest raises serious concerns about the sustainability of the products for both food and economic purposes [5].

To reduce the loss of berries throughout the entire logistics chain "harvest – post-harvest processing of berry raw materials – transportation – storage – sale", it is necessary to slow down the evaporation of water from the fruits, prevent possible physiological damage and microbiological spoilage of the products.

However, the use of only artificial cooling or fruit treatment with drugs does not allow to reliably protect the fruits from physiological disorders and microbiological diseases, and therefore avoid losses.

The solution to this issue is the use of edible films and coatings. In recent years, edible coatings have emerged as a natural and inexpensive alternative for preserving produce. They consist of natural substances: proteins (collagen, gelatin, zein, gluten, soy isolates, casein), fats (acetoglycerides, glycerides, fatty acids) and carbohydrates (starch, chitosan, alginate, carrageenan, pectin, polysaccharides), which are biodegradable. They are applied in a thin layer to the fruit and provide protection against moisture evaporation. Polymeric materials used as coatings form a semi-permeable membrane on the surface of the fruit, which acts as a barrier to the passage of microorganisms, water vapor and gases. Therefore, the coating slows down the metabolism of the fruit in the post-harvest period and increases its shelf life [6].

The most commonly used food coatings are polysaccharides chitosan and alginates. These are polymeric carbohydrates consisting of monosaccharides linked together by glycosidic bonds. These compounds are widely available in nature, being part of algae, plants, microorganisms and animals.

Chitosan is a natural biopolymer from crab shells, which is known for its biocompatibility, biodegradability and bioactivity. Such coatings reduce the rate of respiration and putrefaction [7]. It is important to note that treatments with chitosan at lower concentrations and higher storage temperatures may not have a positive effect.

In a study [8], the effectiveness of commercial mixtures based on chitosan, phosphoric acid with trace elements and sweet orange essential oil for reducing decay and optimizing the quality of strawberries was analyzed. The results show that natural compounds can improve the quality of strawberries after harvest. Chitosan treatment preserved the quality of the fruit harvest and was effective in controlling post-harvest decay. Since chitosan showed the best results in terms of quality preservation and reducing post-harvest decay, it can be considered as a reliable replacement for chemical-synthetic fungicides for preserving berries from post-harvest gray mold. It should be noted that the aim of this study was to determine the Infection Index, which is known as the McKinney Index. This study is limited to the determination of the symptoms of decay and the growth of one species of fungi (i. e. Botrytis cinerea). The determination of the species composition of microorganisms and their development during storage of berries and the yield of marketable products remains unresolved.

Chitosan-based food coatings slow down the weight loss and respiration rate of cherry fruits [9] and strawberries during storage [10].

Chitosan is well combined with essential oils. Strawberries (Fragaria ananassa) were coated with 1.0 % chitosan with (0.1 and 0.2 %) lemongrass oil or (0.1 and 0.2 %) thyme oil, and uncoated fruits were used as controls. Strawberries were stored at room temperature (24 °C) and cold storage at 4 °C. The shelf life of the control samples was 2 and 8 days when stored at room temperature and cold storage, respectively, while the coated samples had a shelf life of 4 and 15 days at the same storage temperatures. Films with these essential oils were found to be effective in improving the quality of strawberry berries and extending the shelf life up to 15 days [11]. It should be noted that the effectiveness of the coating of such a composition is explained by the properties of the essential oil. Siberian fir oil, oregano oil, thyme, ash, marjoram, lavender, rosemary, wormwood and marsh mint contain tannins, ascorbic acid, tocopherols, tannins, phenolcarboxylic acids, phytoncides, alkaloids, flavonoids. All of them have bactericidal properties, suppress staphylococci and rod-shaped microorganisms. Scientists [12] have proven the effect of chitosan and chitooligosaccharide on the content of vitamin C and polyphenols in cherries and strawberries during storage in the refrigerator. Treatment with chitosan and chitooligosaccharides inhibits the synthesis of vitamin C in strawberries and promotes the synthesis of vitamin C in cherries. Treatment with chitosan and chitooligosaccharides helps to slow down the loss of firmness of strawberries. The strengthening effect of chitosan and chitooligosaccharide may be due to their ability to bind to negatively charged cell walls and membranes. The inhibitory effect of chitosan on vitamin C synthesis may be related to this. Obviously, further studies should focus on the molecular mechanisms of chitosan and chitooligosaccharide in controlling vitamin C, anthocyanin and total phenolic content during storage. New approaches at the molecular and proteomic levels are indeed needed for further study.

