OPEN ACCESS
Potravinarstvo Slovak Journal of Food Sciences
Crossref Similarity Check

potravinárstvo®
Slovak Journal of Food Sciences

Received: 25.7.2022
Revised: 17.8.2022
Accepted: 31.8.2022
Published: 14.9.2022

Potravinarstvo Slovak Journal of Food Sciences
vol. 16, 2022, p. 622-635
https://doi.org/10.5219/1785
ISSN: 1337-0960 online
www.potravinarstvo.com

Development of a scientific concept of industrial storage systems for environmentally safe apples

Albina Alekseevna Varivoda, Elena Valentinovna Svetlakova, Irina Vladimirovna Ziruk, Inna Sergeevna Kirichenko, Olga Yurievna Kolosova, Sergey Nikolaevich Povetkin, Bogdan Olegovich Ivakhnenko

ABSTRACT
The research project has developed and justified the storage modes of apples in a modified gas environment by creating an isolated "closed loop" of high-pressure polyethylene; the expediency of creating highly efficient technologies for storing fresh fruits in a controlled atmosphere, in bioactive bactericidal packages and by creating microfilm on the surface of fruits has been confirmed. The prospects of using a progressive method of storing fruits in a modified gas atmosphere by creating an isolated "closed circuit" in a separate refrigerating chamber without using expensive equipment (in normal and subnormal gas environments) are proved. New technologies have been developed for storing apple fruits susceptible to infectious and physiological diseases based on improved storage methods with minimal losses. The consumption rates of *Phytosporin-M* for the surface treatment of fruits were determined and optimized to control the intensity of biochemical and microbiological processes during storage. The modes and technologies of post-harvest fruit processing with the *Phytosporin-M* biopreparation have been substantiated.

Keywords: apple, storage, gas environment, closed loop, bioactive coatings, bactericidal packaging

INTRODUCTION
A significant part of the grown fruit products is lost during storage. For some types, these losses often reach 30% and sometimes 50% **[1]**, **[2]**. Therefore, developing highly efficient storage technologies is an urgent task today **[3]**, **[4]**, **[5]**, **[6]**. All methods of storing fruits in a modified gas atmosphere can be classified according to the type of medium used, the method of management, methods of creating the medium, etc. **[7]**, **[8]**. The history of developing methods for storing fruit and vegetable products shows that atmospheric air and its components are used in most cases. Storage in artificially created gases (for example, ozone) has not found wide application in practice due to their high cost or low efficiency (for fruits) **[9]**, **[10]**, **[11]**.
Based on the gas composition of atmospheric air and depending on the type of environment created on its basis, we conducted research on the storage of fruits and vegetables:
- in a controlled atmosphere (CA);
- in bioactive bactericidal packaging;
- with a surface coating of fruits with biologically active preparations.

The advantages of storing fruit products in a controlled atmosphere (CA) are well known. However, such storage does not replace storage in the refrigerator (its temperature is usually 3 – 5 °C higher than in the refrigerator). The storage of fruit products in the CA slows down the processes of maturation and overripe, as a result of which its shelf life is lengthened, the quality and yield of marketable products are increased, immunity is preserved, microbial spoilage and physiological damage are reduced **[12]**, **[13]**, **[14]**. Biological oxidation (respiratory gas exchange or respiratory activity) is at the center of physiological and biochemical processes during fruit ripening. All physiological and biochemical changes in fruit products are made due to the energy released during breathing **[15]**, **[16]**, **[17]**.

In plant cells, cytochrome oxidase, polyphenol oxidase, ascorbate oxidase and flavin enzymes can perform the functions of O_2 activators at the final stages of respiration. With a change in the concentration of O_2 and CO_2, the proportion of participation of individual oxidases in the respiration process changes. At very low concentrations of O_2, cytochrome oxidase and peroxidase activity increases sharply, and the activity of flavoprotein enzymes decreases. The middle position is occupied by polyphenol oxidase and ascorbate oxidase. High concentrations of CO_2 (7 – 10%) block respiration due to a sharp decrease in carboxylase, cytochrome oxidase, pyruvate dehydrogenase, etc., and also disrupt many other processes of fruit metabolism **[18]**, **[19]**, **[20]**. The composition of the gaseous medium (CO_2 and O_2) and temperature are important factors regulating the rate of biological oxidation in plant cells. Therefore, data on the effect of individual components of the gaseous medium on the rate of fetal respiration are of particular interest **[21]**, **[22]**. The transition of one phase of development (maturation) to another (overripe) is characterized by a change in the predominance of certain enzymatic systems that catalyze this process during respiration **[23]**, **[24]**, **[25]**, **[26]**.

Therefore, developing a method for storing fruits in a modified gas atmosphere is promising and relevant by creating an isolated "closed loop" and a system for reducing fruit losses based on complex post-harvest treatments with biologically active preparations.

Scientific Hypothesis

Creating an isolated "closed loop" and carrying out complex post-harvest treatments of apples with biologically active preparations can ensure a reduction in fruit losses during storage.

MATERIAL AND METHODOLOGY

Samples

The samples were the fruits of promising varieties of domestic and foreign breeding, grown in the soil-climatic conditions of the Krasnodar Territory (Russia): Jonathan, Reinette Simirenko, Idared and Korey.

Chemicals

Ethanol, Sodium carbonate, Sodium phosphoric acid, Sodium sulphate, Potassium ferruginous, Zinc acetic acid, Zinc sulphate, Lead acetic acid, Nitric acid, Sulfuric acid, Hydrochloric acid, Oxalic acid, Sodium hydroxide, Potassium permanganate, Phenolphthalein. All chemicals above were purchased by LenReactive LLC (Sants Petersburg, Russia) and were of analytical grade quality).

Apple samples were treated with Phytosporin-M preparation (BashInkom Inc., Russia).

Animals and Biological Material

The apple variety *Malus domestica* (var. Idared, Korey, and Jonathan).

Instruments

GHP-75 gas analyzer (Alta LLC, Stavropol, Russia), FT - 372 penetrometer with plunger (Alitus LLC, Moscow, Russia), Abbe NAR-4T Refractometer (ATAGO Inc., Tokyo, Japan), UV-1800 spectrophotometer (Shimazy Inc., Tokyo, Japan), Climate camera BINDER KBW 240 (BINDER GmbH, Tuttlingen, Germany).

Laboratory Methods

Analytical and experimental studies were based on the macroscopic theory of gases, modern ideas about the physiological state of storage objects, mass transfer theory, and various fruits' storage technologies.

