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SUBSTANTIATON OF SELECTING THE METHOD OF PRE-COOLING OF FRUITS

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Встановлено, що комбінований спосіб попереднього охолодження плодів відрізнявся високою константою швидкості зниження інтенсивності дихання та тепловиділення і низькими втратами маси. Їх кількісне значення варіювало в межах від 0,005 % до 0,014 % залежно від виду плодів. Отримані результати дають змогу рекомендувати даний спосіб попереднього охолодження плодів для використання у виробничих умовах

Ключові слова: попереднє охолодження, антиоксиданти, гідроохолодження, інтенсивність дихання, тепловиділення плодів, втрати маси

Установлено, что комбинированный способ предварительного охлаждения плодов отличался высокой константой скорости снижения интенсивности дыхания и тепловыделения и низкими потерями массы. Их количественное значение варьировало в пределах от 0,005 % до 0,014 % в зависимости от вида плодов. Полученные результаты позволяют рекомендовать данный способ предварительного охлаждения плодов для использования в производственных условиях

Ключевые слова: предварительное охлаждение, антиоксиданты, гидрохлаждение, интенсивность дыхания, тепловыделение плодов, потери массы

1. Introduction

Pome and stone fruits are considered to be indispensable and important part of the high-quality, balanced diet of a human [1]. They contain many useful substances which possess dietary and medicinal properties. The main among them are vitamins, phenolic compounds, sugars, organic acids, microelements, enzymes and other biologically active substances [2].

Today in Ukraine, the problem of establishing a balanced diet and provision the population with fruits during the whole year is not a lack of raw materials but the imperfect technologies of its storage. Maximum preservation of food, biological value, quality and harmlessness of fruit raw materials under modern manufacturing conditions may only be achieved when using artificial cold. And the first stage of using artificial cold in the technologies of fruits storage is the pre-cooling.

Pre-cooling is the technological process of fast decrease in temperature from the initial to the temperature of the further storage of fruit. The efficiency of pre-cooling is associated with its significant positive influence on the preserving factors of fruit raw materials. The faster the temperature of the fruits after gathering is reduced, the longer the period of storage will last and the higher is quality [3, 4].

The relevance of the research in this direction is due to the lack of information on the impact of different ways and modes of pre-cooling on the kinetics of main physical and physiological processes that occur in fruit raw materials and are accompanied by deterioration of their quality and biological value.

2. Literature review and problem statement

The most important stage of the storage technology is the pre-cooling of fruits [5–8]. Timely pre-cooling reduces intensity of the fruit breathing, slows the rate of accumulation and consumption of energy substances on the processes of vital activity of plant tissues, which significantly delays the process of ripening. Herewith the fruits organoleptic characteristics are formed slower that determines consumer ripeness: color, taste, flavor, their dense consistency and biological value are maintained longer and better. Rapid temperature drop creates unfavorable conditions for development of thermophilic and mesophilic microorganisms, at the same time psycrophilic microorganisms significantly reduce their activity [9, 10].

So, as a result of timely pre-cooling, the wastes from microbial diseases, physiological disorders are significantly reduced as well as the evaporation of moisture. At the same time, the shelf-life of fruits with high nutrition value significantly increases [11].

Technical and economic feasibility of pre-cooling is predetermined by simultaneous loading of the entire volume of the chamber with cooled product that allows creating optimal and stable temperature conditions from the first hours of storage. Such loading of chambers requires less cooling productivity of the equipment, and this, in its turn, has a positive effect on economic indicators of storage [12].

Pre-cooling is performed by one of the following ways: cold air in conventional storage chambers at relatively low speed (up to 1 m/s) and multiplicity of air exchange (30–40 volumes per hour); cold air in special chambers of intensive cooling at relatively high speeds of air motion (up to 3–4 m/s) and a large multiplicity of air exchange (60–120 or more volumes per hour); cold water (hydro-cooling); in the isothermal wagons or auto refrigerators [13].