In the study [13], different composite edible coating formulations were developed to improve the post-harvest quality of pomegranate variety Chudovyi, from gum arabic (a natural substance obtained from air-frozen acacia sap), corn starch, lemongrass oil and glycerin using response surface methodology. Mathematical models were developed with variables including weight loss, respiration rate, total soluble solids, titratable acidity and antioxidant capacity. Changing the concentration of gum arabic and corn starch mainly reduced weight loss, increased total soluble solids, titratable acidity and reduced antioxidant capacity loss. The positive value of this study is the response surface methodology, which has the potential to optimize composite edible coatings as post-harvest treatments. However, future studies are needed to determine the effect of the optimized coating on the physiological responses, physicochemical properties and antioxidant capacity of pomegranate fruits during storage and shelf life. An innovative multifunctional bioactive food coating was developed [14] using a mixture of buckwheat starch, chitosan and curry leaf essential oil. The coating extended the shelf life of grapes up to 12 days at room temperature and up to 20 days when stored in a refrigerator. Overall, it helps to preserve the natural appearance of the berries. To create a polysaccharide-based composite coating, starch was extracted from buckwheat groats, and its extreme analysis revealed a high amylose content (21.91±0.32 %), making it an excellent base for coating formation. However, due to its hydrophilic nature, starch has various undesirable properties, including poor tensile properties and higher solubility in water. It should be noted that the study left unresolved the observation of the dynamics of berry weight loss

Among different concentrations of chitosan, the coating with a chitosan content of 1000 mg is the best, which extends the shelf life of mango fruits, preserves quality characteristics. The developed coating has promising potential for successful commercialization of this edible coating for mango producers and industry [15]. However, successful commercialization requires comprehensive studies that will be aimed at studying various parameters, such as enzymatic studies, antioxidant activity, membrane damage, etc., associated with increasing the shelf life of mangoes coated with chitosan

Chitosan-based coatings of different concentrations affect the preservation of strawberries. The effectiveness of chitosan coating of fruits for retaining the quality and nutritional properties of three strawberry varieties, as well as the effect of chitosan on antioxidant enzymes, was evaluated. The fruits were coated with 1 % and 2 % chitosan solution and stored at 2 °C for 9 days. Chitosan coating enhances the activity of some antioxidant enzymes, preventing pulp darkening and reducing membrane damage. [16]. The determination of strawberry fruit weight loss, total losses and daily losses, which could be used to determine the storage period with minimal weight loss and quality deterioration, remained unresolved.

Strawberries immersed in a chitosan solution of 0.5, 1.0 and 1.5 g/100 ml for 5 minutes at 20 °C retained better fruit quality with a higher content of phenolic compounds, anthocyanins, flavonoids, and low antioxidant enzyme activity. Treatment of fruits with chitosan slowed down the decrease in ascorbic acid content and reduced glutathione content and β-1,3-glucanase activity compared to the control [17].

It can be noted that scientific information on the effect of edible coatings based on chitosan on the preservation and quality of mulberry fruits is insufficient. This is explained by the fact that such studies have not been conducted. This gives grounds to argue that it is advisable to conduct a study on the selection of concentrations of components of the protective composition for the treatment of berries. The treatment of berries is aimed at reducing the loss of fruit weight due to the inhibition of negative microbiological and physiological processes during the storage of berry products. The use of edible coatings almost does not require changes in the technology of storing berries.

The disadvantage of this method is the selection of optimal concentrations of chitosan-based solutions for the treatment of fruits and berries before storage, depending on the individual species characteristics of the fruit.

3. The aim and objectives of the study

The aim of the study is to determine the safety of mulberry fruit depending on the treatment with chitosan before storage, which will reduce product losses during storage and extend the duration of its consumption.

To achieve the aim, it is necessary to solve the following objectives:

– determine the natural weight loss of mulberry fruit during storage when treated with chitosan solutions of different concentrations;

– establish the average level of daily weight loss during storage of mulberry fruit when treated with chitosan solutions;

– dentify the relationship between the yield of commercial mulberry fruit and the concentration of chitosan;

– determine the nutritional value of berries when treated with chitosan solutions of different concentrations.

4. Materials and methods

The object of the study is the technology of pre-treatment of mulberry fruits using edible coatings based on chitosan.

The subject of the study is mulberry fruits and protective coatings with different concentrations of chitosan, ascorbic acid.

The hypothesis of the study is as follows: the treatment of fruit and vegetable products with film-forming substances, antimicrobial drugs after harvesting affects the reduction of product losses during storage, preservation of the nutritional value of berries, reduction of damage by microorganisms and physiological disorders. Storage of products in MGS increases the yield of marketable products and the duration of storage.

The following assumptions were made. Given that the effectiveness of chitosan treatment of various fruits, in particular strawberries and strawberries, can be assumed to have similar results during the post-harvest treatment of mulberry fruits.

The study was conducted with mulberry fruits of the early-ripening variety Korolivska Chorna. The harvest was harvested in the first decade of June. The fruit is oval in shape, weighing 3.3–3.7 g, 2.5–3.0 cm long, black-blue in color (Fig. 1). The skin is of medium thickness. The fruit is complex, juicy, aromatic. The taste of the berries of the variety is sweet with a sourness. They are ideal for fresh consumption and for industrial processing.

