CHAPTER 2

A multi-criteria strategy for assessing the quality of frozen raw cherry fruits

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Abstract

The optimization of the food chains, in particular the storage and processing of raw materials into final products, is becoming a particularly difficult task for the regions which face humanitarian crises, protracted political conflicts and natural disasters. Cherries are one of the most popular fruits in the confectionary industry used. Freezing is one of the most effective methods of long-term preservation of cherries. At the same time, frozen raw materials, like any other product, can undergo changes that negatively affect the quality of the final product. This may include deterioration of taste characteristics, loss of vitamins, and risk of developing microbiological processes in case of the violation of storage or transportation conditions. In this context, the implementation of comprehensive assessment of the cherry fruits quality becomes especially relevant. Therefore, systematic monitoring of physical, biochemical and sensory parameters is necessary to obtain high-quality frozen raw materials. A method of multi-criteria evaluation of frozen fruit was proposed. The objective functions were calculated and a ranking series of the suitability of the frozen fruits for the production of candied fruit was formed. By using a multi-criteria optimization method, the most suitable cherry cultivars for freezing were determined. A scientifically based complex of quality parameters of functional technological indicators of frozen fruit is presented. The selection of the optimal cultivar of fruit raw materials with high quality indicators and minimal losses was carried out by means of a comparative evaluation of the cultivars according to their properties using a multi-criteria method based on a geometric convolution of criteria. Chemical, physical and

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organoleptic criteria of frozen semi-finished products may change depending on the varietal characteristics of cherries. Therefore, choosing the optimal cultivar requires a comprehensive approach. The use of a multi-criteria optimization method made it possible to establish relationships between the quality characteristics of the fruits and their permissible values. This made it possible to determine the fruit of Griot Melitopol cultivar as the best frozen raw material according to functional, technological and sensory indicators. This can further be used to improve criteria for evaluating the quality of frozen fruit pulp within a zero-waste fruit supply chain, ensuring efficiency and sustainable use of resources for all stakeholders.

Keywords

Fruit, amount of juice loss, sensory analysis, biochemical indicators, freezing, storage, geometric convolution criteria.

2.1 Introduction

Today's global food system remains vulnerable and unstable. The consequences of Russian aggression on the territory of Ukraine have deepened the negative trends in the global food sector. The food system covers all stages from the production of food to the consumption of ready-made food. An important chain of the food system is storage and processing of raw materials into a final product [1]. Food industry, in particular the processing of fruit raw materials, is an integral part of a food system and an important lever for the transformation of value chains in the context of achieving sustainable development goals [2].

In modern conditions of increased requirements for the quality of food products, ensuring the stability of the technological characteristics of semi-finished products is of particular importance. Frozen fruit raw material, in particular cherries, is widely used in the production of confectionary and candied products, yogurt and other food products and their quality directly affects the consumer properties of the final products, the economic efficiency of production and the competitiveness of the enterprises in the processing industry. A modern strategy for the processing of fruit raw materials requires the implementation of innovative approaches to the preparation and selection of raw materials for production [3].

A modern strategy for the processing of fruit raw materials requires the implementation of innovative approaches to the preparation and selection of raw materials for production [4]. High competition among stakeholders stimulates them to constantly improve not only the range of products, but also the technological processes of preparing semi-finished products. According to literature reviews, there is growing interest in the extended period of the use of fruit raw materials, in particular, in the practice of fruits pre-freezing. This approach is important because freezing allows to significantly extend the storage life of fruit raw materials, which makes it possible to ensure a continuous process of raw material processing throughout a year, despite the seasonality of fruit harvesting [5, 6]. The use of frozen fruit in the food industry allows to for efficient processing of fruit that requires a quick marketing solution to reduce spoilage and minimize wastage. This approach allows to integrate fruits of different degrees of ripeness and commercial grade into a zero-waste processing chain. Delayed processing of fruits for further use is possible if they are previously frozen [7].

The suitability of fruits of different cultivars for freezing is assessed on the basis of physical, technological and sensory characteristics. Frozen candied fruits for further use must meet a number of quality requirements: organoleptic parameters (taste, smell, color), physicochemical properties (solids content, acidity, degree of freezing) and safety parameters (absence of pollution, pesticide residues, etc.). In addition, the technological properties of raw material are important, in particular, its ability to retain its shape, color and texture after the processes of defrosting and sugaring [8, 9].

One of the main problems affecting the quality of fruit raw material is the deterioration of its properties during freezing and storage. In the process of freezing, damage to the cellular structure of fruit can occur due to the formation of large ice crystals, which leads to the loss of cell juice during defrosting, changes in texture, darkening of color and reduction of aroma. The intensity of these changes depends on a number of factors, in particular the cultivar and varietal characteristics of raw material.

Cherry is a valuable fruit raw material for the processing industry due to its sensory properties and the presence of components important for full nutrition. It contains organic acids (from 0.7 to 3.0%), sugars (from 6.5 to 21.5%), as well as vitamin C (from 13 to 19 mg/100 g of product weight). Freezing is one of the most effective methods of a long-term storage of fruits, in particular, of cherries. Studies of the suitability of different cultivars of cherries for freezing were conducted by both Ukrainian and European scientists. Experimental studies made it possible to draw conclusions about the suitability of certain cherry cultivars for freezing as well as to determine the optimal storage period for these fruits [10, 11].

The quality of frozen cherry raw materials for further use depends on several factors, such as a cultivar, stage of ripeness, pre-treatment and duration of storage in the freezer. The choice of cherry cultivars is critically important, as they are characterized by different physical and chemical parameters [12, 13]. This significantly affects the quality of the final product.

The relevance of quality control of frozen cherry raw materials for further use is due to the need to ensure the stability of the final product parameters. Control of organoleptic, physico-chemical and microbiological indicators not only prevents the production of low-quality finished products, but also guarantees the safety for consumers. Therefore, proper control at all stages of storage and processing of frozen cherries is a key element of an effective production process that ensures high quality of semi-frozen products [7].

Food products are polydisperse systems, which differ in various physical properties and composition of biochemical components. One of the main factors determining the quality of a fruit product of fruit origin is the composition of raw material to be processed. Therefore, frozen fruit products require additional research on functional and technological indicators to select optimal cultivars, that are suitable for further use of raw materials [14].

However, the analysis of each quality indicator separately does not allow to form a set of parameters that determine the best cultivar. Therefore, in order to choose the optimal cultivar of fruits that can be recommended for further of use semi-finished products, it is necessary to use a comprehensive assessment. One of the modeling methods based on complex quality indicators is the generalized desirability function proposed by Harrington. This function is based on the transformation of the natural values of individual indicators (feedback) into a dimensionless scale reflecting desirability or preference [15]. In scientific studies, it was used to determine minimal product losses and optimal methods of fruit freezing. This made it possible to summarize quality indicators of frozen cherry fruits in different ways and determine the best variant [16]. The approach, based on the desirability function, was used for the optimization of extraction conditions of the antioxidant olive leaf compounds by means of water- alcohol solvent [17].

