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MINIMIZING SWEET CHERRY FRUIT LOSSES DURING STORAGE UNDER THE INFLUENCE OF HYDROCOOLING AND PROTECTIVE ORGANIC COMPOSITION

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Reducing fruit losses is one of the most important strategies for improving diets and strengthening food systems. Therefore, improving modern technologies for storing sweet cherries, assessing the potential of the necessary capacities and technologies for fruit storage to reduce post-harvest losses and extend the shelf life of fruits remains relevant. Improvement of pre-cooling methods optimize the shelf life of fresh fruit and contributes to the growth of demand for fruit by consumers in the European market. The object of the study is the technology of pretreatment of sweet cherry fruits using an organic composition. The fruits of the model variety Valerii Chkalov were used as experimental material.

The minimum natural losses from microbiological diseases and physiological disorders were recorded on the 40th day of sweet cherry fruit storage. Fruit weight losses during storage of sweet cherries of the Valerii Chkalov variety were minimal when hydro cooling was applied in combination with a protective organic composition of lactic and acetic acid (1.75 %:2.00 %). The optimum concentration of lactic and acetic acids (2.00 %:1.75 %) was determined, which ensures minimal daily fruit losses (0.068 %) under the influence of hydro-cooling during storage of sweet cherries. The analysis of the regression model reveled the optimal value of the average level of daily losses during storage of sweet cherry fruit of Valerii Chkalov variety – 0.0642 % at concentrations of lactic and acetic acid 2.161 % to 1.705 %, respectively. The tendency to minimize sweet cherry fruit losses during storage under the influence of hydrocooling and the optimal concentration of organic acids in the protective composition was identified. The results could be used to improve pre-cooling methods in the food industry to preserve the quality of fruit raw materials in a waste-free fruit supply chain for all relevant stakeholders

Keywords: sweet cherry fruits, natural losses, microbiological diseases, physiological disorders, regression model, minimization criterion

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1. Introduction

The world population is growing rapidly and may exceed 9.7 billion by 2050 [1]. To solve the problems of food security, it is necessary to ensure sustainable food systems. According to the recommendations by the International Health Organization, FAO/WHO, 70 % of the daily diet should consist of vegetable raw materials and their processing products.

Due to the growing awareness of consumers about food and food safety, the main aspect is the production and storage of fresh cherry fruits [2]. Fruits are unique food products. As a component of a healthy diet, they supply the human body with all the necessary substances: carbohydrates, vitamins, mineral and polyphenolic compounds. Fruit consumption strengthens immunity, vessels of the heart and brain, promotes the removal of heavy metals and has detoxifying properties. The consumption of fruit products due to its therapeutic and energy attractiveness is recommended for a complete human nutrition [3]. As an element of a healthy diet, fruit products should enter the human body every day all year round. Cherry fruits have high taste and dietary characteristics. However, cherry fruits have a short harvest period within different ripening periods, which differ in quality parameters depending on varietal characteristics and growing conditions [4–6]. This limits the marketing window of the fruit. The choice of fruit products by consumers depends on the visual and sensory assessment of fruit quality [7]. An important criterion for evaluating the quality of fruits is their harmonious taste, which depends on the indicator of the sugar-acid index [4, 8]. This affects the competitiveness of cherries and determines the choice of raw materials for further storage and direction of use. Taking into account the initial parameters of fruits to manage their storage and post-harvest processing could improve the properties of raw materials in the chain of the production cycle of processing enterprises. The cited work presents the imperatives of ensuring the quality of the production cycle to ensure its efficiency according to the scheme "resources - structure - efficiency - system development" [9]. An increase in the period of consumption of fruit products can be solved by forming a continuous or extended production cycle of enterprises. It has been proven that the integration of food industry branches with a long continuous cycle causes certain functional changes in their efficiency. The specified approach would increase the competitiveness of food industry entities in the system of ensuring the economic security of the country [10]. Therefore, the study of preserving the quality of fruit raw materials becomes relevant in connection with the value of cherry fruits as a food product for dessert and technological purposes in the processing industry. Investigating the influence of different methods for cooling cherry fruits will allow producers to choose the optimal technique for storing fruits over a long period of time and increase the quality of products in the market.

Therefore, taking into account the initial parameters of fruits to manage their storage and post-harvest processing could improve the properties of raw materials in the chain of the production cycle of processing enterprises.