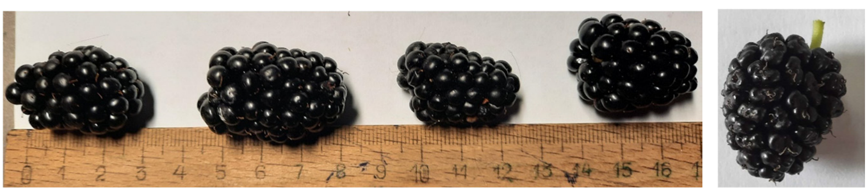

Fig. 1. Mulberry fruit of the Korolivska Chorna variety, grown in the Kharkiv region

After harvesting, mulberry fruit was sprayed with solutions of chitosan of different concentrations, dissolved in water and dissolved in 0.5 % ascorbic acid. To form a more uniform coating film on the surface, it is recommended to dissolve chitosan in acid [18]. It was dried by blowing air, created artificially by a fan, at 25 °C.

Experiment options:

1. No treatment (control).
2. 0.2 % chitosan dissolved in water.
3. 0.4 % chitosan dissolved in water.
4. 0.6 % chitosan dissolved in water.
5. 0.2 % chitosan dissolved in 0.5 % ascorbic acid.
6. 0.4 % chitosan dissolved in 0.5 % ascorbic acid.
7. 0.6 % chitosan dissolved in 0.5 % ascorbic acid.

The main condition of existing storage technologies is preliminary cooling of berries, which must be carried out no later than 4 hours after their collection.

Mulberry fruit was cooled for 2 hours to a temperature of 3...4 °C. Prepared fruit was stored at a temperature of 3±0.5 °C and a relative humidity of 95±1 % in booties with a lid kit 250 h53 rpet, weighing up to 0.250±0.1 kg. Filter paper was placed at the bottom of the bootie to absorb moisture that evaporates during fruit respiration (Fig. 2).

In closed boots, due to the respiration of the fruits, the gas environment was changed to MGS. The effectiveness of treatments in extending the shelf life of fruits was assessed by weight loss, Botrytis cinerea damage, and qualitative signs of visual appearance. The criterion for the end of fruit storage was weight loss of no more than 10 %. During fruit storage, natural weight loss, yield of marketable products, change in dry matter, dry soluble matter, taking into account weight loss were determined. Samples for analysis were selected according to DSTU ISO 874–2002, weight loss by the fixed sample method. The number of fixed samples of each variant was 3. Weight loss (*B*) was calculated as a percentage of the initial weight by the formula (1):

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

where a – weight of products when placed in storage, g;

b – weight of products after storage, g.

Fig. 2. Mulberry fruits prepared for storage

The effectiveness of the effect of different concentrations of chitosan was determined by the average daily fruit losses during storage, which consist of the sum of weight losses and losses caused by microbiological diseases and physiological disorders, attributed to the number of days of storage (2):

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

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

L_W – weight loss, %;

τ – the total weight loss caused by microbiological diseases and physiological disorders, %;

τ is the duration of storage, days.

The marketable quality of products after storage according to DSTU 8320:2015, the content of dry soluble substances was determined by a refractometer RPL-3M according to DSTU 402:2015. The percentage of natural weight losses was determined after 3 days of storage.

The data presented in the work are the average value between three measurements. Statistical analysis was performed using Microsoft Excel 2007 (USA). Differences were considered statistically significant at the significance level α=0.05.

5. Results of the study of mulberry fruit losses after treatment with chitosan of different concentrations and ascorbic acid

5. 1. Natural weight loss of mulberry fruit during storage after treatment with chitosan solution of different concentrations

The weight loss of mulberry fruit of the Korolivska Chorna variety after treatment with aqueous solutions of chitosan after 12 days of storage ranged from 3.09 % to 6.08 % (Fig. 3). The maximum natural weight loss of 7.8 % was recorded in the control variant.

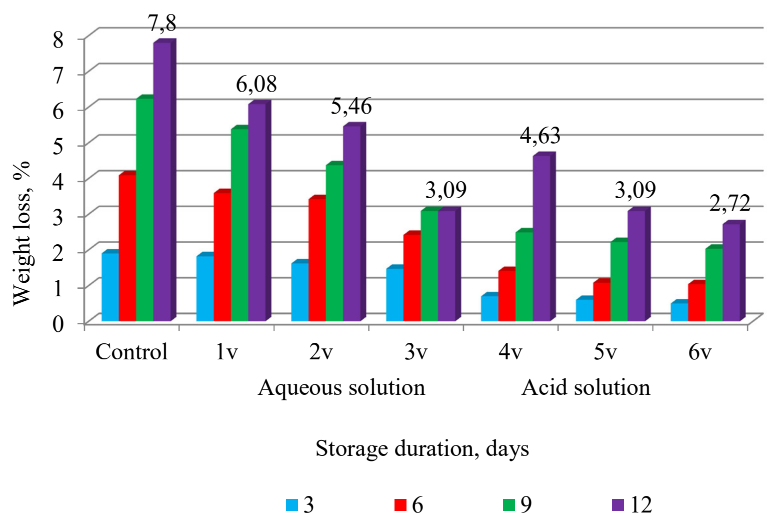

Fig. 3. Weight loss of mulberry fruit, %

It should be noted that weight loss depends on the type of chitosan solvent. Treatment with chitosan dissolved in ascorbic acid provided lower weight loss: from 2.72 % to 6.43 %. The difference between the minimum loss values is statistically significant and is 1.65–2.18 % according to NIP_{05} – 0.65 % (Table 1).