Today the most common way of pre-cooling of fruits is considered to be cooling in conventional fruit storing chambers.

Its advantage without any doubt is the absence of reloading the fruits from one chamber to another. But the significant disadvantage of this method is significant duration of the process, especially for the batches of fruits of large size. This reduces technological efficiency of pre-cooling significantly and sometimes questions the appropriateness of its conducting. In view of the foregoing, there is a technological need for further study of existing methods of the fruit pre-cooling before storing them for preservation.

On the other hand, it is stated in many scientific studied [14–17] that traditional storage methods, based only on the use of artificial cold, do not allow solving in full the problem of long-term preservation of product quality. Low positive temperatures do not totally slow redox processes and development of pathogenic micro-organisms. Therefore, the effect of low temperatures during storage in practice is increased by other ways: the use of the modified external gas medium – controlled and modified (CGE and MGE), ozonation, ionizing radiation, etc.

Increasingly applied in the practice of storing is the pre-treatment of fruit and vegetable products by antioxidant substances [18, 19]. The treatment with antioxidant compositions can be performed in various ways: by spraying in the garden or by irrigation or immersion on the line of preparation the fruits for storage [20, 21]. In the course of conducting further scientific research, the question arose about the possibility of combination of technological operations of treating the fruits with antioxidant compositions and preliminary cooling. This research is devoted to the solution of this problem.

3. The purpose and objectives of the study

The conducted studies set the goal of scientific substantiation of expediency of combination of pre-cooling of fruits and their treatment with antioxidant compositions before the long-lasting storage, as well as setting the optimum conditions and ways of performing the given technological operation.

To implement the set goal, it was necessary to solve the following tasks:

– to determine experimentally duration of pre-cooling of fruits in different ways;

– to explore and analyze the impact of different ways of pre-cooling on the intensity of breathing and heat dissipation and loss of weight of the fruits;

– to determine the best method and the mode settings of pre-cooling the fruits.

4. Materials and research methods of the process of pre-cooling of fruits

The object of the study was the process of pre-cooling of fruits such as apple, pear and plum. Technological process was performed in experimental chambers of slow (Fig. 1) and intensive cooling, as well as in baths filled with cooling solution.

Fig. 1. Pre-cooling of apple fruit in the chambers of slow cooling: *a* – external view of the chamber, *b* – cooling of apples, *c* – apples prepared for pre-cooling

The chambers of slow cooling are equipped with radiator system with the natural movement of air, the chambers of intensive cooling have air system, in which heat is fed by air cooler by the forced air circulation.

The methodology of the experiment is described in detail in the previous publication [22]. The intensity of the breathing of fruits before and after cooling was determined by standard methods [23].The weight loss – by the method of fixed samples (Fig. 2) [23].

Fig. 2. Determining the weight loss of the fruits by the method of fixed samples

In the analysis and processing of experimental data, the methods of variation statistics were used, with the help of the "MS Office Excel 2007" computer software, the "Statistica 6" package and a personal computer.

5. Results of the research into the process of the fruit pre-cooling

5. 1. Experimental determining of the duration of the process of pre-cooling of fruits

Cooling of the fruits in a conventional storing chamber proceeded rather slowly (Fig. 3).

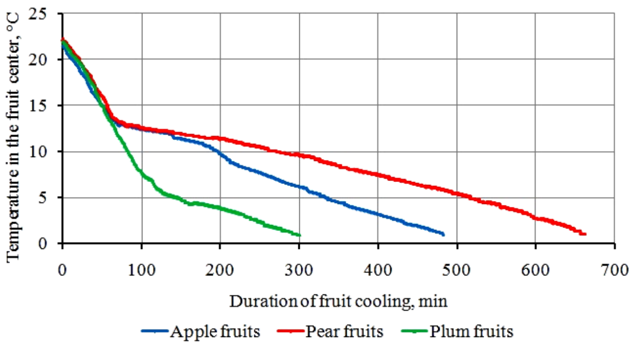

Fig. 3. Kinetics of the fruit cooling in a storing chamber

Thus, the duration of cooling of the batch of apple fruits with the mean diameter 65 mm was 8 hours, the batch of pear fruits of the mean diameter 70 mm amounted to 11 hours and the plum fruits of the mean diameter 38 mm reached 5 hours.