2. Literature review and problem statement

Preserving the consumer quality of fresh fruits and postponing the onset of their spoilage for a long period is a solution to the continuous supply of fruit products to the population. This can be achieved by managing microbiological and physiological indicators of fruits before and after harvesting [2]. High water content in cherry fruits causes quality loss of up to 60 %. Microbiological diseases and physiological disorders can also be identified among the main causes of daily losses during post-harvest storage of fruit raw materials [11]. Therefore, in order to supply consumers with high-quality cherry fruits on the market, it is necessary to prevent possible physiological damage and microbiological spoilage of products during the entire logistics chain "harvesting of fruit raw materials - transportation - storage - sale". This will reduce fruit waste and increase the availability and quality of food for consumers. As a result of the analysis of the pathogenic microflora on the fruits of Ambrunes cherries in the post-harvest period, it was determined that the optimal storage period for raw materials is 21 days [12]. To suppress the development of pathogenic microflora and increase the energy efficiency of the process of cooling cherries for storage, pre-cooling of products is carried out. Pre-cooling methods optimize the shelf life of fruits for fresh consumption. One of the recognized modern methods of pre-cooling fruits is shower-type hydrocooling [13]. Hydro-cooling is applied immediately after picking cherry fruits in the garden or at packing plants in storage [14]. The hydrocooling method is based on the principle of rapid heat transfer from the fruit to the cooling medium. Hydrocooling has a positive effect on reducing mass loss, which was experimentally proven during processing and storage of Cordia and Regina cherries [15]. It was determined that hydrocooling reduces by 2.3–2.6 times the loss of cherry fruits during storage for 15 days compared to fruits stored without cooling. However, hydrocooling does not ensure the preservation of fruit quality for a long period due to the continuation of physiological processes and the development of microbiological lesions due to the creation of a favorable environment for microorganisms by residual moisture. Scientists have proposed various ways to overcome these difficulties. One of the ways to slow down physiological processes and inhibit microorganisms is the use of protective coatings with antioxidant properties. This is the approach used in the research of microbiological characteristics of plum and pear fruits after processing them before storage with an antioxidant composition consisting of ionol, dimethyl sulfoxide, and lecithin. Treatment of fruits with an antioxidant composition significantly reduced the growth rate of epiphytic microflora on the surface of fruits [16]. To enhance the bactericidal effect, horseradish root extracts and other plant extracts are also used in protective antioxidant coatings for fruit and vegetable products [17, 18]. However, such solutions have certain disadvantages in practical application. After all, plant extracts do not have a stable composition, are unstable in storage, and cannot be recovered from the used solutions. Chlorinated water is widely used to disinfect fresh fruits, and especially vegetables. It was established that hydrocooling using chlorine provides decomposition of 75 % of pathogenic microorganisms compared to non-chlorinated water [19]. However, disinfection of fresh fruit with chlorine compounds causes the formation of carcinogenic halogenated compounds and poses a threat to human health. Therefore, there are certain restrictions on its use. In such European countries as Switzerland, Belgium, Germany, and Denmark, a ban was introduced on the use of chlorine as a disinfecting agent [20].

A solution to this problem is the search for alternative organic protective compositions for fruit processing. This is exactly the approach proposed in the work of Egyptian scientists. For two years, they studied the effect of processing guava fruits with citric acid (2 %) and honey (15 %) on their post-harvest quality [21]. This composition during fruit ripening contributed to the reduction of fruit weight loss, slowing down of color change, the content of dry soluble substances, the level of acidity and ascorbic acid, and also reduced the rate of respiration.

Work [22] highlights the positive effect of calcium chloride and salicylic acid on the quality of apricot fruits after harvesting. According to research, the use of salicylic acid and putrescine effectively slows the rate of post-harvest spoilage, significantly reduces fruit weight loss and rotting, and extends the shelf life of Murcott mandarins with high quality [23]. Research has determined the effectiveness of using peracetic acid in a hydrocooler in the fight against post-harvest cherry diseases at the storage stage [24]. Acetic acid is a derivative after the decomposition of peracetic acid. Other researchers also noted the possibility of using acetic acid in the fight against post-harvest rot of stone crops [25].

In addition to acetic acid, lactic acid is widely used in the food industry. The interest in lactic acid is explained by the fact that the chemical is safe and recognized as harmless (it has GRAS status). The degree of antimicrobial activity of acetic, citric, and lactic acids against *Shigella* species: *S. sonnei*, *S. flexneri*, *S. boydii*, and *S. dysenteriae* on the surface of inoculated lettuce was established. Acetic acid showed the greatest antimicrobial activity in a paper disk diffusion experiment, but lactic acid was the most effective antimicrobial agent against *Shigella* species artificially inoculated on lettuce [26].

Our review of the literature [2, 12, 24] indicates the need to find improved methodological approaches to ways of preserving the quality of fruit raw materials, which can be used in a waste-free supply chain of cherry fruits to all interested parties to solve food security problems. Interesting from a theoretical point of view is the construction of a regression model, which could reveal the most significant factors influencing the process of further storage of cherry fruits. To select the optimal concentrations of active substances in the working solutions of the protective composition for the treatment of cherry fruits, the method of regression analysis was chosen. This method is used to identify the most significant factors affecting the process of further storage. Also, the regression model will make it possible to estimate the optimal value of the indicator and the factors at which this optimal value is achieved, according to the methodology proposed in paper [27].

In view of the above, the problem of preserving the quality of fresh fruits and delaying the onset of their spoilage for a long period has no final solution. The specified method of fruit processing by hydrocooling was not applied with a complex of acetic and lactic acids for cherry fruits, and the quality indicators of raw materials were not investigated.

Usually, to optimize the shelf life of fruits for fresh consumption, the method of hydrocooling is used. The choice of optimal concentrations of components in protective compositions for the treatment of fruits before storage depends on the individual species characteristics of the fruits. Given this, the developed protective compositions and their concentrations for various types of fruit raw materials will not have a positive effect during cooling and further storage of cherry fruits [19, 20, 22, 23, 25]. The above gives reason to assert that it is expedient to carry out a study on the selection of concentrations of the components in the protective composition for the processing of cherry fruits under the action of hydrocooling. This will reduce the loss of fruit weight due to inhibition of negative microbiological and physiological processes during cherry storage.