Table 1

Dynamics of weight loss of mulberry fruit, during storage, %

Option	Chitosan of various concentrations dissolved in							
	Water				0.5 % ascorbic acid			
	Storage duration, days				Storage duration, days			
	3	6	9	12	3	6	9	12
Control	1.90	4.09	6.23	7.80	1.90	4.09	6.23	7.80
0.2 % (1v, 4 v)	1.82	3.59	5.38	6.08	0.70	1.41	2.49	4.63
0.4 % (2v, 5 v)	1.62	3.42	4.37	5.46	0.60	1.08	2.22	3.09
0.6 % (3 v, 6 v)	1.47	2.42	3.09	4.90	0.50	1.04	2.03	2.72
$LSD_{05\ factor\ A}$ 0.79								
$LSD_{05\ factor\ B}$ 0.65								
The influence strength of factor A – 4.0 %								
The influence strength of factor B – 64.0 %								
The influence strength of the interaction of factors – 20.0 %								
The influence of other factors – 12.0 %								

The dynamics of weight loss of mulberry fruits was observed, which was uneven. In the first three days of storage, when treated with an aqueous solution of chitosan of different concentrations, the losses ranged from 0.95 % to 1.77 %. In the following storage period, the intensity of losses decreased and amounted to 0.67–1.75 %. In the variants of treatment with chitosan dissolved in ascorbic acid, a different dynamics of weight loss was observed. In the first three days, weight loss was minimal and amounted to 0.48–0.71 %. In the next three days, they increased slightly, and in the following days they decreased to 0.69–0.87 %. It is possible to predict weight loss of fruits during storage using regression analysis. It was found that weight loss depending on the duration of storage is described by the regression equation given in Table 2. Comparing the R^2 of the linear and curvilinear dependence of weight loss depending on the storage duration, it can be stated that there is a curvilinear correlation dependence of the second order of weight loss of mulberry fruit on the storage duration (R^2=0.9779–0.9969) under the conditions of dissolution of chitosan in water. A similar dependence (R^2=0.986–0.9895) is observed when chitosan is dissolved in ascorbic acid. Deviations of individual observations from the trend line are unaccounted for random fluctuations.

Natural weight loss of mulberry fruit consists of evaporation of moisture and dry matter (Table 3).

In natural weight loss, the proportion of dry matter loss ranges from 27.55 % to 39.80 % in a solution of chitosan in water, while in a solution of ascorbic acid it is 41.54–42.54 %. In the control variant, water evaporation is 77.51 % of the total weight loss, which exceeds the studied variants.

Table 2

Correlation dependence of weight loss of mulberry fruit over the storage period depending on treatment with chitosan solution

Option	Linear equation	Coefficient of determination R^2	Curvilinear equation	Coefficient of determination R^2
Chitosan of various concentrations dissolved in water				
Control	y=1.793x–1.975	0.9468	y=0.235x^2+ +0.383x–0.33	0.9696
0.2 % (1 v)	y=1.572x–1.342	0.9809	y=–0.1586x^2+ +2.5234x–2.452	0.9949
0.4 % (2 v)	y=1.367x–1.127	0.9832	y=–0.1364x^2+ +2.1856x–2.082	0.9969
0.6 (3 v)	y=1.142x–1.05	0.977	y=0.0286x^2+ +0.9706x–0.85	0.9779
Chitosan of various concentrations dissolved in 0.5 % ascorbic acid				
0.2 % (4 v)	y=0.9837x	0.8767	y=0.216x^2+ +0.2638x	0.9860
0.4 % (5 v)	y=0.726x	0.9497	y=0.0842x^2+ +0.4454x	0.9884
0.6 % (6 v)	y=0.6517x	0.9626	y=0.0621x^2+ +0.4447x	0.9895

Table 3

Ratio of evaporation of water and dry matter in natural weight loss of mulberry fruit depending on chitosan treatment

Option	Chitosan of various concentrations dissolved in			
	Water		0.5 % ascorbic acid	
	Weight loss due to			
	Moisture evaporation	Dry matter	Moisture evaporation	Dry matter
Control	77.51	22.49	77.51	22.49
0,2 % (1в, 4в)	60.20	39.80	51.46	42.54
0,4 % (2в, 5в)	66.36	33.64	54.95	42.05
0,6 % (3в, 6в)	72.45	27.55	58.46	41.54

5. 2. Average daily weight loss during storage of mulberry fruits treated with chitosan solution

The effectiveness of the effect of different concentrations of chitosan was determined by the average daily weight loss of mulberry fruits during storage. Consist of the sum of weight loss and losses caused by microbiological diseases and physiological disorders, attributed to the number of days of storage (Table 4).