Fruit quality assessment was conducted according to the "Program and methodology of variety study of fruit, berry and nut crops" **[27]**. The fruits for analysis were selected at removable maturity. During the technical analysis, the mass, the size of the fetus, and the shape index, i.e., the ratio of height and diameter, were measured. Biochemical studies were carried out in 3-5-fold repetition in the biochemical laboratory of fruit storage and processing. The hardness of the apple pulp was determined by an FT - 372 penetrometer with a plunger with a diameter of 11 mm; tasting evaluation – according to GOST 8756.1-79 **[28]**; the chemical composition of apples was determined by methods generally accepted in fruit biochemistry: soluble dry substances – by the refractometric method (GOST 28562-90) **[29]**; sugars – by the Bertrand spectrophotometric method (GOST 8756.13-87) **[30]**; titrated acidity – by titration with 0.1N NaOH solution (GOST 25555.0-82) **[31]**; vitamin C – with potassium iodate (GOST 24556-89) **[32]**; pectin substances – by titrometric method (GOST 29059-91) **[33]**; alcohols and aldehydes – by spectrophotometric carbazole method **[34]**, polyphenolic substances – by vanillin method **[34]**. Natural decline, spoilage, total losses, and output of marketable products were determined according to recommendations of GOST 34314-2017 **[35]**.

Description of the Experiment

Sample preparation: To prepare the apples for the experiment, the samples were packed in a polyethylene film with a thickness of 40 – 120 microns or lowered into a solution of the drug Phytosporin-M to form an active nanofilm.

Number of samples analyzed: 100 in each experimental group.

Number of repeated analyses: 3.
Number of experiment replication: 2.
Design of the experiment:

Analytical and experimental studies were based on the macroscopic theory of gases, modern ideas about the physiological state of storage objects, mass transfer theory, and various fruits' storage technologies. To prepare the apples for the experiment, the samples were packed in a polyethylene film with a thickness of 40 – 120 microns, or lowered into a solution of the drug Phytosporin-M to form an active nanofilm (Figure 1).

Figure 1 Experimental samples of apple.

Fruit quality assessment was conducted according to the "Program and methodology of variety study of fruit, berry and nut crops" **[27]**. The fruits for analysis were selected at removable maturity. During the technical analysis, the mass, the size of the fetus, and the shape index, i.e., the ratio of height and diameter, were measured. Biochemical studies were carried out in 3-5-fold repetition in the biochemical laboratory of fruit storage and processing. The hardness of the apple pulp was determined by an FT-372 penetrometer with a plunger with a diameter of 11 mm; tasting evaluation – according to GOST 8756.1-79 **[28]**; the chemical composition of apples was determined by methods generally accepted in fruit biochemistry: soluble dry substances – by the refractometric method (GOST 28562-90) **[29]**; sugars – by the Bertrand spectrophotometric method (GOST 8756.13-87) **[30]**; titrated acidity – by titration with 0.1N NaOH solution (GOST 25555.0-82) **[31]**; vitamin C – with potassium iodate (GOST 24556-89) **[32]**; pectin substances – by titrometric method (GOST 29059-91) **[33]**; alcohols and aldehydes – by spectrophotometric carbazole method **[34]**, polyphenolic substances – by vanillin method **[34]**. Natural decline, spoilage, total losses, and output of marketable products were determined according to recommendations of GOST 34314-2017 **[35]**.

Statistical Analysis

Statistical processing of experimental data was carried out using the NSR.BASE Excel software and analysis of variance using Student's criterion with confidence probability ($\alpha = 0.95$) **[36]**. Statistically significant values were assumed at $p < 0.05$. Values with $p > 0.05$ were not taken into account in the experiment.

RESULTS AND DISCUSSION

Our research has shown that under optimal storage conditions in CA, the respiration of apples of various varieties proceeds evenly and slowly. So, after 5 – 7 months, the respiration rate of Jonathan and Reinette Simirenko apples was 55 – 77% compared to fruits stored under normal conditions (control). A similar trend was previously established by other researchers in the study of different varieties and fruits **[37]**, **[38]**, **[39]**.

In the most long-stored variety of Korey apples, the initial state is characterized by the lowest respiratory intensity (2.3 mg/kg/h), which is slightly higher in Idared apples (2.7 mg/kg/h), but different periods of climacteric rise. In the control storage variant, the climacteric rise of respiration in the Korey variety began after 5.5 months, in Idared after 4 months. When stored in a "closed loop" with increased CO_2 content, the climacteric rise in respiration was weakly pronounced and stretched over time, which corresponds to the results of other researchers **[40]**, **[41]**.

According to Calegario et al. (2001), the timing of the climacteric rise of fetal respiration and the steepness of the fall correlates with the rate of entering the gas regime in a "closed loop" and with the rate of biochemical processes **[42]**.

To clarify the respiratory gas exchange during the storage of apples in a "closed loop", the gas composition was determined using the GHP-75 gas analyzer. The results obtained are presented in Table 1.

Table 1 The content of O_2 and CO_2 in the "closed loop" (p <0.05).

Apple variety	The composition of the air in a "closed loop" during storage, %							
	1 month		2 months		4 months		7 months	
	O_2	CO_2	O_2	CO_2	O_2	CO_2	O_2	CO_2
Idared:								
p/e film 120 µm	14.5	6.5	13.0	8.0	12.0	9.0	nitrogen purging or perforation	
p/e film 40-60 µm	18.0	3.0	14.2	6.8	12.8	8.2	12.8	8.2
Korey								
p/e film 120 µm	15.2	5.8	14.0	7.0	12.5	8.5	nitrogen purging or perforation	
p/e film 40-60 µm	19.0	1.0	15.3	5.7	13.5	7.5	13.0	8.0

From the data in Table 1, it can be seen that when storing fruits in a "closed loop", the gas composition changes in the direction of increasing the concentration of carbon dioxide. The degree of change in the gas environment depends on the varietal characteristics of the fruits **[43], [44]**. According to our data, significant changes in the gas composition in the package occur during the first month of storage: a decrease of O_2 from 1.5 to 3.7% and an increase of CO_2 from 1.5 to 4.7%. For further storing, there is a gradual decrease in oxygen and an increase in carbon dioxide. In the contour of a 40 – 60 µm film, the steady-state mode (due to fruit respiration) is stable until the end of storage (7 months). In a "closed loop" of a 120 µm film, the gas medium was also created as a result of fruit respiration, but after 4 months of storage, it was maintained by blowing or opening the valve.

Biochemical quality indicators are presented in Table 2. After 7 months of storage in a "closed loop" (120 µm), Fruits had good preservation of dry substances and sugars and a sourer taste than fruits stored with free access to air. At the same time, the higher acidity of the fruit is mainly due to the content of malic acid, which is explained by the inhibitory effect of carbon dioxide on the intensity of respiration **[45]**, **[46]**.

Changes in the mass fraction of ascorbic acid in apples under the influence of a gaseous medium differed little from control samples. This confirms the assumption of Sapei and Hwa (2014) that the dynamics of vitamin C is less dependent on the composition of the medium and a greater correlation with the temperature regime of storage **[47]**. The increased content of carbon dioxide and the reduced oxygen content in the medium contributed to the ripening of the fruits to a lesser extent, as evidenced by the data on the content of alcohol and acetaldehydes after 7 months of storage. The mass fraction of them, when stored in a "closed loop" was minimal compared to the control (Table 2).

It should be noted that apples stored in a modified gas atmosphere in p/e films of 40 and 60 µm also had good storage results in terms of commodity and chemical quality indicators (in comparison with the control) but were inferior to apples in a "closed loop" (120 µm) in all indicators.