3. The aim and objectives of the study

The purpose of our research was to establish the optimal concentrations of organic acids in the protective composition and to determine the point of the global optimum in the average level of daily losses during the storage of cherry fruits at hydrocooling. The improvement of modern pre-cooling technologies will contribute to the sustainable provision of fresh fruit to consumers in accordance with the requirements of the European market and will satisfy the preferences of all interested parties. The use of the developed protective composition will contribute to the preservation of quality indicators and the extension of the fruit storage period.

To achieve the goal of research, the following tasks must be solved:

– to assess the dependence of cherry fruit weight loss on microbiological diseases and physiological disorders during storage after treatment with a protective composition;

– to investigate mass losses and determine the average level of daily losses during storage of cherry fruits treated with a protective composition;

– to build a regression model and determine the optimal values of the studied components of the protective composition.

4. The study materials and methods

The object of our research is the technology of preliminary processing of cherry fruits using an organic composition.

The subject of the study is the influence of fruit treatment with a protective composition with different ratios of acetic and lactic acids under the action of hydrocooling on fruit weight loss during cherry storage.

The research hypothesis is as follows. The construction of a regression model will make it possible to optimize the value of the studied components in the protective composition for processing fruits under the action of hydrocooling and to determine, based on the model, the points of the global optimum of daily losses during cherry storage. This, in turn, will improve the provision of the market with the necessary volume of quality fruit products and will balance its supply to the consumer. It is also expected to improve the scheme of waste-free sale and processing of cherry fruits with the minimization of losses in the consumer quality of fruit raw materials and the reduction of the risk zone from an economic point of view.

Cherry fruits were selected for research in the state of consumer ripeness according to DSTU ISO 874-2002. The quality of the fruits met the standard requirements for cherry fruits according to DSTU 8153:2015. The date of fruit removal was determined by the following indicators: appearance (shape and color typical for this pomological variety), presence or absence of a peduncle, mechanical damage to the skin, damage by pests and fungal diseases, fruit diameter. Immediately after harvesting, the fruits were packed in bulk in plastic boxes (container size 600×400×116 mm), 10 kg each. The study of quality indicators was carried out at the laboratories of the Scientific Research Institute of Agricultural Technologies and Ecology, the Dmytro Motorny Tavryiski State University of Agrotechnology (Melitopol).

In order to extend the storage period of fruit raw materials and preserve their quality, the influence of hydrocooling of cherry fruits in combination with the developed protective compositions was investigated. The active substances of protective compositions were lactic (LA) and acetic (AA) acids. Valery Chkalov's early ripening cherry fruits were used as a model variety.

Hydrocooling was carried out in a stationary pallet hydrocooler MAS-HC-2000-PAL-ST with a capacity of 2 t/h. Pre-cooling of the fruits was carried out immediately after their collection by the combined technique (CT) in two stages:

Stage 1. Fruits were cooled with ice water (1.0±0.5 °C) with the addition of organic acid compositions (LA and AA). The cooling period is 10±2 minutes until the temperature inside the fruit is 4±1 °C.

The initial temperature of fruits during the harvest season depended on the ambient temperature and was 28±5 °C.

At stage 1, based on the results of analytical studies, 10 complex protective compositions were formed. The following concentrations of LA and AA were used to study the effectiveness of protective compositions: 0.00; 0.25; 0.50; 0.75; 1.00; 1.25; 1.50; 1.75; and 2.00 %. In complex protective compositions, the LA:AA ratio was 1:1. In the control variant, hydrocooling of fruits was carried out without adding organic acids.

Stage 2. In intensive cooling chambers, cherry fruits were further cooled with cold air for 30±2 minutes to a temperature of 2±0.5 °C. After-cooling with cold air to the storage temperature makes it possible to remove residual moisture from the surface of the fruits, which leads to rotting of the products. The speed of air movement was 3.0 m/s. The air exchange rate was 90 volumes per hour. In intensive cooling chambers, the temperature was 0±1 °C. The relative humidity of the air was 90±1 %.

The total duration of pre-cooling of fruits by the combined technique was 40±2 min. The cooling process took place until the temperature in the middle of the fruit was set at 2±0.5 °C (near the stone). Repeat each option five times. The size of the repetition is one box.

After the 2nd stage of cooling, the cherry fruits were stored at a temperature of 1.5±0.5 °C, relative humidity of 93±1 %. Fruit products were stored in modernized KH-48 refrigerating chambers, which are equipped with an Eliwell EWDR 902 temperature control system and Eliwell EWHS 31 relative humidity sensors. The cooling system of the storage chambers is battery powered. The physical storage conditions in the chambers were determined and controlled according to DSTU ISO 2169:2003.

The study of the effect of protective compositions on the quality of cherry fruits of the Valery Chkalov variety was carried out twice a year. Cherries of the model variety were put into storage in 2018–2020.

The temperature inside the fruit was measured with a TM-902 SR digital thermometer with a K-type thermocouple. The measuring range of the thermometer is from minus 50 °C to 1300 °C, the resolution is 0.1 °C in the temperature range of minus 50–200 °C.