It should be noted that the speed of cooling during the first hour was almost the same for all types of fruits, as evidenced by the calculated velocity constants (Table 1).

Table 1

Velocity constants of the process of cooling fruits in storing chambers

Time of cooling, min	Velocity constants, k, min^{-1}		
	apple fruits	pear fruits	plum fruits
0...60	–0,036	–0,035	–0,036
from 61 till full cooling	–0,006	–0,004	–0,011

After the first hour of the cooling, the process proceeded at a slower pace. The highest speed of temperature decrease was displayed by the plum fruits, and minimal – by the pear fruits. The calculated coefficient of correlation between the largest transverse diameter of fruits and velocity constant of the cooling process (r=–0.99±0.01) confirms the existence of a close inverse dependence.

The kinetics of the fruits cooling in chambers of intensive cooling was different (Fig. 4). Thus, general period of cooling the apple and pear fruits to the temperature 0 °C lasted about 2 hours, and that of the plum slightly exceeded 1 hour. The velocity constant of the cooling process under these conditions was also much lower. Thus, for the apple and pear fruits it was the same and equaled k=–0.025 min^{-1}, and for the plum fruits it was 1.6 times larger and equaled k=0.041min^{-1}.

At the same time, the velocity constant of the process of pre-cooling in the chambers of intensive cooling was higher than in the conventional storing chambers for the pear fruits by 6.3 times, by 4.2 times – for the apple fruits and by 3.7 times – for the plum fruits.

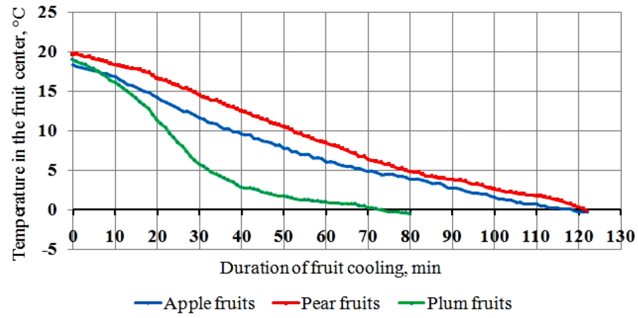

Fig. 4. Kinetics of fruits cooling in chambers of intensive cooling

In the study of the modes of the fruit pre-cooling by the method of hydro-cooling, the AOC solutions were used as the cooling medium. To set the optimal temperatures of the working AOC solutions during cooling of the fruits we identified their cryoscopic temperatures. Thus, the process of formation of the DPM composition occurs in the temperature range from 0.7 to minus 0.9 °C, the DL composition – from 0.6 to 0.1 °C and the AARL composition – at 0.3 °C. The duration of crystallization of all working solutions of antioxidant compositions is 2 hours. Therefore, for pre-cooling the fruits, the temperature of working solutions of 1.5±0.5 °C can be recommended.

Termograms of the fruit cooling in working solutions of antioxidant compositions (Fig. 5–7) demonstrate similar kinetics.

The total duration of cooling the apple and pear fruits to the temperature of 1 °C is about 3.5 hours, the plum fruits – 1.5 hours.

The velocity constants of hydro-cooling process of the apple and pear fruits in different antioxidant compositions did not differ significantly and varied within –0,014...–0,016 min^{-1} (Table 2), of the plum fruits was 2.3 times higher and amounted to 0.035 min^{-1}.