One of the methods of a comprehensive assessment of fruits based on a set of quality indicators is a method of multi-criteria optimization. This approach is based on taking into account the measurement units of quality indicators and values of the intervals of permissible values of each indicator when choosing the best cultivar of fruit for freezing [18].

In this regard, the task of developing an effective strategy for multi-criteria selection of frozen cherry raw material, which will allow to optimize the process of semi-finished products production and ensure high quality of the final product, arises. This approach involves taking into account a complex of parameters and applying methods of quantitative and qualitative analysis to make substantiated decisions. The relevance of this issue is increasing in the conditions of modern production, where the consumers make high demands for the products quality. Increased attention to the technological processes of storage, processing and quality control of raw materials allows to minimize the risks of deterioration of the final product quality, which directly affects the reputation of the producer and the competitiveness of its product in the market.

The purpose of this section is to substantiate and develop a multi-criteria strategy for choosing frozen cherry raw material for further use of semi-finished products, aimed at achieving the highest quality of a final product. Special attention is paid to the assessment of key parameters of raw materials and the implementation of a systematic approach to decision-making at all stages of its selection.

2.2 Development of the methodology for selecting the best cherry cultivars suitable for freezing on the basis of criterion indicators

In the process of production of frozen semi-finished products, it is especially important to select a scientifically based cultivar. In Ukraine, cherry is one of the most popular fruits used for the production of frozen products. As mentioned earlier, each cherry cultivar has a unique biochemical, commodity and sensory characteristics. These functional and technological parameters determine the taste qualities of fruits after freezing and significantly affect their suitability for further processing.

The scientific substantiation of the selection of cultivars suitable for freezing was carried out using a modified method. The basis of this method is the use of decision-making mechanism based on several predefined criteria, which allows to eliminate the influence of measurement units and the interval values of permissible values of each criterion on a cultivar selection (objective function).

The selection of the most suitable cultivar for freezing was carried out by the method of multi-criteria optimization [18]. The selection criteria were determined by the main requirements for cherry fruits. The most important among them are the following: the fruits should be large in size, of a uniform intense red color, with a thin skin, dense pulp and a small stone. An important characteristic is a low tendency to browning, as well as an optimal ratio of organic acids and sugars (sugar-acid index). Cherry fruits should not have too sour taste.

In order to scientifically justify the selection of cherry fruits suitable for freezing, using the method of multi-criteria optimization, the following algorithm of the main stages was developed:

1. Formulation of the optimization task. At this stage, the main criteria and their significance for the final product were determined. As the main criteria A_j key physico-chemical parameters and sensory evaluation of frozen cherry fruits were selected: amount of juice loss, % (A_1); content of dry soluble substances, % (A_2); sugar content, % (A_3); titrated acids content, % (A_4); total content of phenolic compounds (A_5); vitamin C content mg (A_6); general sensory evaluation of fruits (A_7).

2. Collection of experimental data. The research was conducted during 2007–2019. The objects of the research were fresh fruits of ten cherry cultivars. The line of experimental cultivars included: Ozhydanie (Early maturing period); Vstrecha, Shalunia, Siyanets Turovtsevoi, Griot Melitopolskiy, Modnytsia, Ekspromt (medium maturing period); Melitopolska Purpurna, Solidarnist, Igrushka (late maturing period).

Cherry fruits for further freezing were collected at the consumer stage of ripeness. The fruits were sorted, inspected, washed and frozen loosely in a freezer in a slow way. The freezing temperature was minus 24 ± 1°C until the internal temperature of the fruit was minus 18°C. After that, they were packed in polyethylene film bags of 0.5 kg each and stored for three months at a temperature of minus 18°C. Determination of the components of the chemical composition, technological and organoleptic indicators were performed three times in fresh fruits on the day of collection: in fresh frozen fruits, in frozen fruits after 1 and after 13 months of storage.

All measurements were performed according to standard methods [18]:

– **the amount of cell juice loss** – by determining the difference of fruit weight before and after defrosting;

– **the content of dry soluble substances** was determined using a refractometer.

The method is based on determination of the mass fraction of dry soluble substances by the refractive index. The refractive index of the analyzed solution was measured at a temperature of (20.0 ± 0.5°C) on the ABBE AR12;

– **the mass concentration of sugars** was determined by the ferricyanide method. This method is based on the ability of reducing monosaccharides to reduce potassium ferricyanide K3[Fe(CN)6] (red blood salt) in ferric blue (ferrocyanide) potassium K4[Fe(CN)6] (yellow blood salt) in an alkaline medium. Methylene blue was used as an indicator. When reducing potassium ferricyanide, a change in the color of the solution from blue to colorless or light yellow was observed. The amount of sucrose was determined by previously converting it to invert sugar;

– **the content of titrated acids** was determined by the titrimetric method. The method consists in the neutralization of organic acids contained in the studied product with the help of 0.1 alkali solution. Titration is carried out until the moment of transition of the solution from an acidic environment to an alkaline one. This transition is recorded visually by the appearance of a pink color of the solution in the presence of the phenolphthalein indicator. The accuracy of the method is ± 0.5%;

– **the content of phenolic substances** was determined using the Folin-Denis reagent. The method is based on the complexation reaction of polyphenols with the Folin-Denis reagent, which results in the formation of colored compounds that allow to determine the optical density. The rutin standard was used to calculate the content of polyphenols in cherry fruits;

– **the content of ascorbic acid** was determined by the iodometric method using the Tillmans reagent. The method is based on the reducing properties of ascorbic acid. Under the influence of ascorbic acid, the solution of the indicator 2.6-dichlorophenolindophenol, which was a blue color, was reduced to a colorless compound.

The general sensory evaluation of frozen cherry fruits was carried out on a 9-point scale.

The obtained data will be analyzed below.

3. Normalization of criteria. This was done in order to eliminate the influence of units' measurement of physico-biochemical and sensory criteria of fruits of various cultivars, which allows to transit their values into dimensionless quantities ($f_j \to \widehat{f}_j$).

Before carrying out the normalization operation, it is necessary:

– to set the maximum (f_j^+) and minimum (f_j^-) values of *j*-criterion of the studied cultivars (x_i);

– the optimal value of *j*-criterion was determined according to the following rule:

a) if the evaluation criterion (f_j) tends to the minimum value, then

$(f_j^{opt} \to \min)$, then $f_j^{opt} = f_j^-$;

b) if the evaluation criterion (f_j) tends to the maximum value, then

$(f_j^{opt} \to \max)$, then $f_j^{opt} = f_j^+$.