Daily losses of mulberry fruits during storage ranged from 1.18 to 1.66 % when treated with aqueous solutions of chitosan. Treatment with solutions with ascorbic acid reduced daily losses of fruits by 6.8–22.6 % compared to treatment with aqueous solutions.

The share of the influence of the chitosan solution (factor A) on the daily losses of mulberry fruits was 59 % and prevailed over the influence of the concentration (factor B).

In the structure of losses, it is worth noting the damage of fruits by Botrytis cinerea microorganisms. The addition of ascorbic acid inhibited their development by 1.5–2.1 times.

storage is 86.1–91.7 % when treated with an aqueous solution of chitosan of various concentrations. Dissolving chitosan in ascorbic acid contributes to an increase in the yield of marketable products to 90.4–95.1 % (Fig. 4).

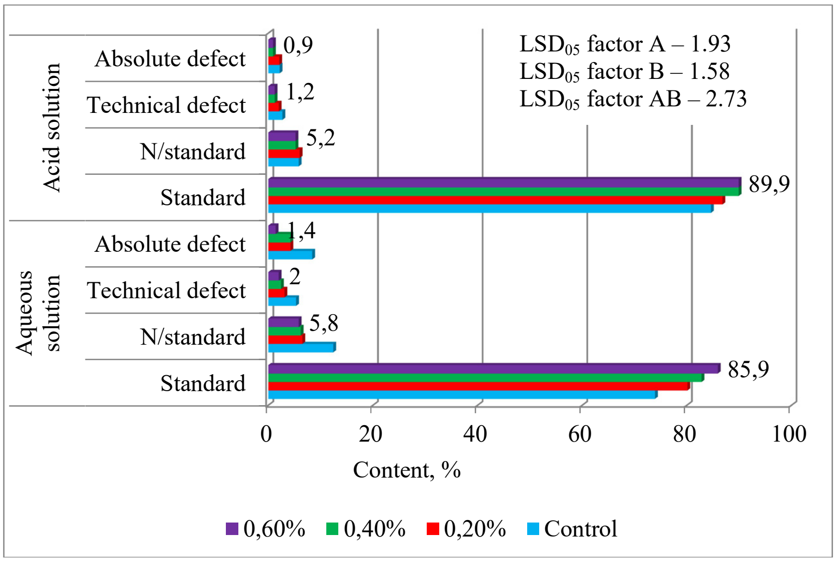

Fig. 4. Yield of marketable products from mulberry fruits after treatment with chitosan solution with different concentrations

Table 4

Average daily weight loss during storage of mulberry fruits treated with chitosan solutions, %

Option	Natural weight losses, %	Losses from physiological disorders, %	Losses from damage to the body, %	AVERAGE level of total losses, %	AVERAGE level of daily weight losses, %
Aqueous solution of chitosan					
Control	7.8	5.3	8.4	21.5	3.58
0.20 %	6.08	3.1	4.22	19.9	1.66
0.40 %	5.46	2.4	4.2	18.2	1.52
0.60 %	4.9	2.0	1.4	14.1	1.18
Chitosan solution in ascorbic acid					
Control	7.8	5.3	8.4	21.5	3.58
0.20 %	4.63	2.7	2.15	15.3	1.28
0.40 %	3.09	2.0	2.1	13.2	1.10
0.60 %	2.72	1.2	0.9	10.1	0.84
$LSD_{05\ factor\ A}$ 0.12					
$LSD_{05\ factor\ B}$ 0.10					
The influence strength of factor A – 33.0 %					
The influence strength of factor B – 59.0 %					
The influence strength of the interaction of factors – 1.0 %					
The influence of other factors – 7.0 %					

5. 3. Relationship between the yield of marketable products of mulberry fruits and the concentration of chitosan

The main requirement for fruit and berry products is its good quality. That is, the product according to the commercial assessment meets the requirements of a certain standard. The yield of marketable products is a criterion for maintaining product quality during storage. Marketable products consist of standard and non-standard parts. It was found that the yield of marketable mulberry products after 12 days of storage is 86.1–91.7 % when treated with an aqueous solution of chitosan of various concentrations.

It was found that the yield of marketable products correlates with the concentration of chitosan solution, natural weight losses, the yield of standard and non-standard products; products affected by diseases, absolute defects and total losses (Table 5).