Analysis of the obtained data shows that the velocity constant of the process of hydro-cooling the apple fruits was larger than the velocity constant of cooling in storing chambers by 2.5 times and lower than the velocity constant of the intensive air cooling by 1.7 times. For the fruits of other cultures, similar dynamics is characteristic with the numeric values for pear – by 3.75 and 1.7 times, for plum – by 3.2 and 1.2 times, respectively.

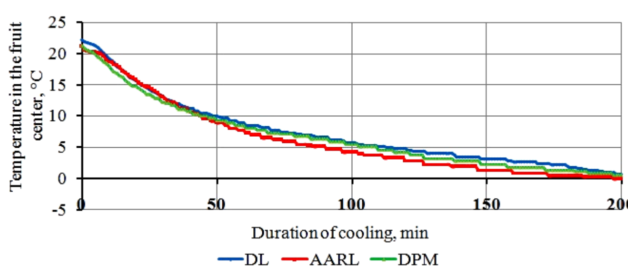

Fig. 5. Kinetics of cooling of apple fruits in the solutions of antioxidant compositions

Therefore, the most intensive way of pre-cooling is the cooling by air at temperature – 2 ...–4 °C and the airflow velocity of 3 m/s.

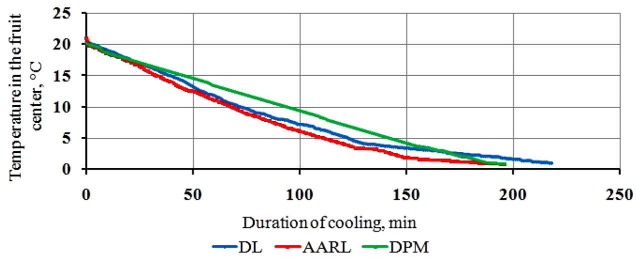

Fig. 6. Kinetics of cooling of pear fruits in the solutions of antioxidant compositions

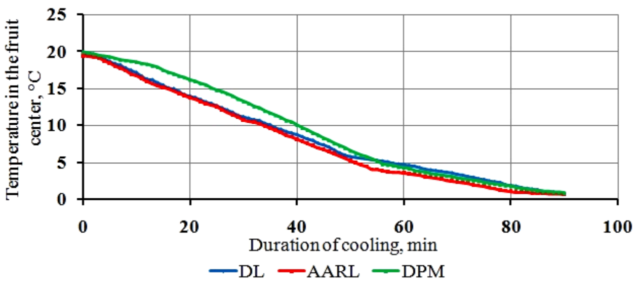

Fig. 7. Kinetics of cooling of plum fruits in the solutions of antioxidant compositions

Table 2

Velocity constants of the process of cooling fruits in the solutions of antioxidant compositions

AOC	Velocity constants k, min^{-1}		
	apple fruits	pear fruits	plum fruits
DL	–0,015	–0,014	–0,034
AARL	–0,016	–0,016	–0,036
DPM	–0,015	–0,015	–0,034

5. 2. Study of the effect of the methods of preliminary fruit cooling on the intensity of breathing and heat release

The difference in the speeds of cooling the fruits is directly related to the intensity of breathing. Thus, it is generally known that when breathing, not only CO_2 and H_2O are released, but a large volume of energy, too. This is an additional heat load, which significantly slows down the process of lowering the temperature. During cooling, the intensity of breathing reduces, and, accordingly, the heat release of the raw materials reduces as well.

The intensity of the fruits breathing before and after pre-cooling, as well as the intensity of the heat release at breathing, is shown in Table 3.