The optimal value of *j*-criterion (f_j^{opt} min; f_j^{opt} max) is taken into account when choosing formula (2.1) for the normalization operation

$$\widehat{f}_j(x_i) = \begin{cases} \dfrac{(f_j(x_i) - f_j^-)}{(f_j^+ - f_j^-)}, \text{if } f_j^{opt} \to \max; \\ \dfrac{(f_j^+ - f_j(x_i))}{(f_j^+ - f_j^-)}, \text{if } f_j^{opt} \to \min, \end{cases} \quad (2.1)$$

where $\widehat{f}_j(x_i)$ – the value of *j*-criterion in the normalized form for the *i*-cultivar; $f_j(x_i)$ – the value of *j*-criterion for the *i*-cultivar in the corresponding units of measurement; $f_j^+; f_j^-$ – the area of permissible values of *j*-criterion of the compared cultivars.

4. Calculation of the values of the objective function. After the normalization operation, the values of the target function (*j*) were calculated for each cultivar (x_i) according to formula (2.2)

$$\varphi(x_i)=\sum^n\left|\hat{f}_j(x_i)-\hat{f}_j(x^i)\right|\to\min,\text{ where }0\le\hat{f}_j(x_i)\le1;\qquad(2.2)$$

$$\hat{f}_j\left(x^i\right)=1,$$

where $j(x_i)$ – a target function for the *i*-cultivar; *n* – number of criteria; $\hat{f}_j\left(x_i\right)$ – value of *j*-criterion in a normalized form for the *i*-cultivar; $\hat{f}_j\left(x^i\right)$ – value of *j*-criterion in a normalized form for the ideal cultivar; x^i – an ideal cultivar (with optimal criteria values).

Proof that $\hat{f}_j\left(x^i\right)=1$.

If $f_j^{opt}\to\max$, then according to formula (2.2), the value of *j*-criterion in the normalized form for an ideal cultivar, can be calculated using formula (2.3)

$$\hat{f}_j\left(x^i\right)=\frac{f_j\left(x^i\right)-f_j^-}{f_j^+-f_j^-},\text{ as }f_j\left(x^i\right)=f_j^{opt}=f_j^+.\qquad(2.3)$$

If $f_j^{opt}\to\min$, then according to formula (2.2) it is possible to calculate the value of *j*-criterion in normalized form for an ideal cultivar using formula (2.4)

$$\hat{f}_j\left(x^i\right)=\frac{f_j^+-f_j\left(x^i\right)}{f_j^+-f_j^-},\text{ as }f_j\left(x^i\right)=f_j^{opt}=f_j^-.\qquad(2.4)$$

5. Analysis of the obtained results. The choice of the best cultivar is determined by the conditions of maximum approximation of its target function to the target function of an ideal cultivar, which is equal to 0.

Let's prove that $\varphi\left(x^i\right)=0$.

According to formula (2.5)

$$\varphi\left(x^i\right)=\sum^n\left|\hat{f}_j\left(x^i\right)-\hat{f}_j\left(x^i\right)\right|=\sum^n\left|1-1\right|=0.\qquad(2.5)$$

Therefore, the smaller the value of the target function of the cultivar in the range of criteria values of the studied cultivars, the higher the suitability of the frozen raw material for the production of candied fruit. The construction of ranked series and the selection of the best cherry cultivar suitable for freezing in the range of criteria values is based on this principle.

2.3 Dynamics of juice loss in cherry fruits during freezing and further storage

One of the most important technological indicators characterizing the quality of frozen product is the amount of juice loss. It directly reflects the degree of structural damage to the cellular tissue of the fruit. Determining the amount of juice loss makes it possible to predict the behavior of cherry fruits cultivars in various technological processes. **Table 2.1** shows the results of influence of defrosting of frozen cherry fruit on the amount of juice loss.

Table 2.1 Amount of juice loss during defrosting of frozen cherry fruits (average during 2007–2019), %

Cultivar	Storage period			LSD_{05}
	after freezing	30 days of storage	90 days of storage	
Vstrecha	7.10 ± 0.11	7.8 ± 0.12	8.1 ± 0.15	0.46
Ozhydanie	6.20 ± 0.07	7.0 ± 0.13	7.4 ± 0.07	0.22
Shalunia	5.70 ± 0.12	5.9 ± 0.11	6.2 ± 0.19	0.54
Siyanets Turovtsevoi	5.90 ± 0.09	6.3 ± 0.11	6.5 ± 0.17	0.46
Griot Melitopolskyi	4.20 ± 0.19	5.1 ± 0.1	5.8 ± 0.15	0.53
Melitopolska Purpurna	4.10 ± 0.09	4.3 ± 0.1	4.3 ± 0.15	0.18
Modnytsia	4.60 ± 0.15	5.1 ± 0.16	5.3 ± 0.16	0.33
Expromt	6.20 ± 0.09	6.9 ± 0.15	7.2 ± 0.18	0.54
Solidarnist	6.80 ± 0.19	7.4 ± 0.25	8.0 ± 0.19	0.70
Igrushka	6.10 ± 0.21	6.9 ± 0.18	7.4 ± 0.19	0.77
Average value	5.7 ± 0.18	6.3 ± 0.16	6.6 ± 0.17	0.75
LSD_{05}	0.36	0.39	0.41	–

It was established that the maximum loss of cell juice occurred immediately after fruit freezing. In cherry fruits this indicator varied from 7.10% (Vstrecha cultivar) to 4.00% (Melitopolska Purpurna cultivar). The obtained results can be explained by physico-chemical and structural characteristics of the investigated cherry cultivars. Fruits with higher values of juice loss contain a larger mass fraction of free moisture compared to those with minimum values of this indicator. During freezing free moisture forms larger ice crystals, which can lead to the destruction of the histological structure. Presumably, the percentage of free moisture in the fruits of Vstrecha cultivar is significantly lower, which contributes to the formation of smaller ice crystals during freezing and ensures better preservation of the histological structure.

In addition, the dry substances of cherries contain significantly more pectin substances, fiber and organic acids compared to sweet cherries. Pectin substances and fiber strengthen intercellular connections, reducing the possibility of cell juice loss after defrosting. The higher content of organic acids creates increased osmotic pressure in the cells, which helps retain moisture inside them and ensures better preservation of the histological structure of the fruits. Therefore, higher losses of juice during cherry fruits defrosting, especially of early cultivars, are caused by a more delicate pulp structure, a lower content of dry substances, in particular pectin, fiber and organic acids, as well as an increased content of free moisture.

During the storage process, changes in the amount of cell juice loss after defrosting were significant, compared to the initial stage. After 30 days of storage, this indicator was 4.3–7.8%, depending on the varietal characteristics of the fruits. The maximum loss of cell juice was found in early ripening cherries. The increase in juice loss in the period from 30–90 days of storage was significant and was within the limits of stationary error. As a result of the analysis of the experimental studies, it was established that among the researched cherry cultivars the minimum loss of cell juice after freezing and three-month storage was observed in Melitopolska Purpurna cultivar, and maximum in Vstrecha cultivar. Therefore, the amount of loss of cell juice during defrosting is an important criterion for assessing the structural integrity of fruits, which affects the quality of frozen semi-finished products.