Control measurements during the storage of cherry fruits were carried out twice: at the time of storage and after the end of storage. During control measurements, total losses of cherries after storage were determined. The total losses included natural losses of fruit mass, as well as losses of fruits that are the consequences of the development of physiological disorders and microbiological diseases in each version of the experiment. According to DSTU 8153:2015 Fresh cherries. Technical conditions of a lot of cherries, in which more than 10 % of the fruits have inappropriate quality indicators, are considered to be non-compliant with the requirements of the standard. In view of this, the end of the storage period was determined by the quantitative value of total fruit losses of more than 10 %. During our research, the first batches of fruits with a total loss of more than 10 % were discovered after 40 days of storage. Therefore, experimental data after 40 days of storage were selected to build a regression model.

The change in quality indicators during inspections was determined after they were taken out of storage and warmed to a temperature of 15–20 °C.

Determination of the number of fruits with signs of physiological disorders and microbiological diseases was carried out by their visual inspection. The fruit sample was 5 kg. The percentage of fruits affected by diseases and with signs of physiological disorders was determined.

Natural weight loss of fruit raw materials during storage was determined by the method of selecting fixed samples weighing 5 kg. Weighed cherry fruits were placed in nets with a label, which were tied. The grid number, cooling option, product name, variety, net weight, and date were indicated on the label. The number of fixed samples of each option is 5. Mass loss (B) was calculated as a percentage of the initial mass according to formula (1):

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

where a is the mass of the product during storage, g;

b – mass of products after storage, g.

The effectiveness of the influence of different concentrations of organic acids was determined by the average level of daily losses of fruits 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 is the average level of daily losses, % per day,

L_w – mass loss, %,

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

τ – duration of storage, days.

It was decided to build a regression model and determine the optimal values of the studied indicator (average level of daily losses during storage of cherries of the Valeriy Chkalov variety) in the following stages:

Stage 1. Construction of a regression model based on experimental data.

Stage 2. Model-based determination of the point of the global optimum and construction of a confidence interval for the optimum.

Stage 1. Building a regression model.

The regression model was built by the method of least squares according to the criterion of minimizing the sum of squares of the deviations of the theoretical values of the resulting characteristic from the experimental ones (3):

$$F=\min\sum_{i=1}^{n}\left(y_i-\hat{y}_i\right)^2, \quad (3)$$

where y is the experimental value of the resulting characteristic,

$\hat{y}$ – theoretical values of the resulting characteristic.

The regression model was built in the form of a second-order polynomial (4):

$$\hat{y}=b_0+b_1x_1+b_2x_2+b_3x_1^2+b_4x_2^2+b_5x_1x_2. \quad (4)$$

To identify the dependence between the factors and the resulting feature, the multiple correlation coefficient was determined according to formula (5):

$$R=\frac{\sum_{i=1}^{n}\left(y_i-\overline{y}_i\right)\left(\overline{y}_i-y_i\right)}{\sqrt{\sum_{i=1}^{n}\left(y_i-\overline{y}_i\right)^2\sum_{i=1}^{n}\left(\overline{y}_i-y_i\right)^2}}, \quad (5)$$

where y is the experimental value of the resulting characteristic,

$\hat{y}_i$ – theoretical values of the resulting characteristic,

$\bar{y}$ is the average value of y.

The significance of the multiple correlation coefficient was checked by the Student's test. At a significance level of α=0.05, the null hypothesis H_0 was put forward: ρ=0, where ρ is the coefficient of multiple correlation of the general population. To test the hypothesis, we determined the t statistic according to formula (6):

$$t=\frac{R\sqrt{n-p-1}}{\sqrt{1-R^2}}, \quad (6)$$

where R is the sample multiple correlation coefficient,

n is the number of observations,

p is the number of factors.

The significance of the obtained regression coefficients was determined by the Student's test. For each parameter of the model at the level of significance α=0.05, the null hypothesis was tested regarding the significance of each of the parameters of the regression model: H_0: $\beta_j=0$, where β_j are the generalized regression coefficients.

Confidence intervals for β parameters of the generalized regression model were found using formula (7):

$$\left[b_j\pm t_{crit}\sqrt{\hat{\sigma}_{b_j}^2}\right],\ \left(j=\overline{0.5}\right), \quad (7)$$

where b_j are parameters of the regression model,

t_{crit} is the critical value of Student's criterion,

$\hat{\sigma}_{b_j}$ is the mean square deviation of the regression parameters.

The cumulative coefficient of determination was calculated to assess the quality of the model. The coefficient of determination was determined by formula (8):

$$R_{yx_1x_2\ldots x_n}^2=\frac{\sum_{i=1}^{n}\left(\hat{y}_i-\overline{y}\right)^2}{\sum_{i=1}^{n}\left(y_i-\overline{y}\right)^2}, \quad (8)$$

where $\hat{y}_i$ are the theoretical values of the resulting feature;

$\bar{y}$ is the average value of y.

Adequacy of the built model was checked on the basis of Fisher's test. At the given level of significance α=0.05, the null hypothesis H_0 was put forward: $\hat{\sigma}_{\hat{y}}^2=\hat{\sigma}_{\varepsilon}^2$ (the obtained model is inadequate). To test this hypothesis, the F-statistic (9) was calculated:

$$F=\frac{\sum_{i=1}^{n}\left(\hat{y}_i-\overline{y}\right)^2\Big/p}{\sum_{i=1}^{n}\left(y_i-\overline{y}\right)^2\Big/\left(n-p-1\right)}, \quad (9)$$

where $\hat{y}_i$ are the theoretical values of the resulting feature,

$\bar{y}$ is the average value of y,

n is the number of observations,

p is the number of factors.