Table 3

Intensity of breathing and heat release of fruits during cooling

Type of fruit	Method of cooling	Intensity of breathing, mg CO_2/kg·hour		Intensity of heat release, kJ/kg·°C	
		1*	2**	1	2
Apple fruits (average 2005–2006)	Slow	19,622±0,893	11,314±0,580	209,763	120,949
	Intensive		4,792±0,406		51,227
	DL		5,815±0,438		62,157
	AARL		5,805±0,327		62,059
	DPM		5,712±0,445		61,059
	Combined		4,881±0,456		52,178
Pear fruits (average 2002–2003)	Slow	25,227±1,249	14,484±0,852	269,679	154,837
	Intensive		7,529±0,535		80,490
	DL		8,602±0,195		91,957
	AARL		8,102±0,272		86,607
	DPM		8,442±0,316		90,247
	Combined		7,415±0,484		79,261
Plum fruits (average 2010–2011)	Slow	27,785±0,706	7,219±0,424	297,023	77,180
	Intensive		4,385±0,522		46,879
	DL		4,582±0,176		48,977
	AARL		4,782±0,128		51,114
	DPM		5,057±0,249		54,057
	Combined		4,389±0,376		46,917

Note: 1 – before cooling, 2* – after cooling*

In this case, the intensity of the heat release of fruits was calculated by the following formula:

$$Q = q_{sp} I, \tag{1}$$

where q_{sp} is the specific heat of breath, 10.69 kJ on 1 g of CO_2; I is the intensity of breathing of fruits, mg CO_2/kg per hour.

The specific heat of breath was determined as follows: the process of aerobic breathing simplistically can be described by the equation:

$$C_6H_{12}O_6+6O_2 \rightarrow 6H_2O+6CO_2+2824, \text{ kJ}.$$

Since the molecular weight of CO_2 equals 44, then, by the equation of the breathing process, 44·6=264 g of CO_2 is released. Thus, 2824 kJ of heat will be released at 264 g of CO_2 and 10.69 kJ of heat will be released at 1 g of CO_2.

The obtained data indicate the dependence of the intensity of breathing of the fruits while gathering on their generic and varietal characteristics with substantial variability over the years of studies. The largest intensity of breath was characteristic of the plum fruits, somewhat less – pear fruits and the minimum – apple fruits. The mean coefficient of variability of this indicator equaled 24 %, with variation depending on the species and varieties of fruit within 13 % (plum fruits, variety Ugorka Italian) to 39 % (pear fruits, variety Cure).

According to this, the intensity of the heat release of the plum fruits while gathering was maximum and amounted to around 300 kJ/kg·°C, the pear fruits – 270 kJ/kg·°C, the apple fruits – 210 kJ/kg·°C.

The correlation analysis revealed that the main weather factor that has the most significant impact on the intensity of breathing of fruits is the amount of active temperatures of the last month of their formation. The defined correlation coefficients r equaled: for apples – 0.88±0.03, for pears – 0.02±0,92 and plums – 0.95±0.04.

Along with this, the velocity constant of reduction in the intensity of breathing of the plum fruits was by 2.3 and 2.8 times larger than the apple and pear fruits, respectively (Table 4). This means that, when cooling the plum fruits, additional heat load from their breath is reduced significantly.

Table 4

Velocity constants of reduction in the intensity of fruits breathing during cooling

Type of fruit	Velocity constants in the pre-cooling methods, k min^{-1}				
	Slow	Intensive	DL	AARL	DPM
Apple fruits	–0,0043	–0,0229	–0,0131	–0,0134	–0,0132
Pear fruits	–0,0036	–0,0238	–0,0129	–0,0154	–0,0150
Plum fruits	–0,0101	–0,0438	–0,0361	–0,0387	–0,0355

Regarding the methods of cooling treatment, we determined that the maximum velocity constant was reached at intensive cooling for all varieties of fruits, with exceeding the velocity constant of slow cooling by 6.6 times for pear fruits, by 5.3 times – for apple fruits and by 4.3 times – for plum fruits. During hydro-cooling in the AOK solutions, the speed of reduction in the intensity of breathing was lower compared with the intensive by 1.6, 1.2 and 1.5 times, respectively.

Thus, pre-cooling by intensive method promotes the fastest decrease in the intensity of breathing and heat release of fruits.