2.4 Dynamics of dry matter content in cherry fruits during freezing and further storage

The study of the changes in the content of dry substances during freezing and further storage of fruits is important for the production of semi-finished products. According to the available literature, the numerical values of this indicator and its changes affect the qualitative characteristics of the finished product. Taking into account the opinions of scientists regarding the determination of the quality of semi-finished products based on the initial parameters of dry substances, the study of their content in fresh fruit is of great importance. Such research is also important at the stages of storage and for the scientific substantiation of the choice of raw material for the production of semi-finished products. As a research result, it was found that the minimum accumulation of dry substances was observed in dry cherry fruits of Ekspromt cultivar – 16.48% (**Table 2.2**).

The fruits of Griot Melitopolskiy cultivar were characterized by the highest dry matter content of 20.63% (LSD_{05} = 0.50). The preservation of dry substances in cherry fruits immediately after freezing was 70.4–95.8% of their content in fresh fruits. The highest content of dry soluble substances in fresh-frozen fruits was noted in Griot Melitipolskiy cultivar (19.37%). Frozen cherry fruits of Griot Melitopolskiy cultivar both before and after 90 days of storage were characterized by a stable minimum content of dry substances at the level of 19.09–20.63%. The content of this indicator after freezing and at all stages of storage remained stable, and minor changes were statistically unreliable (LSD_{05} = 0.15–1.57%). So, based on the analysis of the experimental data, it can be concluded that the main losses of dry substances, regardless of the varietal characteristics of the fruits, occur at the stage of freezing. Therefore, for the scientific justification of the suitability of the cherry fruit cultivars for freezing and semi-finished products production, it is possible to use the range of data for this stage of control.

Table 2.2 Dynamics of dry substances content in frozen cherry fruits (average for 2007–2019), %

Cultivar	Stages of control				LSD_{05}
	fresh fruits	after freezing	30 days of storage	90 days of storage	
Vstrecha	17.87 ± 2.81	13.21 ± 0.55	13.06 ± 0.40	12.87 ± 0.38	1.58
Ozhydanie	18.31 ± 2.02	16.54 ± 0.20	16.13 ± 0.13	16.02 ± 0.18	0.48
Shalunia	17.94 ± 2.70	16.83 ± 0.30	16.87 ± 0.18	16.68 ± 0.29	0.42
Siyanets Turovtsevoi	19.02 ± 3.53	17.75 ± 0.21	17.45 ± 0.11	17.23 ± 0.07	0.31
Griot Melitopolskyi	20.63 ± 3.31	19.37 ± 0.08	19.14 ± 0.13	19.09 ± 0.11	0.32
Melitopolska Purpurna	17.79 ± 2.81	16.88 ± 0.05	17.08 ± 0.08	17.02 ± 0.07	0.15
Modnytsia	19.05 ± 2.92	17.83 ± 0.09	17.54 ± 0.05	17.24 ± 0.15	0.19
Expromt	16.48 ± 2.53	15.92 ± 0.05	15.02 ± 0.30	15.21 ± 0.11	0.52
Solidarnist	17.03 ± 3.63	15.08 ± 0.11	15.28 ± 0.11	15.37 ± 0.10	0.37
Igrushka	18.58 ± 2.80	15.13 ± 0.08	15.13 ± 0.09	15.04 ± 0.11	0.35
Average value	18.27 ± 3.00	16.45 ± 0.24	16.26 ± 0.24	16.18 ± 0.23	–
LSD_{05}	0.59	0.67	0.52	0.53	–

2.5 Dynamics of sugars content in cherry fruits during freezing and further storage

Sugars and organic acids are the most important dry substances that directly affect the quality of candied fruit. The content of sugars determines the intensity of dehydration process, the osmotic pressure, as well as the taste properties of the final product. Organic acids, in turn, form a sugar-acid balance and ensure the preservation of fruit texture [19]. From this point of view, the study of changes in the content of these components of the chemical composition during freezing and further storage is of particular importance for the scientific justification of the choice of the raw material for the production of semi-finished products.

In fresh cherry fruits the minimum accumulation of sugars was recorded in the fruits of Ekspromt and Solidarnist cultivars – 10.4 and 10.7% respectively (**Table 2.3**).

Table 2.3 Dynamics of sugars content in frozen cherry fruits (average for 2007–2019), %

Cultivar	Stages of control				LSD_{05}
	fresh fruits	after freezing	30 days of storage	90 days of storage	
Vstrecha	10.80 ± 1.51	8.4 ± 0.53	8.1 ± 0.24	8.0 ± 0.15	1.03
Ozhydanie	11.69 ± 1.90	10.2 ± 0.16	10.1 ± 0.11	10.1 ± 0.17	0.45
Shalunia	10.84 ± 1.92	9.1 ± 0.13	8.9 ± 0.14	8.8 ± 0.14	0.41
Siyanets Turovtsevoi	11.55 ± 2.43	10.3 ± 0.10	10.6 ± 0.09	10.2 ± 0.19	0.39
Griot Melitopolskyi	12.19 ± 2.51	11.0 ± 0.37	10.9 ± 0.48	10.9 ± 0.13	0.99
Melitopolska Purpurna	11.33 ± 2.20	10.4 ± 0.06	10.1 ± 0.09	10.0 ± 0.07	0.26
Modnytsia	11.73 ± 2.84	10.8 ± 0.08	10.5 ± 0.07	10.4 ± 0.09	0.17
Expromt	10.35 ± 1.73	9.3 ± 0.05	9.2 ± 0.06	9.2 ± 0.09	0.29
Solidarnist	10.70 ± 2.72	7.9 ± 0.13	7.8 ± 0.07	7.8 ± 0.10	0.42
Igrushka	11.59 ± 2.21	10.2 ± 0.07	10.0 ± 0.10	10.0 ± 0.09	0.27
Average value	11.28 ± 2.20	9.9 ± 0.15	9.6 ± 0.16	9.5 ± 0.15	–
LSD_{05}	0.50	0.65	0.55	0.39	–

Fruits of Ozhydalie, Solidarnist, Modnytsia, Shalunia, Siyanets Turevtsovoy cultivars were characterized by a high sugar content (11.6–11.8%, LSD_{05} = 0.50). The maximum sugar content in cherry fruits was recorded in Griot Melitopolskiy cultivar – 12.2%. The freezing process is accompanied by statistically significant decrease in sugars content in the fruits regardless of the cultivar and ripening period. The percentage of sugars retention in cherry fruits varied from 90.2 to 92.3% in Griot Melitopolskiy, Modnytsia, Melitopolska Purpurn cultivars. The lowest preservation of sugars (73.8%) was found in the fruits of Solidarnist cultivar. The decrease in sugars content was observed during storage for 30 and 90 days, but these changes were statistically unreliable. So, on the basis of the analysis of the experimental data, it can be concluded that the main losses of sugars, regardless of the varietal characteristics of the fruits, occur at the stage of freezing. Therefore, for the scientific justification of the suitability of the cherry fruit cultivars for freezing and semi-finished products production, it is possible to use the data range for this stage of control.