Stage 2. Model-based determination of the point of the global optimum and construction of a confidence interval for the optimum.

We found the stationary point of function (10):

$$\hat{y}=b_0+b_1x_1+b_2x_2+b_3x_1^2+b_4x_2^2+b_5x_1x_2.$$

Under condition:

$$\nabla f\left(X_0\right)=0. \quad (10)$$

As is known, the global optimum point is found by studying the Hessian matrix [27].

We checked the sufficient condition for the existence of an extremum at the point X_0.

Decision-making and the summary of calculation values were carried out based on the values of the Hessian matrix. If the Hessian matrix is defined with a negative value, then the point X_0 is the minimum point. If the Hessian matrix has a positive value when defined, then the point X_0 is the maximum point.

5. Results of investigating losses of sweet cherry fruits after treatment with a composition of organic acids of different concentrations

5. 1. Assessment of fruit loss from microbiological diseases and physiological disorders after treatment with a protective composition

Losses of sweet cherry fruits of the Valery Chkalov model variety from microbiological diseases and physiological disorders after treatment with acetic and lactic acid solutions after 40 days of storage ranged from 1.014 % to 13.242 % (Table 1).

The maximum rate of natural fruit losses of 13.242 % was recorded in the control variant, in which hydrocooling was carried out without adding LA and AA. Minimal natural losses from microbiological diseases and physiological disorders were recorded in the model variety Valery Chkalov after 40 days of storage at the level of 1.014 to 1.077 %. The difference between the minimum loss values is statistically unreliable and amounts to 0.003–0.063 % at HIP_{05} – 0.26 %. Minimal fruit losses (1.014–1.077 %) were recorded during hydrocooling with LA/AA compositions in the acid concentration ratio of 1.75–2.25:1.75–2.25. Also, low losses of fruits (1.065 and 1.068 %) during storage were noted under the action of hydrocooling using the LA/AA composition at acid concentrations in the ratio 1.5:1.75 and 2.0:1.5, respectively.

Table 1

Losses from microbiological diseases and physiological disorders during storage of sweet cherry fruits of the Valeriy Chkalov variety after treatment with acid solutions of different concentrations

Losses (%) after 40 days of storage at appropriate concentrations of the components of the composition										
LA/AAA	0***	0.25	0.50	0.75	1.00	1.25	1.50	1.75	2.0	2.25
0***	13.242	12.075	10.745	9.780	9.025	8.278	8.056	7.515	7.582	8.186
0.25	10.905	9.936	9.0934	8.070	7.687	7.232	7.238	6.562	7.014	7.356
0.50	10.715	8.215	7.421	7.011	6.050	5.745	5.322	4.920	6.010	6.395
0.75	8.190	7.015	6.141	5.491	4.717	4.359	3.973	3.412	4.437	4.829
1.00	6.923	5.763	4.758	4.0602	3.857	3.006	2.463	2.174	3.094	3.925
1.25	5.853	4.810	3.907	3.383	2.631	2.015	2.061	2.005	2.203	2.564
1.50	5.127	3.901	3.220	2.463	2.314	1.596	1.187	1.065	1.154	1.156
1.75	4.514	3.089	2.474	1.848	1.735	1.144	1.115	1.070	1.077	1.014
2.00	4.444	2.798	2.342	1.862	1.434	1.145	1.068	1.011	1.064	1.040
2.25	4.749	3.526	2.786	2.401	2.007	1.883	1.151	1.059	1.027	1.042

Note: HIP_{05} LA– 0.126 %; HIP_{05} AA – 0.126 %.

5. 2. Investigating the weight loss and the average level of daily losses during storage of sweet cherry fruits after treatment with a protective composition

Mass losses during storage of sweet cherry fruits of the Valery Chkalov variety after treatment with acid solutions of different concentrations during 40 days of storage amounted to 1.683–2.777 % (Table 2).

The highest rate of fruit weight loss of 2.777 % was recorded in the variant where hydrocooling was carried out with the addition of the LA/AA composition in the ratio of acid concentrations of 0.25–0.00 %.

Hydrocooling of sweet cherry fruits with the use of LA/AA compositions in the ratio of organic acid concentrations of 1.50–2.25:1.50–2.00 ensured the lowest losses of fruit raw materials (1.683–1.733 %). The difference between the loss values is statistically not reliable and is 0.002–0.050 % with HIP_{05} – 0.060 %. A positive effect and low losses of fruits (1.6845 and 1.720 %) during storage were noted for the effect of hydrocooling using the LA/AA composition at acid concentrations in the ratio 1.5:2.25 and 2.0:2.25, respectively.

Minimal losses of fruit mass (1.683 %) during storage of cherries of the Valeriy Chkalov variety were observed when hydrocooling was used in combination with a protective composition of LA/AA 1.75 % to 2.00 %.

The average daily loss of sweet cherry fruits of the Valery Chkalov variety after treatment with acid solutions of different concentrations during 40 days of storage was 1.683–0.068 % (Table 3).

The highest rate of daily fruit loss of 0.397 % was recorded in the control variant, where hydrocooling was carried out without adding LA and AA.

Hydrocooling of sweet cherry fruits with the use of LA/AA compositions in the ratio of organic acid concentrations of 1.50–2.25:1.75–2.25 ensured the lowest losses of fruit raw materials (0.068%–0.071 %). Minimal daily fruit losses (0.068 %) during storage of sweet cherries of the Valeriy Chkalov variety were observed when hydrocooling was used in combination with the protective composition LA/AA 2.00 % to 1.75 %.