5. 3. Study of the effect of pre-treatment methods on the weight loss of fruit raw materials

Significant technological indicator, which characterizes changes in the quality of fruits after refrigeration treatment, is the weight loss (Fig. 8).

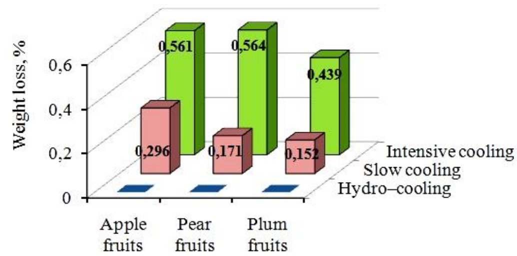

Fig. 8. Loss of weight of fruits at different methodss of pre-cooling

Graphic image demonstrates that the loss of weight of fruits during intensive cooling was maximal and varied in the range from 0.56 % in pear fruits to 0.44 % for plum fruits. During slow cooling in conventional refrigerating chambers, the loss of weight of the fruits was lower for apples almost by 2 times, and for the pear and plum fruits – by around 3 times.

Thus, the high speed of the airflow intensifies the process of fruit cooling. The result is the faster and efficient slowdown of the breathing process. However, at the same time, the natural loss of the fruit weight increases.

6. Discussion of the research results into methods and operational parameters of preliminary cooling of fruits

During cooling the fruits in the AOC solutions, the loss of weight of fruits was absent at all, and the speed and degree of slowing down the processes of breathing conceded a little to the intensive method.

With regard to this, the combined method was examined, which implied pre-cooling of fruits first in the AOC working solutions, then further cooling in the chambers of intensive cooling. During further cooling, the drying process occurs at the same time. In this case, the excess moisture that remains after preliminary stage of the technological process is removed from the surface of fruits instead of natural moisture.

The duration of phases 1 and 2 of the combined pre-cooling of fruits was determined based on the speed of the process of intensive and hydro-cooling. The speed of the processes of lowering the temperature was defined by the formula (2):

$$\vartheta = \tan\alpha = \frac{\Delta t}{\Delta \tau}, \tag{2}$$

where ϑ is the speed of the cooling process, °C/min, $\tan\alpha$ is the tangent of the angle of inclination of the straight line or the first derivative of the equation $t = a\tau + b$, Δt is the difference between the initial and final temperatures, °C, $\Delta\tau$ is the time difference, min.

The speed of the intensive cooling of apples amounted to 0.15 °C/min, pear fruits – 0.16 °C/min, plum – 0.26 °C/min. The speed of hydro-cooling equaled 0.099, 0.106 and 0.220 °C/min, respectively.

Based on this, the following modes of the stages of combined cooling were defined:

For the apple fruits: stage 1 – hydro-cooling in the AOC solutions during 1 hour to the temperature 8.5 °C in the center of the fruit, stage 2 – further cooling in the chamber of intensive cooling for 50 minutes up to the temperature 1 °C in the fruit center;

For the pear fruits: stage 1– hydro-cooling in the AOC solutions during 1.5 hours to the temperature 9 °C in the center of the fruit, stage 2 – further cooling in the chamber of intensive cooling for 50 minutes to the temperature 1 °C in the fruit center;

For the plum fruits: stage 1 – hydro-cooling in the AOC solutions during 40 minutes to the temperature 9 °C in the fruit center, stage 2 – further cooling in the chamber of intensive cooling for 30 minutes to the temperature 1 °C in the center of the fruit.

The loss of weight of fruits during combined method of cooling varied within 0.005 % for plum fruits to 0.014 % – for the apple and pear fruits. The velocity constant of the reduction in the intensity of breathing was 0.0245 min^{-1} for the apple fruits, 0.0215 min^{-1} – for the pear fruits and 0.045 min^{-1} for the plum fruit, that is hardly different from the constant at the intensive cooling.

Thus, the combined method of preliminary cooling is the most suited for both mode parameters and technological index of fruits quality.