2.6 Dynamics of titrated acids content in cherry fruits during freezing and further storage

The share of organic acids in the composition of dry soluble substances of fruits is insignificant. It was established that the main part of the organic acids in fruits is neutralized. It is presented in the form of neutral salts, which do not have the properties of titrated acids. It is the presence of titrated acids (free acids and their acidic and medium salts) that determines the taste of fruits. The average content of titrated acids in fresh cherry fruits is 1.51% (**Table 2.4**).

Table 2.4 Dynamics of titrated acids content in frozen cherry fruits (average for 2007–2019), %

Cultivar	Stages of control				LSD_{05}
	fresh fruits	after freezing	30 days of storage	90 days of storage	
Vstrecha	1.45 ± 0.38	1.27 ± 0.019	1.25 ± 0.01	1.25 ± 0.01	0.07
Ozhydanie	1.51 ± 0.31	1.39 ± 0.013	1.35 ± 0.01	1.33 ± 0.01	0.02
Shalunia	1.49 ± 0.34	1.40 ± 0.032	1.40 ± 0.07	1.39 ± 0.01	0.13
Siyanets Turovtsevoi	1.62 ± 0.30	1.57 ± 0.007	1.55 ± 0.01	1.53 ± 0.01	0.04
Griot Melitopolskyi	1.65 ± 0.31	1.61 ± 0.01	1.62 ± 0.01	1.61 ± 0.01	0.03
Melitopolska Purpurna	1.26 ± 0.31	1.19 ± 0.01	1.17 ± 0.01	1.19 ± 0.01	0.02
Modnytsia	1.26 ± 0.26	1.21 ± 0.01	1.20 ± 0.03	1.20 ± 0.03	0.07
Expromt	1.40 ± 0.22	1.29 ± 0.01	1.27 ± 0.06	1.30 ± 0.01	0.19
Solidarnist	1.79 ± 0.26	1.65 ± 0.01	1.62 ± 0.01	1.70 ± 0.07	0.12
Igrushka	1.65 ± 0.30	1.60 ± 0.07	1.60 ± 0.03	1.60 ± 0.05	0.14
Average value	1.51 ± 0.33	1.42 ± 0.02	1.41 ± 0.02	1.41 ± 0.02	–
LSD_{05}	0.26	0.08	0.10	0.11	–

As a result of the study of fresh cherry fruits quality, it was established that the minimum accumulation of the titrated acids content (1.26%) was observed in

Melitopolska Purpurna and Modnytsia cultivars (LSD_{05} = 0.26%). The maximum content of titrated acids was recorded in Solidarnist cultivar – 1.79%. In general, the content of titrated acids in fresh and frozen fruits showed high stability, regardless of the cultivar and ripening period. The preservation of titrated acids of cherry fruits at the stage immediately after freezing was 87.6–100% of their content in fresh fruits. In cherry cultivar samples after 90 days of storage, the retention of titrated acids relative to freshly frozen fruits was 95.7–100%. A slight increase in the content of titrated acids in the range of 0.03–0.8% was recorded in the Ekspromt and Solidarnist cultivars. The phenomenon of titrated acids stabilization was observed both at the stage of freezing and during a long-term low-temperature storage. Scientists explain this by the fact that the replenishment of acid forms, which were destroyed under the influence of low temperatures in the fruits of cherries and sweet cherries, occurs due to the breakdown of sugars. As a result of the study of cherry fruits suitability for storage according to the content of titrated acids for 90 days, it was established that among the frozen cultivar samples, the highest content was recorded in Griot Melitopolskiy (0.61%) and Solidarnist (0.71%, LSD_{05} = 0.11%). Based on the analysis of the experimental data, it can be concluded that the preservation of titrated acids in fresh and frozen cherry fruits has high stability. Fluctuations in the content of titrated acids in cherry fruits for all cultivars are statistically unreliable. Therefore, as a criterion indicator for scientific justification of the suitability of cherry fruit cultivars for freezing and semi-finished products production, the range data at the stage of control (immediately after freezing) will be used.

2.7 Dynamics of ascorbic acid content in fresh cherry fruits during freezing and further storage

Vitamin C or L-ascorbic acid, is one of the most important phyto-nutrients that determines the biological value of cherry and sweet cherry fruits. Modern technologies of refrigeration processing of plant products are evaluated by the quantitative changes in the content of vitamins in the fruit, in particular, such a labile component as ascorbic acid. The average content of ascorbic acid in fresh cherry samples was 9.17 mg/100 g (**Table 2.5**).

The minimum content of ascorbic acid in fresh cherry fruits was recorded in Griot Melitopolskiy cultivar (8.23 mg/100 g), and the maximum (10.44 mg/100 g) in the fruits of Shalunia cultivar (LSD_{05} = 0.77 mg/100 g). The freezing process was accompanied by a statistically significant decrease in the content of ascorbic acid in the fruits of the studied cultivars. Immediately after freezing, the highest preservation of ascorbic acid of 43.92% was observed in the cherry fruits samples of Solidarnist cultivar (4.01 mg/100 g), and the lowest preservation of 24.91% was observed in the fruits of Igrushka cultivar (2.18 mg/100 g). The preservation of ascorbic acid after 90 days of storage, compared to losses after freezing, varied in the range of 97.26–99.67%. The highest content of ascorbic acid was recorded in the fruits of Solidarnist cultivar (3.90 mg/100 g). Based on the analysis of the experimental data, it can be concluded that the main losses of ascorbic acid, regardless of the varietal characteristics of the fruit, occur at the stage of freezing. Therefore, as a criterion indicator for the scientific substantiation of the suitability of cherry cultivars for freezing and semi-finished products production the data of this stage of control will be used.

Table 2.5 Dynamics of ascorbic acid content in frozen cherry fruits (average for 2007–2019), %

Cultivar	Stages of control				LSD_{05}
	fresh fruits	after freezing	30 days of storage	90 days of storage	
Vstrecha	9.59 ± 1.34	2.89 ± 0.023	2.82 ± 0.01	2.84 ± 0.01	0.02
Ozhydanie	8.97 ± 1.68	2.34 ± 0.01	2.14 ± 0.01	2.20 ± 0.01	0.03
Shalunia	10.44 ± 2.11	3.56 ± 0.014	3.43 ± 0.01	3.48 ± 0.01	0.04
Siyanets Turovtsevoi	10.10 ± 2.29	3.67 ± 0.02	3.61 ± 0.01	3.61 ± 0.01	0.05
Griot Melitopolskyi	8.23 ± 1.28	2.45 ± 0.01	2.43 ± 0.01	2.44 ± 0.012	0.03
Melitopolska Purpurna	8.44 ± 1.20	3.01 ± 0.01	3.00 ± 0.01	3.00 ± 0.01	0.04
Modnytsia	9.00 ± 1.65	3.02 ± 0.02	2.91 ± 0.21	2.99 ± 0.01	0.34
Expromt	9.00 ± 2.18	2.65 ± 0.01	2.61 ± 0.01	2.59 ± 0.01	0.02
Solidarnist	9.13 ± 1.67	4.01 ± 0.03	3.89 ± 0.04	3.90 ± 0.05	0.04
Igrushka	8.75 ± 1.21	2.18 ± 0.0	2.16 ± 0.01	2.17 ± 0.01	0.03
Average value	9.17 ± 1.77	2.99 ± 0.08	2.90 ± 0.09	2.92 ± 0.08	–
LSD_{05}	0.77	0.06	0.21	0.06	–

2.8 Dynamics of the amount of phenolic compounds in cherry fruits during freezing and further storage

The Ukrainian scientists have discovered 20 phenolic compounds in cherry fruits of various cultivars. In the plant world, phenolic compounds are natural antioxidants that can oxidize vitamin C, which, in turn, stabilizes the action of bioflavonoids. The biochemical synergism of natural antioxidants is one of the factors that ensures the preservation of the quality of fruit raw materials for a long period. In view of this, it is advisable to assess the quality of cherry cultivars for their suitability for freezing by quantitative changes in phenolic compounds and the degree of their preservation.