Processing of apples of the Idared variety before laying for storage with the biological preparation *Phytosporin-M* (40, 60 µm) also positively affected the quality of storage, reducing losses from microbial spoilage and reducing the gap in the yield of marketable products between fruits stored in a "closed loop" (120 µm).

Table 2 Biochemical indicators of apple fruit quality after 7 months of storage in a modified gas environment (p <0.05).

The variety of apples with the method of storage	Soluble dry substances, %	Total sugars, %	Total acidity, %	Alcohol, %	Aldehydes, %, mg/dm 3	Pectin substances, %		Polyphenolic substances, mg %	Vitamin C, mg %
						instant pectin	Proto-pectin		
Korey (when laying for storage)	13.0	12.0	0.33	–	–	0.29	0.62	240.0	7.0
Korey control (without treatment) storage in containers	12.2	10.9	0.22	0.150	11.65	0.26	0.40	190.0	4.7
Korey in p/e film 40 μm	12.4	11.2	0.23	0.091	11.42	0.25	0.44	190.0	5.0
Korey in p/e film 60 μm	12.5	11.4	0.24	0.069	9.64	0.23	0.45	196.0	5.5
Korey in p/e film 120 μm ("closed loop")	12.7	11.7	0.26	0.058	6.90	0.22	0.50	220.0	5.9
Idared (when laying for storage)	12.0	10.8	0.58	–	–	0.34	0.50	150.0	8.8
Idared control (without treatment) storage in containers	10.3	9.8	0.36	0.173	17.35	0.13	0.27	123.3	6.9
Idared in p/e film 40 μm	10.4	9.8	0.38	0.104	14.62	0.13	0.30	124.5	7.4
Idared in p/e film 60 μm	10.8	10.0	0.38	0.092	9.00	0.12	0.32	126.3	7.4
Idared in p/e film 120 μm ("closed loop")	11.3	10.4	0.44	0.068	7.80	0.13	0.42	131.5	7.7

From the results obtained, summarized in Table 3, it can be seen that the method of storing apples in an "isolated circuit" gives a pronounced positive effect since losses are significantly reduced (from 4.5% to 0.4%) from weight loss and, very importantly, from microbiological spoilage from 4.6% to 0.8% and physiological diseases, which guarantees the safety of nutrients. At the same time, the yield of commercial varieties increased by 7 – 8.5%, depending on the variety.

When storing apples in a modified gas atmosphere, the following requirements must be observed: to store fruits with high-quality indicators at optimal maturity; to load chambers with products homogeneous in keeping quality and immediately after harvesting; varieties susceptible to sunburn must be treated with antioxidants or biological preparations **[48]**, **[49]**. Failure to comply with these conditions reduces the shelf life, losses, and quality of fruits.

Thus, studies have shown that our proposed method of storing apples in an isolated "closed loop" using high-pressure polyethylene with a film thickness of 120 μm, without the use of expensive equipment and materials for sealing chambers, allows us to achieve storage results close to storing apples in a controlled atmosphere **[50]**, **[51]**, **[52]**. Also, we used existing fruit storage capacities and parts of them while maintaining constant access to the chambers, which is very important for farms that grow small volumes of apples and cannot build separate refrigeration facilities **[53]**, **[54]**.

Infectious and physiological diseases of fruits annually cause huge economic damage to the industry **[55**, **56]**. This problem is solved by treatment with harmless and effective drugs that reduce the microbiological load in food technologies.

Apples of winter varieties were used: Idared, Korey, Jonathan. A prolonged-acting microbiological fungicide with anti-stress properties, *Phytosporin-M*, was used for surface treatment. The apple surface treatment was carried out according to the method proposed by Gvozdenko et al., 2022 **[57]**. The processed apples were dried and sent to refrigerated storage for 7 days. To determine the optimal consumption rates of the *Phytosporin-M* fungicide for post-harvest processing of raw materials, a solution of 1 – 1.5 liters per ton was used.

Table 3 Commercial quality of apples when stored in a modified gas environment (p <0.05).

The variety of apples with the method of storage	For 4 months of storage				For 7 months of storage			
	Natural decline, %	Spoilage, %	Total losses, %	Output of marketable products, %	Natural decline, %	Spoilage, %	Total losses, %	Output of marketable products, %
Idared control, storage in containers	2.4	1.4	3.8	96.2	4.9	3.7	8.6	91.4
Idared in p/e film 40 µm (treated with a bactericidal preparation)	0.0	0.0	0.0	100.0	0.7	3.1	3.8	96.2
Idared in p/e film 60 µm (treated with a bactericidal preparation)	0.0	0.0	0.0	100.0	0.6	2.4	3.0	97.0
Idared in p/e film 120 µm	0.0	0.0	0.0	100.0	0.5	1.1	1.6	98.4
Korey control, storage in containers	21	2.7	4.8	95.2	4.2	5.1	9.3	90.7
Korey in p/e film 40 µm	0.0	0.0	0.0	100.0	0.6	3.9	4.4	95.6
Korey in p/e film 60 µm	0.0	0.0	0.0	100.0	0.5	2.0	2.5	97.5
Korey in p/e film 120 µm	0.0	0.0	0.0	100.0	0.4	0.7	1.1	98.9

The results of the optimal solution concentration were judged by the commodity assessment of the quality of raw materials during storage: the presence of rot, diseased, and sprouted specimens. The experimental batch of plant raw materials received the best commodity rating and was studied according to organoleptic, biochemical, and microbiological quality indicators.

Comparative data on the quality of fruits treated with a solution of Phytosporin-M and control (without treatment) are presented in Table 4, Table 5, and Figure 2 and Figure 3.

Table 4 Commercial quality of apples treated with *Phytosporin-M* during storage at 0 +2° C (p <0.05).

The variety of apples with the method of storage	For 4 months of storage				For 7 months of storage			
	Natural decline, %	Spoilage, %	Total losses, %	Output of marketable products, %	Natural decline, %	Spoilage, %	Total losses, %	Output of marketable products, %
Korey control, storage in containers	2.1	2.7	4.8	95.2	4.2	5.1	9.3	90.7
Korey, treated with a bactericidal preparation, storage in containers	1.4	1.0	2.4	97.6	3.0	2.3	5.3	94.7
Idared control, storage in containers	2.4	1.4	3.8	96.2	4.7	2.9	7.6	92.4
Idared, treated with a bactericidal preparation, storage in containers	1.8	1.1	2.9	97.1	3.7	2.0	5.7	94.3
Jonathan control, storage in containers	3.5	2.0	5.5	94.5	7.8	4.6	12.4	87.6
Jonathan, treated with a bactericidal preparation, storage in containers	2.5	1.2	3.7	96.3	5.6	2.6	8.2	91.8

According to research results, pretreatment with *Phytosporin-M* provides the best yield of marketable products, minimal microbial spoilage (Figure 2 and Figure 3), and loss of biologically active substances (Figure 4).