Table 5

Correlation between chitosan concentration, marketable product yield, weight loss, loss structure

Factors	x_1	x_2	x_3	x_4	x_5	x_6
Aqueous solution of chitosan						
x_1	1	0	0	0	0	0
x_2	–0.99558	1	0	0	0	0
x_3	0.954518	–0.92432	1	0	0	0
x_4	0.995867	–0.98297	0.974607	1	0	0
x_5	0.970859	–0.97611	0.922791	0.955774	1	0
x_6	0.878148	–0.91905	0.710681	0.831072	0.90944	1
Chitosan solution in ascorbic acid						
x_1	1	0	0	0	0	0
x_2	–0.98833	1	0	0	0	0
x_3	0.945253	–0.96966	1	0	0	0
x_4	0.991181	–0.99923	0.959704	1	0	0
x_5	0.961423	–0.9852	0.996853	0.977793	1	0
x_6	0.979781	–0.99003	0.927062	0.993869	0.953413	1

Note: x_1 – natural weight losses, %, x_2 – standard product yield, %; x_3 – non-standard product yield, %, x_4 – disease damage, %; x_5 – absolute defect, %; x_6 – total losses, %.

There is a close inverse relationship between the yield of marketable products and the concentration of chitosan solution. An increase in chitosan concentration reduces natural weight losses, physiological disorders, and therefore absolute defect of products.

5. 4. Preservation of nutritional value of berries by treatment with chitosan solution of different concentrations

The content of dry soluble substances determines the marketable quality of products after storage. The content of dry soluble substances changed throughout the storage period. Treatment of mulberry fruits with chitosan solution significantly affected the change in the content of dry and dry soluble substances and depended on the concentration of the solution (Fig. 5).

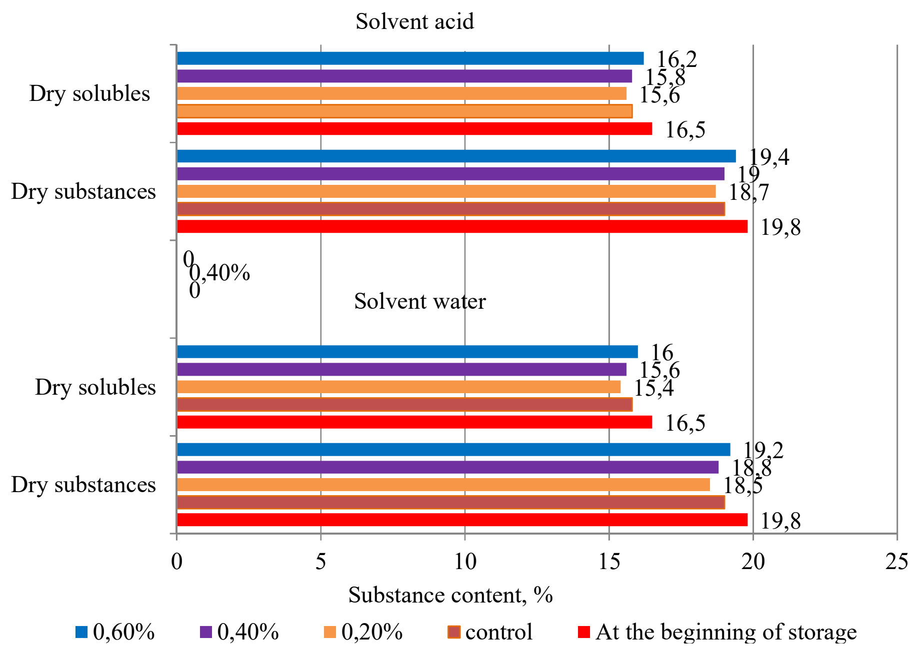

Fig. 5. The content of dry matter and dry soluble matter in mulberry fruits at the end of storage depending on the concentration and method of dissolution of chitosan, %

The greatest loss of dry matter from 19.8 % to 18.5 % was observed when treated with a 0.2 % aqueous solution of chitosan. With an increase in the concentration of the solution to 0.6 %, the loss of dry matter decreased to 19.2 %. A similar pattern was observed when treated with a solution of chitosan and ascorbic acid.

6. Discussion of the results of the possibility of improving the consumer quality of mulberry fruits during storage

Post-harvest preservation has always been one of the main problems in the production of perishable berry products, including mulberries. Thus, this study was aimed at maintaining the quality after harvest of fully ripe mulberry fruits using stable edible coatings of chitosan dissolved in water and ascorbic acid.

Treatment of mulberry fruits with a chitosan solution of different concentrations contributed to the extension of the storage period to 12 days, while untreated fruits were stored for up to 6 days (Table 1, Fig. 3). These results are explained by the data obtained by other scientists [19, 20]. In [20], the effect of different concentrations of chitosan solutions on the quality and duration of raspberry storage in refrigerated conditions was studied. The berries were treated by spraying with 0.5 %, 1.0 % and 2.0 % chitosan solutions. In contrast to [20], where the lowest losses over the entire storage period of the samples were with the treatment with chitosan of a lower concentration of 0.5 % and reached 6.2–10.4 % and 5.2–8.9 %. Treatment of mulberry fruit with chitosan of a concentration from 0.2 % to 0.6 % reduced losses by 19.4 % (i.e. from 6.08 % to 4.9 %). This is possible due to the thickness of the formed film on the surface of the fruit, its gas permeability, as well as the characteristics of the raspberry and mulberry culture as a storage object.