Table 2

Mass losses during storage of sweet cherry fruits of the Valery Chkalov variety after treatment with acid solutions of different concentrations

losses (%) after 40 days of storage at appropriate concentrations of the components of the composition										
LA/AAA	0.00**	0.25	0.50	0.75	1.00	1.25	1.50	1.75	2.00	2.25
0.00	2.648	2.725	2.643	2.620	2.581	2.522	2.504	2.485	2.458	2.414
0.25	2.777	2.664	2.667	2.650	2.553	2.408	2.362	2.358	2.346	2.324
0.50	2.642	2.625	2.579	2.549	2.430	2.375	2.358	2.320	2.230	2.205
0.75	2.650	2.642	2.579	2.540	2.483	2.401	2.387	2.348	2.243	2.211
1.00	2.637	2.597	2.562	2.540	2.423	2.394	2.337	2.226	2.226	2.195
1.25	2.427	2.350	2.333	2.177	2.169	2.145	1.899	1.835	1.837	1.836
1.50	2.353	2.179	2.060	2.017	1.886	1.804	1.733	1.695	1.686	1.684
1.75	2.286	2.191	2.126	2.112	2.065	2.016	1.685	1.690	1.683	1.746
2.00	2.196	2.122	2.058	2.018	1.966	1.775	1.692	1.709	1.696	1.720
2.25	2.091	2.034	2.014	1.959	1.913	1.757	1.689	1.701	1.733	1.758

Note: HIP_{05} LA – 0.060 %; HIP_{05} AA – 0.060 %.

Table 3

The average level of daily losses during the storage of sweet cherry fruits of the Valeriy Chkalov variety with the use of a protective composition

Daily losses (%), at appropriate concentrations of the components of the composition										
LA/AAA	0.00**	0.25	0.50	0.75	1.0	1.25	1.5	1.75	2.0	2.25
0.00**	0.397	0.370	0.334	0.310	0.290	0.270	0.264	0.250	0.251	0.265
0.25	0.342	0.315	0.294	0.268	0.256	0.241	0.240	0.223	0.234	0.242
0.50	0.333	0.271	0.250	0.239	0.212	0.203	0.192	0.181	0.206	0.215
0.75	0.271	0.241	0.218	0.201	0.180	0.169	0.159	0.144	0.167	0.176
1.00	0.239	0.209	0.183	0.165	0.157	0.135	0.120	0.110	0.133	0.153
1.25	0.207	0.179	0.156	0.139	0.120	0.104	0.099	0.096	0.101	0.110
1.5	0.187	0.152	0.132	0.112	0.105	0.085	0.073	0.069	0.071	0.071
1.75	0.170	0.132	0.115	0.099	0.095	0.079	0.070	0.069	0.069	0.069
2.0	0.166	0.123	0.110	0.097	0.085	0.073	0.069	0.068	0.069	0.069
2.25	0.171	0.139	0.120	0.109	0.098	0.091	0.071	0.069	0.069	0.070

5. 3. Building a regression model and determining the optimal values of the studied components of the protective composition

The construction of the regression model, the determination of the optimal value of the indicator and the studied components of the protective composition were carried out by analyzing the average level of daily losses of fruits during storage (Table 3).

At the 1st stage of calculations and construction of the regression model, it was built using the method of least squares under condition (3).

For the experimental data, the data was smoothed by a polynomial of the second power (4).

The values of the parameters b_0, i=0...5 were obtained from the solution of the system of equations.

The resulting regression model takes the following form:

$$\hat{y} = 0.3935 - 0.2023x_1 - 0.1299x_2 + \\ +0.0445x_1^2 + 0.0344x_2^2 + 0.0058x_1x_2. \quad (11)$$

To identify the dependence between the factors and the resulting feature, the multiple correlation coefficient was determined according to formula (5). The obtained value of the multiple correlation coefficient R^2=0.994 is close to unity, which indicated a strong linear correlation between the set of factors and the resulting characteristic.

The significance of the correlation coefficient was checked according to the Student's test (6). The t-statistic value (t=86.87) is greater than the critical value (t_{crit}=1.986), so the null hypothesis was rejected at the significance level of α=0.05. This indicated that the sample multiple correlation coefficient was significant.

The t-statistic value was calculated to check the significance of the coefficients of the obtained regression model.

The calculated values of the t-statistics are given in Table 4.

Table 4

Calculated values of the t-statistics

t-statistics	t_0	t_1	t_2	t_3	t_4	t_5
Value	101.95	39.11	25.097	21.85	16.89	3.214

Estimated values are greater than the critical value (t_{crit}=1.986). The null hypothesis is rejected at the level of significance α=0.05, which indicates the significance of the parameters of the regression model.

Confidence intervals for generalized regression coefficients were found using formula (7). They take the form given in Table 5.

Table 5

Confidence intervals for generalized regression coefficients

β_0	β_1	β_2	β_3	β_4	β_5
[0.3858; 0.4012]	[−0.213; −0.192]	[−0.1401; −0.1196]	[0.0405; 0.0486]	[0.0304; 0.0385]	[0.0022; 0.0093]

According to formula (8), the total coefficient of determination was found. The value of the multiple coefficient of determination R^2=0.988 is close to unity, which indicates a significant influence of the main factors on the resulting feature in comparison with other unaccounted factors and accidents.