7. Conclusions

1. The most intensive way of pre-cooling is the cooling by air at temperature –2 ...–4 °C and airflow velocity 3 m/s. Under such conditions, general period of cooling of apple and pear fruits to the temperature 0 °C is about 2 hours and slightly longer than 1 hour for the plum fruit.

2. It was found that the cooling velocity constant of reduction in the intensity of breathing and heat release of fruits at the intensive cooling was larger than the velocity constant of the analyzed indicators at during slow cooling by 4.3...6.6 times, and by 1.2...1.6 times during hydro-cooling depending on the type of fruit. Along with this, high speed of air motion increased the natural loss of weight of the fruits during cooling. The quantitative value of this indicator during intensive method was maximum and varied in the range of 0.56 % for the pear fruits to 0.44 % for plum fruits.

3. Combined method, which implies initially the pre-cooling in working solutions of antioxidant compositions and further cooling by the intensive method, was characterized by high velocity constant of reduction in the intensity of breathing and heat release of the fruits and low level of the natural loss weight. In this case, the quantitative value of the weight loss varied in the range from 0.005 % for plum fruits to 0.014 % for the apple and pear fruits.

References

1. DeLong, J. M. Erratum to "The influence of pre-storage delayed cooling onquality and disorder incidence in 'Honeycrisp' apple fruit" [Text] / J. M. DeLong, R. K. Prange, P. A. Harrisonn // Postharvest Biology and Technology. – 2004. – Vol. 34, Issue 3. – P. 351. doi: 10.1016/j.postharvbio.2004.10.002
2. Sun, J. Antioxidant and Antiproliferative Activities of Common Fruits [Text] / J. Sun, Y.-F. Chu, X. Wu, R. H. Liu // Journal of Agricultural and Food Chemistry. – 2002. – Vol. 50, Issue 25. – P. 7449–7454. doi: 10.1021/jf0207530
3. Hajrutdinov, Z. N. Sovershenstvovanie tehnologii hranenija plodov jagodnyh kul'tur putem intensifikacii processa ohlazhdenija [Text] / Z. N. Hajrutdinov // Vestnik MichGAU. – 2011. – Vol. 1, Part 1. – P. 206–209.
4. Choi J.-H. Fruit quality and core break down of "Wonhwang" pears in relation to harvest date and pre-storage cooling [Text] / J.-H. Choi, S.-H. Yim, K.-S. Cho, M.-S. Kim, Y.-S. Park, S.-K. Jung, H.-S. Choi // Scientia Horticulturae. – 2015. – Vol. 188. – P. 1–5. doi: 10.1016/j.scienta.2015.03.011
5. Wang, Y. The effect of postharvest calcium application in hydro-cooling water on tissue calcium content, biochemical changes, and quality attributes of sweet cherry fruit [Text] / Y. Wang, X. Xie, L. E. Long // Food chemistry. – 2014. – Vol. 160. – P. 22–30. doi: 10.1016/j.foodchem.2014.03.073
6. Pathare, P. B. Design of Packaging Vents for Cooling Fresh Horticultural Produce [Text] / P. B. Pathare, U. L. Opara , C. Vigneault, M. A. Delele, F. Al.-J. Al-Said // Food and Bioprocess Technology. – 2012. – Vol. 5, Issue 6. – P. 2031–2045. doi: 10.1007/s11947-012-0883-9
7. Moiseeva, N. A. Rekomenduemye rezhimy prodolzhitel'nosti holodil'nogo hranenija nekotoryh plodov i ovoshhej [Text] / N. A. Moiseeva, I. L. Volkind // Ovoshhevodstvo i teplichnoe hozjajstvo. – 2007. – Vol. 3. – P. 50.
8. Vigneault, C. Design of plastic container opening to optimize forced – air precooling of fruits and vegetables [Text] / C. Vigneault, B. Goyette // Applied Engineering in Agriculture. – 2002. – Vol. 18, Issue 1. – P. 73–76. doi: 10.13031/2013.7697
9. Kolodjaznaja, V. S. Prodovol'stvennaja bezopasnost' i holodil'naja tehnologija [Text] / V. S. Kolodjaznaja, E. I. Kiprushkina, D. A. Baranenko, O. N. Rumjanceva, I. A. Shestopalova // Vestnik Mezhdunarodnoj akademii holoda. – 2013. – Vol. 1. – P. 24–28.
10. Liu, B., Study on Forced Air Pre-cooling Mode of Fruit and Vegetable [J] / B. Liu, Y. Guo, W. Guan // Storage and Process. – 2003. – Vol. 6. – P. 7.
11. Wijewardane, R. M. N. A., Effect of pre-cooling, fruit coating and packaging on postharvest quality of apple [Text] / R. M. N. A. Wijewardane, S. P. S. Guleria // Journal of food science and technology. – 2013. – Vol. 50, Issue 2. – P. 325–331. doi: 10.1007/s13197-011-0322-3
12. lal Basediya, A., Evaporative cooling system for storage of fruits and vegetables-a review [Text] / A. lal Basediya, D. V. K. Samuel, V. Beera // Journal of food science and technology. – 2013. – Vol. 50, Issue 3. – P. 429–442. doi: 10.1007/s13197-011-0311-6
13. Dehghannya, J. Mathematical modeling procedures for airflow, heat and mass transfer during forced convection cooling of produce: a review [Text] / J. Dehghannya, M. Ngadi, C. Vigneault // Food Engineering Reviews. – 2010. – Vol. 2, Issue 4. – P. 227–243. doi: 10.1007/s12393-010-9027-z