To preserve the natural stability of fruits and prolong their shelf life, preventing the intensive accumulation of alcohol is of great importance **[58]**. At the next stage of the experiment, apple samples were packed in a polyethylene film with a thickness of 40 – 120 microns or lowered into a solution of the drug Phytosporin-M to form an active nanofilm **[57]**, **[59]**, **[60]**, **[61]**. According to our data (Table 5), the alcohol content in processed fruits by the end of storage (7 months) is 1.5 times lower than in the control.

Table 5 Biochemical quality indicators of apple fruits treated with *Phytosporin-M* after 7 months of storage (p <0.05).

The variety of apples with the method of storage	**Soluble dry substances, %**	**Total sugars, %**	**Total acidity, %**	**Alcohol, %**	**Pectin substances, %**		**Polyphenolic substances, mg %**	**Vitamin C, mg %**
					instant pectin	**Proto-pectin**		
Korey (when laying for storage)	13.0	12.0	0.33	–	0.29	0.62	240.0	7.0
Korey control (without treatment) storage in containers	12.2	10.9	0.22	0.150	0.26	0.43	190.0	4.7
Korey processed Phytosporin-M (in containers)	12.5	11.5	0.29	0.093	0.24	0.45	215.0	5.5
Idared (when laying for storage)	12.0	10.8	0.58	–	0.34	0.50	150.0	8.8
Idared control (without treatment) storage in containers	10.3	9.9	0.38	0.173	0.13	0.27	123.3	6.9
Idared processed Phytosporin-M (in containers)	11.0	10.2	0.42	0.114	0.12	0.30	133.8	7.5
Jonathan (when laying for storage)	12.5	11.5	0.60	–	0.50	0.38	170.0	8.0
Jonathan control (without treatment) storage in containers	10.2	10.0	0.39	0.185	0.16	0.22	130.0	5.9
Jonathan processed Phytosporin-M (in containers)	11.2	10.9	0.44	0.125	0.13	0.25	145.0	6.4

The microbiological studies of apple fruits during storage fully confirm the advantages of storing fruits with their pretreatment with *Phytosporin-M* fungicide (Figure 4). This technology makes it possible to reduce losses from microbial spoilage by 2 times for the Korey and Jonathan varieties and by 1.6 times for the Idared variety (Figure 2 and Figure 3).

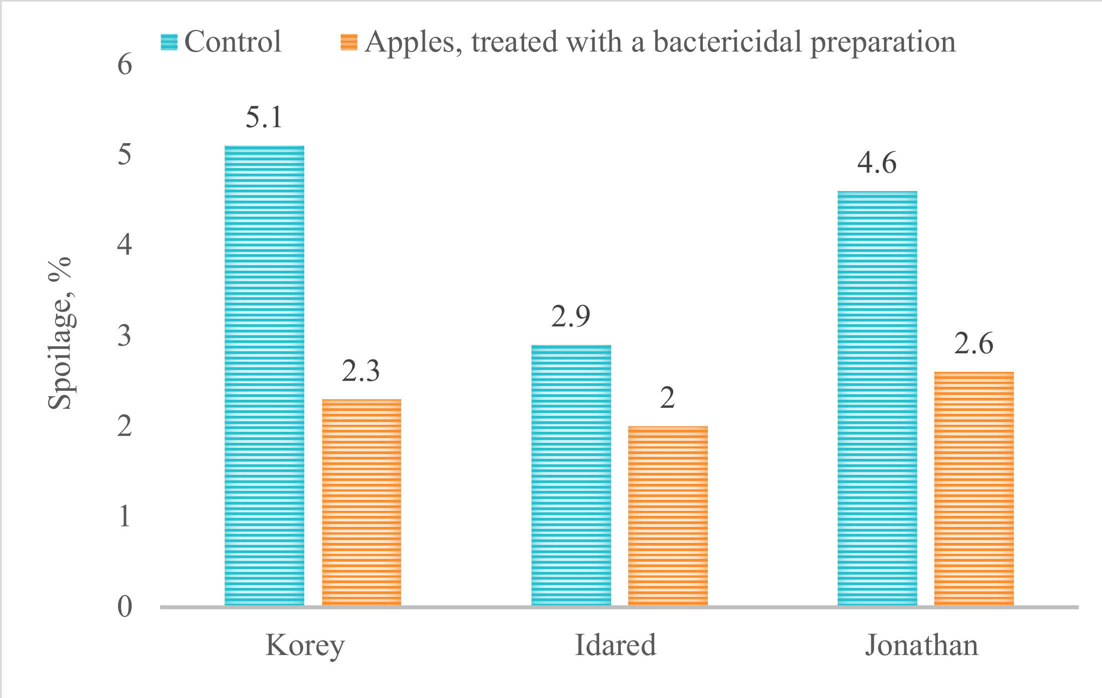

Figure 2 The effect of processing apples with a biological preparation on the amount of microbiological spoilage during 7 months of storage (p <0.05).

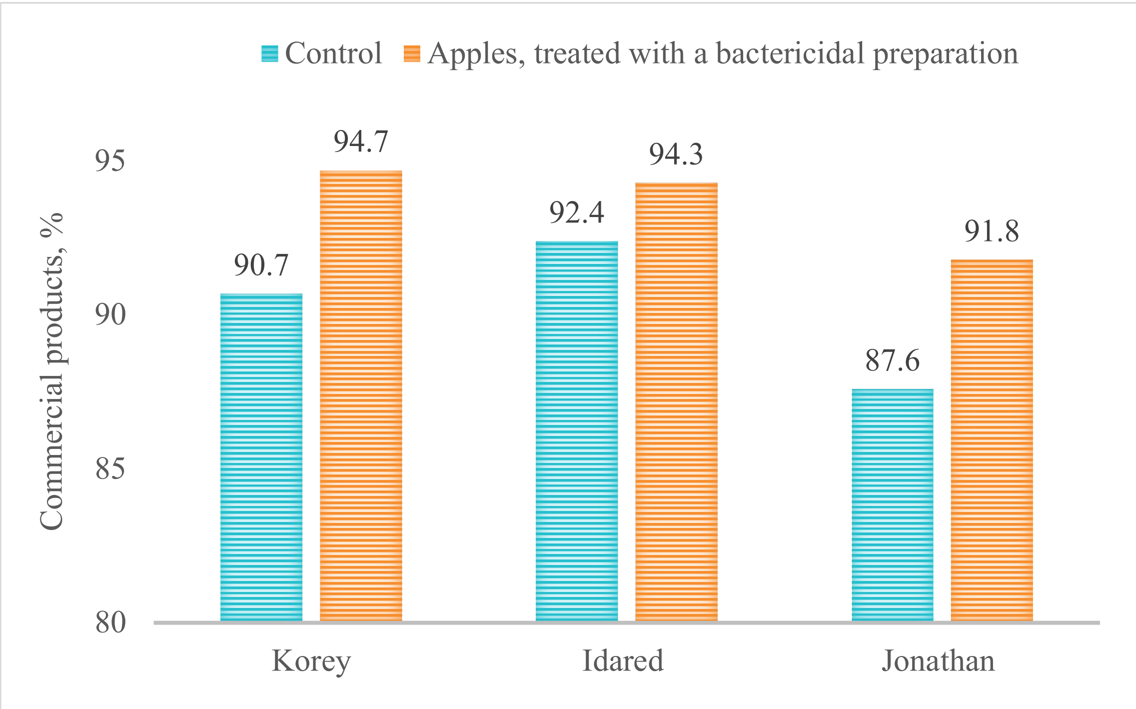

Figure 3 The effect of processing apples with a biological product on the yield of marketable products during 7 months of storage (p <0.05).