Strawberries (Fragaria×ananassa Duch.) were covered with 1 % or 1.5 % chitosan. After treatment, strawberries were stored at 10 °C and a relative humidity of 70±5 % for one week. During the storage period of berries coated with 1.5 % chitosan, no signs of fungal growth were observed. In contrast, 12.5 % of strawberries coated with 1 % chitosan were infected after five days of storage. Chitosan coatings delayed changes in weight loss, firmness, and external color compared to untreated samples. Strawberries coated with 1.5 % chitosan showed less weight loss and reduced browning than strawberries treated with 1 % chitosan [21]. This result confirms the assumptions made in the study of postharvest treatment of mulberry fruits with chitosan (Fig. 4). It should be noted that treatments with chitosan at lower concentrations and higher storage temperatures may not have a positive effect.

The results of similar studies are highlighted in [9]. It was found that the storage duration of untreated (control) cherry fruits was 15 days, and when using chitosan solutions, it was 1.4 times longer – 21 days.

The reduction in weight loss is due to the pre-treatment of fruit and berry products before storage with a chitosan solution, which creates a barrier to the transpiration process. The conclusions are consistent with the results of studies [22].

It was found that the weight loss of mulberry fruit depends on the chitosan solvent. In the treatment options with chitosan dissolved in ascorbic acid, the weight loss of mulberry fruit decreased by 1.3–1.8 times compared to the treatment options with chitosan dissolved in water, and amounted to 2.72–4.63 % (Table 1). Treatment with ascorbic acid solutions reduced daily fruit loss by 6.8–22.6 % compared to treatment with aqueous solutions (Table 4).

The analysis of variance shows that the weight loss of the seedlings depends on the chitosan solvent by 64 %. The variation of the data is 35.7 %. The mean values indicate statistical differences at $p \leq 0.05$ based on the Fisher's least significant difference post-test.

This conclusion is supported by data obtained by other scientists [23]. After application to the surface of the fruit (dipping and spraying), chitosan forms an edible coating, the properties of which (thickness, viscosity, gas and water permeability) depend on the acid in which it is dissolved. Based on literature data, it is possible to assume that the overall activity is from 30 to 40 % of the activity of chitosan, its antimicrobial activity is from 35 to 45 %, and its film-forming activity is from 20 to 30 %, in terms of its effectiveness in control. The effectiveness of treating strawberry berries with chitosan dissolved in acetic acid has been proven [24]. Treatment with chitosan with lactic acid was the most effective in combating blackberry soft mold [25]. To improve the quality of fruit and berry products, the treatment of fruits with salicylic acid in combination with chitosan and other substances is now widely used [26, 27].

Forecasting quality changes makes it possible to determine in advance the duration of storage of berry raw materials and predict with general probability the dynamics of changes in the chemical composition components that occur during this period. It has been established that the loss of fruit weight depends on the duration of storage. Regression analysis of the study results makes it possible to predict the end of the storage duration of fruits (Table 2). A trend line was used to analyze (estimate) the errors of the regression analysis. In the conditions of classical linear multiple regression, the coefficient (R) takes values from 0 to 1. It is believed that the closer the coefficient is to 1, the better the model. The coefficient of determination (R^2) is used as one of the metrics for judging the accuracy of the model. The accuracy of the regression analysis is determined by the value of R^2. According to the results of the study, R^2=0.9779–0.9969 and R^2=0.9860–0.9895 were determined for the curvilinear dependence of the weight loss of mulberry fruits depending on the concentration of the aqueous solution and the solution of chitosan with ascorbic acid, respectively. The second-order curvilinear correlation dependence of the weight loss of mulberry fruits on the concentration of the chitosan solution is more reliable: R^2=0.9779–0.9969, R^2=0.9860–0.9895, R^2=0.9758–0.9903 (Table 2). The coefficients of determination for weight loss are given in Table 2, and the experimental data in Table 5. Negative values of the coefficient for weight loss indicate that when the concentration of chitosan increased, the weight loss values decreased. This observation is desirable, as it indicates that the coating minimized the weight loss of the fruit during storage. An important indicator of the quality of the fruit after storage is the yield of marketable products. The market value determines the competitiveness of the product in the market. Studies have shown that the treatment of mulberry fruit with a solution of chitosan in ascorbic acid has a greater effect than treatment with an aqueous solution of chitosan. There is an inverse close relationship between the yield of marketable products and the concentration of the chitosan solution. An increase in the concentration of chitosan from 0.2 % to 0.6 % reduces natural weight loss, physiological disorders of the fruit, and absolute shortage of products (Table 5). The yield of marketable products increases from 91.7 to 95.1 %. Analysis of variance showed that the concentration of chitosan had a 51 % effect on the preservation of mulberry fruits, and the addition of ascorbic acid increased the yield of marketable products by 30 % compared to an aqueous solution of chitosan (Fig. 4). This conclusion is confirmed by the data obtained by other scientists. According to [28–31], the yield of marketable products of strawberry berries after 21 days of storage significantly depended on the use of pre-treatment and the concentration of the chitosan solution. With an increase in the concentration of the solution, a decrease in substandard products, technical defects, and absolute waste was observed.