The adequacy of the constructed model was checked according to Fisher's criterion (9).

The estimated value of the F-statistic is F=1509.2; critical value is F_{crit}=2.31.

Based on the fact that $F>F_{crit}$, the hypothesis was rejected at the level of significance α=0.05. The built model is adequate to the experimental data.

The chart of the built model is shown in Fig. 1.

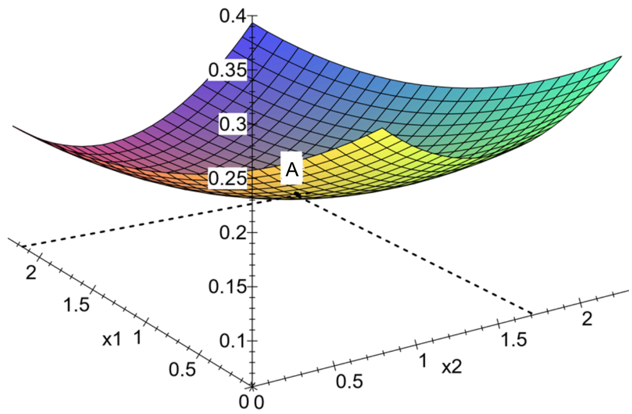

Fig. 1. The response surface and the optimum point for determining the optimal value of the average level of daily losses during the storage of sweet cherry fruits of the Valeriy Chkalov variety using a protective composition

At the second stage, the point of the global optimum was determined based on the model and the confidence interval for the optimum was constructed.

To determine the extremum of function (11), the system of equations was solved:

$$\begin{cases} \dfrac{\partial y}{\partial x_1} = 0, \\ \dfrac{\partial y}{\partial x_2} = 0. \end{cases} \quad (12)$$

Solving this system of equations helped find a stationary point with coordinates x_1=1.705; x_2=2.161.

To verify the fulfillment of the sufficiency condition, the Hessian matrix was calculated:

$$H = \begin{pmatrix} \dfrac{\partial^2 y}{\partial x_1^2} & \dfrac{\partial^2 y}{\partial x_1 x_2} \\ \dfrac{\partial^2 y}{\partial x_1 x_2} & \dfrac{\partial^2 y}{\partial x_2^2} \end{pmatrix} = \begin{pmatrix} 0.0897 & 0 \\ 0 & 0.0688 \end{pmatrix},$$

$$\Delta = \frac{\partial^2 y}{\partial x_1^2}\frac{\partial^2 y}{\partial x_2^2} - \left(\frac{\partial^2 y}{\partial x_1 x_2}\right)^2 > 0, \quad \frac{\partial^2 y}{\partial x_1^2} > 0,$$

this indicates that the point X(2.161;1.705) is the minimum point.

At the same time, the minimum value of the function at the optimum point is 0.0642.

The constructed regression model helped optimize the values of the studied components of acetic (X_1) and lactic acids (X_2), which were x_1=1.705 %; x_1=2.161 %, respectively. The optimal value of the indicator of the average level of daily losses during storage of sweet cherry fruits of the Valeriy Chkalov variety was 0.0642 %.

These results indicate a positive effect of the investigated components of acetic and lactic acids on the quality of raw materials during cherry storage. The obtained data are of practical importance and may be important for improving the technology of pre-treatment of sweet cherry fruits after harvesting.

6. Discussion of results related to the possibility of improving the consumer quality of sweet cherry fruits during storage

The need for fruits, in particular sweet cherries, is predetermined by national characteristics, the needs of the population, and modern trends in healthy eating [28, 29]. Sweet cherry (*Prunus avium L.*) is a nutritious fruit rich in polyphenols and high antioxidant potential. But the fruits are perishable with a short harvest period. Therefore, in the research, it is planned to solve the problem of extending the shelf life and preserving the consumer quality of fruits. In research, losses from microbiological diseases and physiological disorders were observed during storage of cherry fruits of the Valeriy Chkalov variety for 40 days (Table 1). It has been established that the main fungal diseases of cherries during long-term cold storage of fruits are gray rot (*moniliosis*) and hole spotting (*clusterosporiosis*). The obtained results are quite comparable to the data obtained by other authors who note that microbiological diseases are the main cause of losses during cherry storage [11, 24]. Wilting is a manifestation of a physiological disorder of fruits, which depends on the morphological and physical-chemical characteristics of the fruit, the state of moisture in the storage, the qualitative composition and concentration of substances during the processing of fruits in the post-harvest period.

Post-harvest quality preservation of fresh fruit is a challenge for producers and researchers as they strive to combat the high post-harvest losses that occur during the transition from the orchard to the consumer [2]. In this regard, the efforts of scientists around the world are aimed at studying the effectiveness of various technologies for managing the quality of fresh fruit products after harvesting in the supply chain [1].

Our research results show that the treatment of fruits with protective compositions of organic acids of different concentrations under the action of hydrocooling contributes to the reduction of mass loss during storage of cherries for 40 days (Table 2). Similar results were reported by other researchers. It has been established that hydrocooling extends the shelf life and shelf life of fruits due to the minimization of water, weight loss, and slowing of respiration [30]. Extending the shelf life of fruits owing to hydrocooling ensures efficient transportation and export of cherry fruits over long distances [13, 14]. In order to stabilize the quality characteristics of fruits in the post-harvest period and extend the shelf life of fruits, the efforts of scientists from many countries are aimed at finding optimal combined techniques for cooling raw materials.