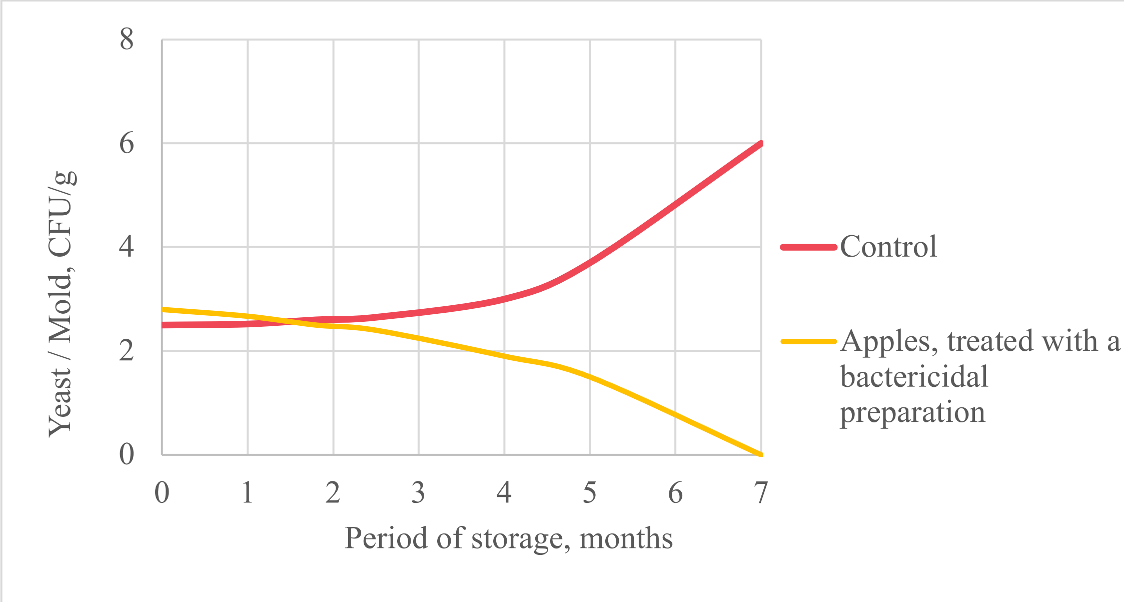

Figure 4 The effect of the apple storage method on microbiological indicators.

The tasting evaluation of apple fruits after 7 months of storage shows that the experimental samples exceeded the control ones in taste, presentation, and dense consistency (turgor of tissues) and no signs of wilting.

Thus, the results show that during long-term storage of apple fruits, there was a pronounced positive effect for fruits treated with a solution of the *Phytosporin-M* biological preparation, which allowed to increase the yield of high-quality commercial products by 8 – 9%, which positively affected the economic indicators of production.

CONCLUSION

A low-cost technology of non-generator storage of apple fruits in an isolated "closed loop" has been developed. It allows you to implement the controlled atmosphere (CA) technology in a typical environment (7 – 8% CO_2) and (13 – 14% O_2) and a subnormal environment (3% O_2 and 5% CO_2) without using a gas generator. The technology of apple fruit storage with pretreatment of raw materials, containers, and internal storage surfaces with a solution of the biological preparation Phytosporin-M are scientifically substantiated. The developed technology made it possible to reduce the moisture loss of the studied raw materials significantly, losses from microbial spoilage, and increase the yield of high-quality commercial products by 8 – 13%, which positively affected the economic indicators of production. Thus, our research aimed at extending the shelf life and reducing the loss of raw materials will provide an opportunity to increase the output of valuable canned fruit, improve the assortment, reduce the cost and generally increase the efficiency of their production.

REFERENCES

1. Vasylyshyna, E. (2016). Influence of freezing and storing cherry fruit on its nutritional value. In Acta Scientiarum Polonorum Technologia Alimentaria (Vol. 15, Issue 2, pp. 145–150). Uniwersytet Przyrodniczy w Poznaniu (Poznan University of Life Sciences). https://doi.org/10.17306/j.afs.2016.2.14
2. Siddiqui, S. A., Blinov, A. V., Serov, A. V., Gvozdenko, A. A., Kravtsov, A. A., Nagdalian, A. A., Raffa, V. V., Maglakelidze, D. G., Blinova, A. A., Kobina, A. V., Golik, A. B., & Ibrahim, S. A. (2021). Effect of Selenium Nanoparticles on Germination of Hordéum Vulgáre Barley Seeds. In Coatings (Vol. 11, Issue 7, p. 862). MDPI AG. https://doi.org/10.3390/coatings11070862
3. Piskov, S., Timchenko, L., Rzhepakovsky, I., Avanesyan, S., Bondareva, N., Sizonenko, M., & Areshidze, D. (2019). Effect of pre-treatment conditions on the antiatherogenic potential of freeze-dried oyster mushrooms. In Foods and Raw Materials (pp. 375–386). Kemerovo State University. https://doi.org/10.21603/2308-4057-2019-2-375-386
4. Bogonosova, I. A., Kenijz, N. V., Zaitseva, T. N., Artemova, E. N., Kulikov, D. A., & Barsukova, N. V. (2020). Development of functional products from vegetables for schoolchildren’s nutrition. In IOP Conference Series: Earth and Environmental Science (Vol. 613, Issue 1, p. 012019). IOP Publishing. https://doi.org/10.1088/1755-1315/613/1/012019