The research has established that the content of phenolic compounds in fresh cherry fruits ranged from a minimum of 164.97 mg/100 g in Ekspromt cultivar to a maximum of 243.14 mg/100 g in Melitopolska Purpurna cultivar (**Table 2.6**).

Table 2.6 Dynamics of the sum of phenolic compounds in frozen cherry fruits (average for 2007–2019), mg/100 g

Cultivar	Stages of control				LSD_{05}
	fresh fruits	after freezing	30 days of storage	90 days of storage	
Vstrecha	198.725 ± 28.801	78.36 ± 0.046	72.81 ± 0.011	72.80 ± 0.014	0.076
Ozhydanie	218.823 ± 39.213	85.17 ± 0.019	81.23 ± 0.015	82.67 ± 0.039	0.069
Shalunia	197.487 ± 22.458	89.24 ± 0.018	82.15 ± 0.019	86.14 ± 0.014	0.235
Siyanets Turovtsevoi	224.615 ± 28.776	95.15 ± 0.019	90.36 ± 0.024	94.81 ± 0.018	0.055
Griot Melitopolskyi	193.264 ± 25.662	81.13 ± 0.005	80.99 ± 0.006	81.01 ± 0.14	0.086
Melitopolska Purpurna	243.143 ± 45.721	89.76 ± 0.023	84.12 ± 0.033	83.99 ± 0.048	0.083
Modnytsia	168.275 ± 19.512	83.43 ± 0.013	82.15 ± 0.013	82.29 ± 0.015	0.068
Expromt	164.975 ± 20.670	65.17 ± 0.024	60.35 ± 0.013	60.00 ± 0.148	0.227
Solidarnist	196.584 ± 24.147	70.65 ± 0.012	70.29 ± 0.019	71.01 ± 0.034	0.116
Igrushka	185.474 ± 18.383	80.89 ± 0.036	80.6 ± 0.01	81.02 ± 0.037	0.091
Average value	199.137 ± 36.016	81.90 ± 1.21	78.512 ± 1.15	79.57 ± 1.29	–
LSD_{05}	1.778	0.063	0.048	0.215	–

The highest content of phenolic compounds (224.61 mg/100 g) was recorded in the fruits of Siyanets Turovtsevoi cultivar (LSD_{05} = 0.05 mg/100 g). The freezing process was accompanied by a statistically significant decrease in the content of phenolic substances in cherry fruits, regardless of the ripening period. The preservation of this quality indicator after 90 days of storage ranged from 92.07 to 99.64% compared to the loss of phenolics substances immediately after freezing. At the last stage of storage, the largest amount of phenolic substances was observed in the fruits of Siyanets Turovtsevoi cultivar (94.81 mg/100 g), and the lowest – in Ekspromt cultivar (60.00 mg/100 g, LSD_{05} = 0.21 mg/100 g). After three months of storage during defrosting, an increase in the amount of phenolic compounds in the range of 0.16–0.50% was recorded in cherry fruits of two cultivars. In the frozen fruits of Igrushka and Solidarnist cultivars, an increase in the content of phenolic compounds by 0.13–0.36 mg/100 g was observed compared to the indicator immediately after freezing (LSD_{05} = 0.09–0.11 mg/100 g). This is due to the breakdown of complex complexes of substances, which include BAS of phenolic nature. Based on the analysis of the experimental data, it can be concluded that the main losses of phenolic substances, regardless of the varietal characteristics of the fruits, occur at the stage of freezing. Therefore, as a criterion indicator for the scientific substantiation of the suitability of cherry fruit cultivars for freezing and semi-finished products production, the data range of this stage of control will be used.

2.9 Sensory evaluation of cherry fruits under freezing and further storage

Sensory evaluation of fresh and frozen cherry fruits ranged from 7.7 to 8.7 points (**Table 2.7**).

Table 2.7 Sensory evaluation of frozen cherry fruits, average for 2007–2019

Cultivar	Stages of control				LSD_{05}
	fresh fruits	after freezing	30 days of storage	90 days of storage	
Vstrecha	8.5 ± 0.05	8.1 ± 0.07	8.1 ± 0.04	8.1 ± 0.03	0.171
Ozhydanie	8.6 ± 0.05	8.0 ± 0.03	8.0 ± 0.03	8.0 ± 0.05	0.135
Shalunia	8.5 ± 0.04	8.2 ± 0.06	8.2 ± 0.07	7.9 ± 0.03	0.129
Siyanets Turovtsevoi	8.5 ± 0.03	7.9 ± 0.1	7.9 ± 0.03	7.8 ± 0.04	0.186
Griot Melitopolskyi	8.7 ± 0.06	8.0 ± 0.03	8.0 ± 0.04	8.0 ± 0.03	0.178
Melitopolska Purpurna	8.6 ± 0.03	7.9 ± 0.1	7.9 ± 0.03	7.9 ± 0.05	0.176
Modnytsia	8.7 ± 0.03	7.8 ± 0.05	7.8 ± 0.04	7.8 ± 0.05	0.101
Expromt	8.5 ± 0.03	7.7 ± 0.05	7.7 ± 0.03	7.7 ± 0.05	0.101
Solidarnist	8.4 ± 0.04	8.0 ± 0.03	8.0 ± 0.03	7.9 ± 0.03	0.097
Igrushka	8.6 ± 0.03	8.1 ± 0.03	8.1 ± 0.04	8.1 ± 0.08	0.146
Average value	8.6 ± 0.04	8.0 ± 0.03	7.9 ± 0.02	7.92 ± 0.02	–
LSD_{05}	0.104	0.182	0.126	0.134	–

Fresh fruits of Griot Melitopolskiy and Modnytsia cultivars received the highest score of 8.7 points (LSD_{05} = 0.10 points). The lowest sensory indicators were recorded for the fruits of Solidarnist cultivar, 8.4 points. The analysis of the sensory characteristics of freshly frozen fruits showed that Shalunia cultivar fruits were the best immediately after freezing – 8.2 points, the fruits of Igrushka and Meeting cultivars – 8.1 points ($LSD_{05} = 0.18$). Immediately after freezing to the final stage of storage, comparable sensory fruit evaluation was obtained. After three months of storage, the fruits of Vstrecha and Igrushka cultivars retained the highest sensory parameters – 8.1 points. Based on the analysis of the experimental data, it can be concluded that the main losses in the quality of the sensory properties of fruit, depending on the varietal characteristics of fruits, occur at the stage of freezing. Therefore, for the scientific substantiation of the suitability of cherry fruit cultivars for freezing and semi-finished products production, the data range of this stage of control will be the criterion indicator.