Pretreatment of mulberry fruit with chitosan slowed down the loss of dry matter and dry soluble matter. It was proven that the weight fraction of soluble dry matter decreased more slowly in samples treated with chitosan. In the control variant, accelerated rates of loss of the weight fraction of soluble dry matter were recorded, which negatively affects the safety of the product. Chitosan solutions are able to form transparent films on the surface of the berries, which inhibit the free access of oxygen, while the intensity of respiration changes, and, as a result, the loss of dry matter (Table 3). It was established that the loss of dry matter content during storage of mulberry fruit ranged from 0.6 to 1.3 % when treated with an aqueous solution of chitosan and 0.4–0.7 % – with a solution of ascorbic acid (Fig. 5). That is, the dry matter content during the storage period decreased by 3.0–6.6 % and 2.0–3.5 %, respectively. A similar pattern was observed with the content of dry soluble substances.

In contrast to [32], where the treatment of blackberry fruits with chitosan inhibited the loss of dry soluble substances by 0.2–0.9 % by weight fraction of sugars, the loss of dry substances during storage of mulberry fruits was 0.4–0.7 %. This is possible due to the slowing down of the intensity of respiration and water evaporation.

The conducted studies on the preservation of mulberry fruits are aimed at finding alternative environmental technologies using edible coatings to reduce weight loss, control diseases and extend the shelf life of fresh berries. As a result of the conducted studies, elements of post-harvest processing of mulberry fruits under the action of a protective organic composition based on chitosan were improved to predict the shelf life of berries and their fresh consumption.

Scientific research on this topic is important, because product losses deprive the population of a significant amount of healthy food and pose food security, environmental, economic and social problems.

Despite the fact that the treatment of mulberry fruit with a solution of chitosan of various concentrations contributed to the reduction of weight loss, water evaporation, maintaining a higher level of total dry matter, dry soluble substances, the study could be expanded. Taking into account varietal characteristics and ripening times will make it possible to more accurately interpret the results obtained. In the future, it would be advisable to expand the study of organoleptic, biochemical indicators and their preservation by various storage methods.

A promising alternative treatment for increasing the shelf life of mulberry fruit was coating with chitosan. Future development of this study may include the effectiveness of pretreatment with chitosan dissolved in acetic, salicylic, lactic and other acids of mulberry fruit, collected in different batches at different stages of ripeness and the introduction of varietal storage regimes.

Among the limitations of this study, it should be noted that its relevance mainly to mulberry fruit, since the results obtained may not be fully applicable to other types of berries. It is also necessary to take into account that the effect of a protective organic film at different storage temperatures may be limited and requires additional study at other temperature regimes. In addition, the varietal characteristics of mulberry and the group of ripeness of the fruit were not taken into account.

It is necessary to note the drawback of the study. The formation of a plastic, soft film on the surface of the fruit requires the presence of plasticizers (gelatinizers) in the protective composition. In food production, 1 % Glycerin is used. In addition to the properties of a plasticizer, glycerin has the ability to absorb moisture from the air and retain it. In air, it can absorb up to 40 % of its weight of water, which minimizes water evaporation from the surface of the fruit during storage. Further studies of film-forming mixtures will include the addition of plasticizers.

7. Conclusions

1. The minimum weight loss of mulberry fruit (2.72 %) during storage was observed after pretreatment with 0.6 % chitosan dissolved in 0.5 % ascorbic acid. The difference between the minimum loss values is statistically significant and is 1.65–2.18 % at LSD $_{05}$=0.65.

2. Treatment with a solution of 0.6 % chitosan with ascorbic acid reduced the daily loss of mulberry fruit to 0.84 %. Compared to treatment with an aqueous solution of chitosan, the daily loss decreased by 6.8 %. The addition of ascorbic acid inhibited the development of Botrytis cinerea by 1.5–2.1 times.

3. There is a close inverse relationship between the yield of marketable products and the concentration of the chitosan solution. Increasing the concentration of chitosan from 0.2 % to 0.6 % reduces natural weight loss, physiological disorders of the fruit, and absolute shortage of products. The yield of marketable products increases from 91.7 to 95.1 %.

4. It was established that the loss of dry matter content during storage of mulberry fruit ranged from 0.6 to 1.3 % when treated with aqueous solutions of chitosan and 0.4–0.7 % solutions in ascorbic acid. That is, the dry matter content during the storage period decreased by 3.0–6.6 % and 2.0–3.5 %, respectively. The smallest losses were observed when treated with a 0.6 % solution of chitosan and 0.5 % ascorbic acid. A similar pattern was observed with the content of dry soluble substances.

Conflict of interest

The authors declare that they have no conflict of interest regarding this study, including financial, personal, authorship or other, that could influence the study and its results presented in this article.

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Data availability

The manuscript contains data included as additional electronic material.

Use of artificial intelligence tools

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

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