5. Nesterenko A. A., Koshchaev A. G., Zabashta N. N., Omarov R. S., & Shlykov S. N. (2019). Basics of the production of protein-fat emulsions based on vegetable raw materials. In Indo American journal of pharmaceutical sciences (Vol. 6, Issue 03, pp. 6337–6346), CSK Publications.
6. Sadovoy, V. V., Selimov, M. A., Shchedrina, T. V., & Nagdalian, A. A. (2017). Nutritional supplement for control of diabetes. In Journal of Excipients and Food Chemicals (Vol. 8, Issue 2, pp 31–38) IPEC-Americas.
7. Profeta, A., Siddiqui, S. A., Smetana, S., Hossaini, S. M., Heinz, V., & Kircher, C. (2021). The impact of Corona pandemic on consumer's food consumption. In Journal of Consumer Protection and Food Safety (Vol. 16, Issue 4, pp. 305–314). Springer Science and Business Media LLC. https://doi.org/10.1007/s00003-021-01341-1
8. Chmyrev, V. P., Polutina, T. N., Moiseev, A. V., Oboturova, N. P., Kolesnikov, R. O., Baklanov, I. S., & Baklanova, O. A. (2022). Analysis of the state of food safety in the russian federation. In Journal of Hygienic Engineering and Design (Vol. 38, pp. 111–118). Consulting and Training Center KEY.
9. Silveira, A. C., Araneda, C., Hinojosa, A., & Escalona, V. H. (2014). Effect of non-conventional modified atmosphere packaging on fresh cut watercress (Nasturtium officinale R. Br.) quality. In Postharvest Biology and Technology (Vol. 92, pp. 114–120). Elsevier BV. https://doi.org/10.1016/j.postharvbio.2013.12.012
10. Serrano, M., & Valero, D. (2017). Application of Polyamines to Maintain Functional Properties in Stored Fruits. In Methods in Molecular Biology (pp. 449–458). Springer New York. https://doi.org/10.1007/978-1-4939-7398-9_37
11. Juhnevica-Radenkova, K., Radenkovs, V., Kundzins, K., & Seglina, D. (2018). Effect of ozone treatment on the microstructure, chemical composition and sensory quality of apple fruits. In Food Science and Technology International (Vol. 25, Issue 3, pp. 252–267). SAGE Publications. https://doi.org/10.1177/1082013218815285
12. Weber, A., Thewes, F. R., Anese, R. de O., Both, V., Pavanello, E. P., & Brackmann, A. (2017). Dynamic controlled atmosphere (DCA): interaction between DCA methods and 1-methylcyclopropene on 'Fuji Suprema' apple quality. In Food Chemistry (Vol. 235, pp. 136–144). Elsevier BV. https://doi.org/10.1016/j.foodchem.2017.05.047
13. Ramírez-Acosta, S., Arias-Borrego, A., Gómez-Ariza, J. L., & García-Barrera, T. (2018). Metabolomic study of bioactive compounds in strawberries preserved under controlled atmosphere based on GC-MS and DI-ESI-QqQ-TOF-MS. In Phytochemical Analysis (Vol. 30, Issue 2, pp. 198–207). Wiley. https://doi.org/10.1002/pca.2805
14. Wood, R. M., Thewes, F. R., Reynaud, M., Kittemann, D., Sautter, C. K., Wünsche, J. N., & Neuwald, D. A. (2022). Apple fruit recovery from anoxia under controlled atmosphere storage. In Food Chemistry (Vol. 371, p. 131152). Elsevier BV. https://doi.org/10.1016/j.foodchem.2021.131152
15. Finnegan, E., Mahajan, P. V., O'Connell, M., Francis, G. A., & O'Beirne, D. (2013). Modelling respiration in fresh-cut pineapple and prediction of gas permeability needs for optimal modified atmosphere packaging. In Postharvest Biology and Technology (Vol. 79, pp. 47–53). Elsevier BV. https://doi.org/10.1016/j.postharvbio.2012.12.015
16. Piskov, S., Timchenko, L., Grimm, W.-D., Rzhepakovsky, I., Avanesyan, S., Sizonenko, M., & Kurchenko, V. (2020). Effects of Various Drying Methods on Some Physico-Chemical Properties and the Antioxidant Profile and ACE Inhibition Activity of Oyster Mushrooms (Pleurotus Ostreatus). In Foods (Vol. 9, Issue 2, p. 160). MDPI AG. https://doi.org/10.3390/foods9020160
17. Selcuk, N., & Erkan, M. (2015). The effects of modified and palliflex controlled atmosphere storage on postharvest quality and composition of 'Istanbul' medlar fruit. In Postharvest Biology and Technology (Vol. 99, pp. 9–19). Elsevier BV. https://doi.org/10.1016/j.postharvbio.2014.07.004
18. Rzhepakovsky, I. V., Areshidze, D. A., Avanesyan, S. S., Grimm, W. D., Filatova, N. V., Kalinin, A. V., Kochergin, S. G., Kozlova, M. A., Kurchenko, V. P., Sizonenko, M. N., Terentiev, A. A., Timchenko, L. D., Trigub, M. M., Nagdalian, A. A., & Piskov, S. I. (2022). Phytochemical Characterization, Antioxidant Activity, and Cytotoxicity of Methanolic Leaf Extract of Chlorophytum Comosum (Green Type) (Thunb.) Jacq. In Molecules (Vol. 27, Issue 3, p. 762). MDPI AG. https://doi.org/10.3390/molecules27030762
19. Phan, M. A. T., Paterson, J., Bucknall, M., & Arcot, J. (2017). Interactions between phytochemicals from fruits and vegetables: Effects on bioactivities and bioavailability. In Critical Reviews in Food Science and Nutrition (Vol. 58, Issue 8, pp. 1310–1329). Informa UK Limited. https://doi.org/10.1080/10408398.2016.1254595
20. Corpas, F. J., Freschi, L., Rodríguez-Ruiz, M., Mioto, P. T., González-Gordo, S., & Palma, J. M. (2018). Nitro-oxidative metabolism during fruit ripening. In Journal of Experimental Botany (Vol. 69, Issue 14, pp. 3449–3463). Oxford University Press (OUP). https://doi.org/10.1093/jxb/erx453