2.10 Analysis of the results of determining the suitability of cherry fruit cultivars for freezing and semi-finished products production by the method of multi-criteria optimization

Functional, technological and sensory indicators of the quality of frozen cherry semi-finished products in absolute values are given in **Table 2.8**.

For the scientific substantiation of the choice of cherry fruit cultivars for freezing and semi-finished products production, calculations were carried out according to the developed algorithm. The rank rating of the fruits of cherry cultivars (**Table 2.9**) shows that the values of the target functions were in the range from $\varphi(x_5) = 1.45$ (Griot Melitopolskiy) to $\varphi(x_8) = 4.20$ (Ekspromt).

The highest tenth rank and the least suitability of fruits for candied fruit production from frozen raw materials were determined in Ekspromt cultivar. Frozen fruits of Vstrecha, Solidarnist, Modnytsa, Igrushka, Shalunia, Ozhydanie, Melitopolska Purpurna, Siyanets Turovtsevoi cultivars had 2–8 ranks according to criterion indicators of fruit quality in terms of their suitability for freezing. The values of the target functions in the listed cultivars ranged from $\varphi(x_1) = 3.30$ to $\varphi(x_4) = 1.71$. Therefore, the performed calculations allow to draw a conclusion about the different degrees of cherry cultivars suitability for freezing and semi-finished products production, which is an important stage in choosing the optimal fruit for further production. As a result of qualitative analysis of frozen cherry fruits, it was established that Griot Melitopolskiy cultivar (1^{st} rank) – $j(x_5) = 1.45$ turned out to be the best in terms of the balance of quality indicators. The optimal set of physico-biochemical and organoleptic criteria for cherry fruits included: juice loss immediately after freezing no higher than 4.2%; initial concentration of dry soluble substances – 18.60%; sugars –12.20%; titrated acids – 1.65%; vitamin C – 8.23 mg/100 g; the sum of phenolic compounds – 193.264 mg/100 g; sensory evaluation – 8.7 points.

Table 2.8 Functional and technological indicators of cherry fruits for the calculation of target functions $\varphi(x_1)\ldots\varphi(x_{10})$ when choosing the optimal cultivar of frozen cherry fruits

Alternatives, X_i	Cultivar	Criteria, A_j							Values of target functions, $\varphi(x_i)$	Rank
		The amount of juice loss (%), A_1	Dry soluble substances (%), A_2	Sugars, (V, %), A_3	Titrated acids, (%), A_4	Phenolic substances, (mg/100 g), A_5	Vitamin C, (mg/100 g), A_6	Sensory evaluation, (points), A_7		
		f_1	f_2	f_3	f_4	f_5	f_6	f_7		
X_1	Vstrecha	7.1	15.9	10.8	1.45	198.725	9.59	8.5	3.30	9
X_2	Ozhydanie	6.2	16.3	11.7	1.51	218.82	8.97	8.6	2.41	4
X_3	Shalunia	5.7	15.9	10.8	1.49	197.487	10.44	8.5	2.62	5
X_4	Siyanets Turovtsevoi	5.9	17	11.6	1.62	224.615	10.1	8.5	1.71	2
X_5	Griot Melitopolskyi	4.2	18.6	12.2	1.65	193.264	8.23	8.7	1.45	1
X_6	Melitopolska Purpurna	4.1	15.8	11.3	1.26	243.143	8.44	8.6	2.37	3
X_7	Modnytsia	4.6	17.1	11.7	1.26	168.275	9	8.7	2.75	7
X_8	Expromt	6.2	14.5	10.4	1.4	164.975	9	8.5	4.20	10
X_9	Solidarnist	6.8	15	10.7	1.79	196.584	9.13	8.4	3.18	8
X_{10}	Igrushka	6.1	16.6	11.6	1.65	185.474	8.75	8.6	2.62	6

Table 2.9 Results of determination of the objective functions $\varphi(x_1)...\varphi(x_{10})$ when choosing the optimal cultivar of frozen cherry fruits

Alternatives, X_i	Cultivar	Criteria, A_j: The amount of juice loss (%), A_1	Dry soluble substances (%), A_2	Sugars, (V, %), A_3	Titrated acids, (%), A_4	Phenolic substances, (mg/100 g), A_5	Vitamin C, (mg/100 g), A_6	Sensory evaluation, (points), A_7	Values of target functions, $\varphi(x_i)$	Rank
		$\widehat{f}_1$	$\widehat{f}_2$	$\widehat{f}_3$	$\widehat{f}_4$	$\widehat{f}_5$	$\widehat{f}_6$	$\widehat{f}_7$		
X_1	Vstrecha	0.13	0.30	0.32	0.38	0.43	0.58	0.55	3.30	9
X_2	Ozhydanie	0.37	0.39	0.64	0.48	0.69	0.39	0.64	2.41	4
X_3	Shalunia	0.50	0.30	0.32	0.44	0.42	0.84	0.55	2.62	5
X_4	Siyanets Turovtsevoi	0.45	0.54	0.61	0.65	0.76	0.74	0.55	1.71	2
X_5	Griot Melitopolskyi	0.89	0.89	0.82	0.70	0.36	0.16	0.73	1.45	1
X_6	Melitopolska Purpurna	0.92	0.28	0.50	0.08	0.99	0.22	0.64	2.37	3
X_7	Modnytsia	0.79	0.57	0.64	0.08	0.05	0.40	0.73	2.75	7
X_8	Expromt	0.37	0.00	0.18	0.30	0.01	0.40	0.55	4.20	10
X_9	Solidarnist	0.21	0.11	0.29	0.92	0.41	0.44	0.45	3.18	8
X_{10}	Igrushka	0.39	0.46	0.61	0.70	0.27	0.32	0.64	2.62	6
	f_j^-	3.8	14.50	9.90	1.21	164.48	7.73	7.90	–	–
	f_j^+	7.6	19.10	12.70	1.84	243.64	10.94	9.00	–	–
	f_j^{opt}	7.1 (max)	19.1 (max)	12.7 (max)	1.84 (max)	243.64 (max)	10.94 (max)	9.0 (min)	–	–

2.11 Conclusions

The analysis of the quality of cherry fruits in terms of functional, technological and sensory parameters in fresh and frozen state made it possible to determine the optimal storage period of cherry fruits for the production of high-quality semi-finished products.