In our research, the average level of daily losses during the storage of cherry fruits using a protective composition during 40 days of storage was 1.683–0.068 % (Table 3). The effectiveness of hydrocooling to reduce mass loss has been shown by other authors [11, 15]. The mass loss recorded by us is significantly lower than that described for Cordia cherries 5.83 % and Sweet heart cherries 8.23 % for 42 days of storage [11]. It is obvious that in the studies more effective reduction of mass loss is explained by the combination of hydrocooling with the use of organic acids. The results are consistent with the data from other studies on the positive effect of protective compositions on the preservation of fruit quality [16, 21, 22]. It was established that the use of an antioxidant composition reduced the level of daily losses from microbiological diseases by 2–3.5 times during the entire storage period of pear and plum fruits. The greatest positive effect was obtained using a composition based on distinol and lecithin [16]. However, in the cited study, the mechanism of action consists only in the antioxidant effect. The organic acids used in the research show a powerful antimicrobial effect, which significantly affects the reduction of the loss caused by the development of microorganisms. This effect is quite comparable to the results obtained by researchers using sodium hypochlorite and peracetic acid [24]. In the studies, a positive effect of sodium hypochlorite was observed under the action of hydrocooling at a pH of 6.5–7 in the washing water. But the accumulation of organic compounds and an increase in pH leads to the inactivation of the hypochlorite ion and the loss of its antimicrobial effect [24]. Studies [22, 23] consider alternative methods for controlling diseases and physiological disorders of many fruits after harvesting using disinfectants. The effectiveness of the drug based on acetic acid depended on the treatment period and requires further research. Based on the review of papers [20, 24, 26], there are limitations regarding the use of a high-quality composition of compositions, the choice of a processing method, high cost and a narrow spectrum of the purpose of protective films. Our research on reducing post-harvest losses is aimed at finding alternative strategies for using organic compounds for disease control and extending the shelf life of fresh fruits. Experimental studies have proven the effectiveness of hydrocooling in solutions of organic acids. As a result of our research, the method of pre-cooling under the action of a protective composition based on organic acids has been improved. Based on the analysis of quality indicators and the constructed regression model, the optimal value of the indicator of the average level of daily losses during storage of sweet cherry fruits of the Valeriy Chkalov variety was determined – 0.0642 %) with the values of the factors x_1=2.161 and x_2=1.705 (Fig. 1). This pre-cooling technique will reduce all types of product losses, extend shelf life, and contribute to safety for the consumer. The practical significance of our results is the establishment of optimal concentrations of acetic and lactic acids in the protective composition for hydrocooling of sweet cherry fruits, which could simplify the use of improved hydrocooling technology and allow reducing losses during storage and contribute to increasing the yield of standard fruit products. A potential effect of improved cherry hydrocooling technology will be to increase the safety of products after storage due to the reduction of the level of microorganisms and the use of organic acids.

Among the limitations of this study is that it is relevant mainly to sweet cherry fruits since the results cannot be fully applied to other types of fruits. Also, it should be taken into account that the effect of the protective organic composition under the action of hydrocooling may be limited and requires additional study on other types of precooling. The main drawback is the limited sample size, which complicates the statistical significance of the results. In addition, varietal characteristics of sweet cherries and fruit ripening periods were not taken into account.

Our research may be advanced through a more detailed study on the method of pre-treatment of fruits after harvesting using the proposed organic protective composition. It is also important to expand the range of sweet cherries for a more in-depth analysis of the impact of the organic composition under different methods of pre-cooling on the quality parameters of the fruits. Taking into account varietal characteristics and ripening periods will make it possible to more accurately interpret the results. In addition, expanding the research to other types of fruit will allow us to draw conclusions about the possibility of using the proposed composition to minimize losses in the consumer quality of a wide range of fruit raw materials.

7. Conclusions

1. Minimal natural losses from microbiological diseases and physiological disorders were recorded in the model variety Valery Chkalov after 40 days of storage at the level of 1.014 to 1.077 %.

2. Minimal losses of fruit mass (1.683 %) during storage of sweet cherries of the Valeriy Chkalov variety were observed when hydrocooling was used in combination with a protective composition LA/AA 1.75 % to 2.00 %. Minimal daily fruit losses (0.068 %) during storage of sweet cherries of the Valeriy Chkalov variety were observed when hydrocooling was used in combination with the protective composition LA/AA 2.00 % to 1.75 %.

3. Our analysis of the regression model revealed the optimal value of the indicator of the average level of daily losses during the storage of sweet cherry fruits of the Valeriy Chkalov variety – 0.0642 % with the value of the factors x_1=2.161 and x_2=1.705. The model is adequate to the experimental data in the range of acetic acid concentration from 0 to 2.25 %, lactic acid – in the range from 0 to 2.25 %. The value of the coefficient of determination indicates a significant influence of the main factors on the resulting feature in comparison with other unaccounted factors and accidents. The results indicate the possibility of using a protective composition of organic acids (acetic and lactic) under the action of hydrocooling in order to minimize the loss of fruit weight during long-term low-temperature storage of sweet cherries and ensure product safety.

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.

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