21. Ho, Q. T., Verboven, P., Verlinden, B. E., Lammertyn, J., Vandewalle, S., & Nicolaï, B. M. (2008). A Continuum Model for Metabolic Gas Exchange in Pear Fruit. In J. Banga (Ed.), PLoS Computational Biology (Vol. 4, Issue 3, p. e1000023). Public Library of Science (PLoS). https://doi.org/10.1371/journal.pcbi.1000023
22. Romero, I., Domínguez, I., Doménech-Carbó, A., Gavara, R., Escribano, M. I., Merodio, C., & Sanchez-Ballesta, M. T. (2019). Effect of high levels of CO 2 on the electrochemical behavior and the enzymatic and non-enzymatic antioxidant systems in black and white table grapes stored at 0 °C. In Journal of the Science of Food and Agriculture (Vol. 99, Issue 15, pp. 6859–6867). Wiley. https://doi.org/10.1002/jsfa.9971
23. Barabanov, P. V., Gerasimov, A. V., Blinov, A. V., Kravtsov, A. A., & Kravtsov, V. A. (2018). Influence of nanosilver on the efficiency of Pisum sativum crops germination. In Ecotoxicology and Environmental Safety (Vol. 147, pp. 715–719). Elsevier BV. https://doi.org/10.1016/j.ecoenv.2017.09.024
24. Nadeem, M., Mushtaq, M., Chughtai, M. F. J., Khaliq, A., Imran, M., Gondal, T. A., Shariati, M. A., Nesterenko, A., & Kulikov, D. (2021). Nutritional and Phenolic Antioxidant Properties of Pakistani Wheat Varieties as Influenced by Planting Period and Variety. In AGRIVITA Journal of Agricultural Science (Vol. 43, Issue 1). Agrivita, Journal of Agricultural Science (AJAS). https://doi.org/10.17503/agrivita.v43i1.2274
25. Cheng, Y., Liu, L., Zhao, G., Shen, C., Yan, H., Guan, J., & Yang, K. (2015). The effects of modified atmosphere packaging on core browning and the expression patterns of PPO and PAL genes in 'Yali' pears during cold storage. In LWT - Food Science and Technology (Vol. 60, Issue 2, pp. 1243–1248). Elsevier BV. https://doi.org/10.1016/j.lwt.2014.09.005
26. Selcuk, N., & Erkan, M. (2014). Changes in antioxidant activity and postharvest quality of sweet pomegranates cv. Hicrannar under modified atmosphere packaging. In Postharvest Biology and Technology (Vol. 92, pp. 29–36). Elsevier BV. https://doi.org/10.1016/j.postharvbio.2014.01.007
27. Sedova, E.N., Ogoltsovoy, T.P. (1999). Program and methodology of variety study of fruit, berry and nut crops. VNIISPK. Orel, VNIISPK Publishing House, 608 p.
28. GOST 8756.1-79. Canned food products. Methods for determining organoleptic parameters, net weight and mass fraction of components. Retrieved from https://docs.cntd.ru/document/1200022618.
29. GOST 28562-90. Fruit and vegetable processing products. A refractometric method for determining soluble solids. Retrieved from https://docs.cntd.ru/document/1200022799.
30. GOST 8756.13-87. Fruit and vegetable products. Methods for determination of sugars. Retrieved from https://docs.cntd.ru/document/1200022639.
31. GOST 25555.0-82. Fruit and vegetable products. Methods for determination of titratable acidity. Retrieved from https://docs.cntd.ru/document/1200022766.
32. GOST 24556-89. Products of fruits and vegetables processing. Methods for determination of vitamin C. Retrieved from https://docs.cntd.ru/document/1200022765.
33. GOST 29059-91. Fruit and vegetable processing products. Titrimetric method for the determination of pectin substances. Retrieved from https://docs.cntd.ru/document/1200022903.
34. Fruit and vegetable processing products. Methods of analysis. Retrieved from https://docs.cntd.ru/document/1200144956.
35. GOST 34314-2017. Fresh apples for retail. Specifications. Rerieved from https://docs.cntd.ru/document/556348922.
36. Siddiqui, S. A., Ahmad, A., Siddiqui, A. A., & Chaturvedi, P. (2021). Stability Analysis of a Cantilever Structure using ANSYS and MATLAB. In 2021 2nd International Conference on Intelligent Engineering and Management (ICIEM). 2021 2nd International Conference on Intelligent Engineering and Management (ICIEM). IEEE. https://doi.org/10.1109/iciem51511.2021.9445357
37. Camen, D, Beinşan, C, Nicolae, I., Renata, S., Doncean, A., & Radu, S. (2021). Research regarding the influence of storage conditions in quality of some apple varieties. In Journal of Horticulture, Forestry and Biotechnology (Vol. 15, pp. 184–186). Banat's University of Agricultural Sciences and Veterinary Medicine.
38. Angelovič, M., Krištof, K., Jobbágy, J., Findura, P., & Križan, M. (2018). The effect of conditions and storage time on course of moisture and temperature of maize grains. In A. Szeląg-Sikora (Ed.), BIO Web of Conferences (Vol. 10, p. 02001). EDP Sciences. https://doi.org/10.1051/bioconf/20181002001
39. Melnyk, O., Drozd, O., & Melnyk, I. (2018). Storage and Quality of Apples 'Reinette Simirenko', Depending on the Dose of Post-Harvest Treatment with Ethylene Inhibitor 1-MCP. In Journal of Horticultural Research (Vol. 26, Issue 2, pp. 95–102). Walter de Gruyter GmbH. https://doi.org/10.2478/johr-2018-0020
40. Jones, J. D., Hulme, A. C., & Wooltorton, L. S. C. (1965). The respiration climacteric in apple fruits. biochemical changes occurring during the development oe the climacteric in eruit detached erom the tree. In New Phytologist (Vol. 64, Issue 1, pp. 158–167). Wiley. https://doi.org/10.1111/j.1469-8137.1965.tb05384.x

41. Li, L., Peters, T., Zhang, Q., Zhang, J., & Huang, D. (2014). Modeling Apple Surface Temperature Dynamics Based on Weather Data. In Sensors (Vol. 14, Issue 11, pp. 20217–20234). MDPI AG. https://doi.org/10.3390/s141120217
42. Calegario, F. F., Cosso, R. G., Almeida, F. V., Vercesi, A. E., & Jardim, W. F. (2001). Determination of the respiration rate of tomato fruit using flow analysis. In Postharvest Biology and Technology (Vol. 22, Issue 3, pp. 249–256). Elsevier BV. https://doi.org/10.1016/s0925-5214(01)00096-5
43. Prichko, T., Ulyanovskaya, E., & Droficheva, N. (2020). Evaluation of biochemical indicators of apple fruits quality for the complex selection of the valuable source material for breeding. In E. Egorov, I. Ilina, & N. Zaporozhets (Eds.), BIO Web of Conferences (Vol. 25, p. 02019). EDP Sciences. https://doi.org/10.1051/bioconf/20202502019
44. Cervantes, L., Ariza, M. T., Miranda, L., Lozano, D., Medina, J. J., Soria, C., & Martínez-Ferri, E. (2020). Stability of Fruit Quality Traits of Different Strawberry Varieties under Variable Environmental Conditions. In Agronomy (Vol. 10, Issue 9, p. 1242). MDPI AG. https://doi.org/10.3390/agronomy10091242
45. Stewart, G. (2017). The Production of Secondary Metabolites with Flavour Potential during Brewing and Distilling Wort Fermentations. In Fermentation (Vol. 3, Issue 4, p. 63). MDPI AG. https://doi.org/10.3390/fermentation3040063
46. Boeckx, J., Pols, S., Hertog, M. L. A. T. M., & Nicolaï, B. M. (2019). Regulation of the Central Carbon Metabolism in Apple Fruit Exposed to Postharvest Low-Oxygen Stress. In Frontiers in Plant Science (Vol. 10). Frontiers Media SA. https://doi.org/10.3389/fpls.2019.01384
47. Sapei, L., & Hwa, L. (2014). Study on the Kinetics of Vitamin C Degradation in Fresh Strawberry Juices. In Procedia Chemistry (Vol. 9, pp. 62–68). Elsevier BV. https://doi.org/10.1016/j.proche.2014.05.008
48. Nikitin, A. L., & Makarkina, M. A. (2021). Some indicators of the quality and cold storage of the fruit of new scab immune columnar apple cultivars. In IOP Conference Series: Earth and Environmental Science (Vol. 640, Issue 6, p. 062013). IOP Publishing. https://doi.org/10.1088/1755-1315/640/6/062013
49. Babich, O., Dyshlyuk, L., Sukhikh, S., Prosekov, A., Ivanova, S., Pavsky, V., Chaplygina, T., & Kriger, O. (2019). Effects of Biopreservatives Combined with Modified Atmosphere Packaging on the Quality of Apples and Tomatoes. In Polish Journal of Food and Nutrition Sciences (Vol. 69, Issue 3, pp. 289–296). Institute of Animal Reproduction and Food Research of the Polish Academy of Sciences. https://doi.org/10.31883/pjfns/110564
50. Butkeviciute, A., Viskelis, J., Liaudanskas, M., Viskelis, P., Bobinas, C., & Janulis, V. (2021). Variation of Triterpenes in Apples Stored in a Controlled Atmosphere. In Molecules (Vol. 26, Issue 12, p. 3639). MDPI AG. https://doi.org/10.3390/molecules26123639
51. Thewes, F. R., Brackmann, A., Both, V., Weber, A., Anese, R. de O., Ferrão, T. dos S., & Wagner, R. (2017). The different impacts of dynamic controlled atmosphere and controlled atmosphere storage in the quality attributes of 'Fuji Suprema' apples. In Postharvest Biology and Technology (Vol. 130, pp. 7–20). Elsevier BV. https://doi.org/10.1016/j.postharvbio.2017.04.003
52. Mditshwa, A., Fawole, O. A., & Opara, U. L. (2018). Recent developments on dynamic controlled atmosphere storage of apples—A review. In Food Packaging and Shelf Life (Vol. 16, pp. 59–68). Elsevier BV. https://doi.org/10.1016/j.fpsl.2018.01.011
53. Dobrzański, B., Rabcewicz, J., & Rybczyński, R. (2006). Handling of apple: transport techniques and efficiency vibration, damage and bruising texture, firmness and quality. B. Dobrzański Institute of Agrophysics Polish Academy of Sciences. (pp. 33–177)
54. Hoang, N. T. T., Golding, J. B., & Wilkes, M. A. (2011). The effect of postharvest 1-MCP treatment and storage atmosphere on 'Cripps Pink' apple phenolics and antioxidant activity. In Food Chemistry (Vol. 127, Issue 3, pp. 1249–1256). Elsevier BV. https://doi.org/10.1016/j.foodchem.2011.01.052
55. Shuttleworth, L. A. (2021). Alternative disease management strategies for organic apple production in the United Kingdom. In CABI Agriculture and Bioscience (Vol. 2, Issue 1). Springer Science and Business Media LLC. https://doi.org/10.1186/s43170-021-00054-7
56. Kwon, D., Kim, S., Kim, Y., Son, M., Kim, K., An, D., & Kim, B. (2015). An Empirical Assessment of the Economic Damage Caused by Apple Marssonina Blotch and Pear Scab Outbreaks in Korea. In Sustainability (Vol. 7, Issue 12, pp. 16588–16598). MDPI AG. https://doi.org/10.3390/su71215836
57. Gvozdenko, A. A., Siddiqui, S. A., Blinov, A. V., Golik, A. B., Nagdalian, A. A., Maglakelidze, D. G., Statsenko, E. N., Pirogov, M. A., Blinova, A. A., Sizonenko, M. N., Simonov, A. N., Zhukov, R. B., Kolesnikov, R. O., & Ibrahim, S. A. (2022). Synthesis of CuO nanoparticles stabilized with gelatin for potential use in food packaging applications. In Scientific Reports (Vol. 12, Issue 1). Springer Science and Business Media LLC. https://doi.org/10.1038/s41598-022-16878-w