It was established that the main losses in the quality of raw materials, depending on the varietal characteristics of fruits, occur at the stage of freezing. Therefore, it is advisable to use the data range of this stage as a criterion indicator for the scientific substantiation of cherry cultivars suitability for freezing and semi-finished products production.

The method of multi-criteria optimization made it possible to rank the fruits of different cherry cultivars according to all indicators and to select the cherry fruits of Griot Melitopolskiy cultivar as the most suitable for freezing and semi-finished products production according to a complex of physical, biochemical and organoleptic characteristics.

Based on the results of multi-criteria optimization, a complex of physical, biochemical and organoleptic characteristics was developed, as well as their values, which will serve as markers when assessing the varietal suitability of cherry fruits for freezing and further use and semi-finished products production.

Proposed method of multi-criteria optimization of cherry cultivars based on a complex of functional, technological and sensory indicators, based on the method of geometric convolution of criteria, allows to ensure the objectivity of the assessment and contributes to an effective decision-making when choosing the best cultivar for freezing. This, in turn, helps to optimize the process of choosing the cherry fruits cultivars further use and semi-finished products production.

Further research in the direction of multi-criteria cherry cultivars optimization can be aimed at adapting the method of geometric convolution of criteria to different areas of production. It is also important to expand the criteria for evaluating the quality of cherries, which affect the final indicators of products. Future work may include the development of integrated models that combine sensory analysis data with the results of laboratory studies to create more accurate forecasts of the quality of frozen raw materials. This will make it possible to optimize the processes of choosing cherry fruit cultivars for freezing and semi-finished products production, taking into account modern requirements for the food products quality and safety.

References

1. Priss, O., Pugachov, M., Pugachov, V., Yaremko, I., Shchabelska, V. (2023). The development of the world economy and the impact of the global food crisis

2022-2023. Economic Affairs, 68 (1s), 35–42. https://doi.org/10.46852/0424-2513.1s.2023.5

2. Michel, M., Eldridge, A. L., Hartmann, C., Klassen, P., Ingram, J., Meijer, G. W. (2024). Benefits and challenges of food processing in the context of food systems, value chains and sustainable development goals. Trends in Food Science & Technology, 153, 104703. https://doi.org/10.1016/j.tifs.2024.104703
3. Hutsol, T., Priss, O., Ivanova, I., Serdyuk, M., Cupiał, M., Tymoshchuk, T. et al. (2024). Effectiveness of cooling methods in reducing losses during cherry storage. Agricultural Engineering, 28 (1), 321–340. https://doi.org/10.2478/agriceng-2024-0020
4. Kocabıyık, B., Alkan, D. (2025). Effect of the production of dried fruit and fruit chips on chemical, sensory and bioactive properties. Exploration of Foods and Foodomics, 3. https://doi.org/10.37349/eff.2025.101077
5. Ziv, C., Fallik, E. (2021). Postharvest storage techniques and quality evaluation of fruits and vegetables for reducing food loss. Agronomy, 11 (6), 1133. https://doi.org/10.3390/agronomy11061133
6. Wenzel, P. M., Mühlen, M., Radgen, P. (2023). Free cooling for saving energy: technical market analysis of dry, wet, and hybrid cooling based on manufacturer data. Energies, 16 (9), 3661. https://doi.org/10.3390/en16093661
7. Znachek, R., Stateva, M., Mardar, M., Cherevata, T. (2017). Marketing environment analysis and competitiveness assessment of new products of high nutritional value. International Scientific Journal "Internauka". Series: "Economic Sciences", 8 (40). https://doi.org/10.25313/2520-2294-2020-8-6237
8. Prichko, T., Droficheva, N. (2021). The influence of varietal characteristics on the quality indicators of candied fruits from plum fruits. Potravinarstvo Slovak Journal of Food Sciences, 15, 891–900. https://doi.org/10.5219/1597
9. Zhao, H., Shu, C., Fan, X., Cao, J., Jiang, W. (2018). Near-freezing temperature storage prolongs storage period and improves quality and antioxidant capacity of nectarines. Scientia Horticulturae, 228, 196–203. https://doi.org/10.1016/j.scienta.2017.10.032
10. Ivanova, I., Tymoshchuk, T., Kravchuk, M., Ishchenko, I., Kryvenko, A. (2023). Sensory evaluation of sweet cherries for sustainable fruit production in the European market. Scientific Horizons, 26 (10), 93–106. https://doi.org/10.48077/scihor10.2023.93
11. Vasylyshina, O., Postolenko, Y. (2019). Influence of variety characteristics on the quality of frozen cherry fruit. Scientific Horizons, 2 (75), 44–49. https://doi.org/10.33249/2663-2144-2019-75-2-44-49
12. Sokół-Łętowska, A., Kucharska, A. Z., Hodun, G., Gołba, M. (2020). Chemical composition of 21 cultivars of sour cherry (prunus cerasus) fruit cultivated in Poland. Molecules, 25 (19), 4587. https://doi.org/10.3390/molecules25194587

13. Viljevac Vuletić, M, Dugalić, K., Mihaljević, I., Tomaš, V., Vuković, D., Zdunić, Z. et al. (2017). Season, location and cultivar influence on bioactive compounds of sour cherry fruits. Plant, Soil and Environment, 63 (9), 389–395. https://doi.org/10.17221/472/2017-pse
14. Vasylyshyna, O. (2019). Application of multicriteria optimization method to select the best varieties of frozen cherry fruit. Scientific Horizons, 80 (7), 70–74. https://doi.org/10.33249/2663-2144-2019-80-7-70-74
15. Aulin, V., Rogovskii, I., Lyashuk, O., Titova, L., Hrynkiv, A., Mironov, D. et al. (2024). Comprehensive assessment of technical condition of vehicles during operation based on Harrington's desirability function. Eastern-European Journal of Enterprise Technologies, 1 (3 (127)), 37–46. https://doi.org/10.15587/1729-4061.2024.298567
16. Vasylyshyna, O. V. (2020). Optimization effectiveness of freezing of cherry fruits the Harrington method. Bulletin of Uman National University of Horticulture, 1, 85–89. https://doi.org/10.31395/2310-0478-2020-1-85-89
17. Vural, N., Algan-Cavuldak, Ö., Akay, M. A. (2024). Desirability function approach for the optimization of hydroalcoholic solvent extraction conditions for antioxidant compounds from olive leaves. Anais Da Academia Brasileira de Ciências, 96 (1). https://doi.org/10.1590/0001-3765202420230602
18. Ivanova, I., Kryvonos, I., Shleina, L., Taranenko, G., Gerasko, T. (2019). Multicriteria optimization of quality indicators of sweet cherry fruits of Ukrainian selection during freezing and storage. Modern Development Paths of Agricultural Production. Cham: Springer, 707–717. https://doi.org/10.1007/978-3-030-14918-5_69
19. Corneanu, M., Iurea, E., Sîrbu, S. (2020). Biological properties and fruit quality of sweet cherry (Prunus avium L.) cultivars from Romanian assortment. Agronomy Research, 18 (4), 2353–2364. https://doi.org/10.15159/AR.20.231