58. Amit, S. K., Uddin, Md. M., Rahman, R., Islam, S. M. R., & Khan, M. S. (2017). A review on mechanisms and commercial aspects of food preservation and processing. In Agriculture & Food Security (Vol. 6, Issue 1). Springer Science and Business Media LLC. https://doi.org/10.1186/s40066-017-0130-8
59. Li, X., Li, W., Jiang, Y., Ding, Y., Yun, J., Tang, Y., & Zhang, P. (2011). Effect of nano-ZnO-coated active packaging on quality of fresh-cut 'Fuji' apple. In International Journal of Food Science & Technology (Vol. 46, Issue 9, pp. 1947–1955). Wiley. https://doi.org/10.1111/j.1365-2621.2011.02706.x
60. Dulta, K., Koşarsoy Ağçeli, G., Thakur, A., Singh, S., Chauhan, P., & Chauhan, P. K. (2022). Development of Alginate-Chitosan Based Coating Enriched with ZnO Nanoparticles for Increasing the Shelf Life of Orange Fruits (Citrus sinensis L.). In Journal of Polymers and the Environment (Vol. 30, Issue 8, pp. 3293–3306). Springer Science and Business Media LLC. https://doi.org/10.1007/s10924-022-02411-7
61. Bugatti, V., Cefola, M., Montemurro, N., Palumbo, M., Quintieri, L., Pace, B., & Gorrasi, G. (2020). Combined Effect of Active Packaging of Polyethylene Filled with a Nano-Carrier of Salicylate and Modified Atmosphere to Improve the Shelf Life of Fresh Blueberries. In Nanomaterials (Vol. 10, Issue 12, p. 2513). MDPI AG. https://doi.org/10.3390/nano10122513

Funds:
This research received no external funding.
Acknowledgments:-
Conflict of Interest:
The authors declare no conflict of interest.
Ethical Statement:
This article does not contain any studies that would require an ethical statement.
Contact Address:
*Albina Alekseevna Varivoda, Kuban State Agrarian University named after I. T. Trubilin, Kalinina Street, 13, 350044, Krasnodar, Russia,
Tel.:+79054014833,
E-mail: zmejka-2007@mail.ru
ORCID: https://orcid.org/0000-0001-5580-4813
Elena Valentinovna Svetlakova, Stavropol State Agrarian University, Zootekhnicheskiy Avenue, 9, 355017, Stavropol, Russia,
Tel.:+79187732899,
E-mail: cluster26@yandex.ru
ORCID: https://orcid.org/0000-0002-4904-697X
Irina Vladimirovna Ziruk, Saraton State Agrarian University, Teatralnaya Square, 1, 410012, Saratov, Russia,
Tel.:+79169793128,
E-mail: iziruk@yandex.ru
ORCID: https://orcid.org/0000-0002-4251-3053
Inna Sergeevna Kirichenko, Moscow State University of Technologies and Management, Zemlyanoy Val Street, 73, 109004, Moscow, Russia,
Tel.:+79054675425,
E-mail: d22003807-help@mail.ru
ORCID: https://orcid.org/0000-0003-3314-9779
Olga Yurievna Kolosova, Technological Institute of Service – Branch of the Don State Technical University in Stavropol, Kulakova Avenue, 41/1., 355000, Stavropol, Russia,
Tel.:+79187778824,
E-mail: artem-kolosov@rambler.ru
ORCID: https://orcid.org/0000-0001-6342-4888
Sergey Nikolaevich Povetkin, North Caucasus Federal University, Pushkina Street, 1, 355009, Stavropol, Russia,
Tel.:+79183500889,
E-mail: ruslankalmykov777@yandex.ru
ORCID: https://orcid.org/0000-0002-8293-3984
Bogdan Olegovich Ivakhnenko, North Caucasus Federal University, Pushkina Street, 1, 355009, Stavropol, Russia,
Tel.:+79895673085,
E-mail: nastya_bogdanova_88@mail.ru
ORCID: https://orcid.org/0000-0003-4077-6981

Corresponding author: *