14. Soliva-Fortuny R. C. New advances in extending the shelf-life of fresh-cut fruits: a review [Text] / R. C., Soliva-Fortuny, O. Martı́n-Belloso // Trends in Food Science & Technology. – 2003. – Vol. 9, Issue 14. – P. 341–353. doi: 10.1016/s0924-2244(03)00054-2
15. Oliveira, M. Application of modified atmosphere packaging as a safety approach to fresh-cut fruits and vegetables–A review [Text] / M. Oliveira, M. Abadias, J. Usall, R. Torres, N. Teixid , I. Vi as // Trends in Food Science & Technology. – 2015. – Vol. 1, Issue 46. – P. 13–26. doi: 10.1016/j.tifs.2015.07.017
16. Janisiewicz, W. J. Biological control of postharvest diseases of fruits [Text] / W. J. Janisiewicz , L. Korsten // Annual review of phytopathology. – 2002. – Vol. 40, Issue 1. – P. 411–441. doi: 10.1146/annurev.phyto.40.120401.130158
17. Argenta, L. C. Influence of 1-methylcyclopropene on ripening, storage life, and volatile production by d'Anjou cv. pear fruit [Text] / L. C. Argenta, X. Fan, J. P. Mattheis // Journal of agricultural and food chemistry. – 2003. – Vol. 51, Issue 13. – P. 3858–3864. doi: 10.1021/jf034028g
18. Priss, O. P. Effect of heat treatment with antioxidants on the content of bioactive compounds during storage of zucchini [Text] / O. P. Priss // Technology audit and production reserves. – 2016. – Vol. 1, Issue 1 (27). – P. 72–76. doi: 10.15587/2312-8372.2016.60339
19. Cisneros Zevallos, L. The Use of Controlled Postharvest Abiotic Stresses as a Tool for Enhancing the Nutraceutical Content and Adding Value of Fresh Fruits and Vegetables [Text] / L. Cisneros Zevallos // Journal of Food Science. – 2003. – Vol. 68, Issue 5. – P. 1560–1565. doi: 10.1111/j.1365-2621.2003.tb12291.x
20. Serdyuk, M. Influence of exogenous treatment with antioxidants on dynamics of phenolic compounds during storage of apples [Text] / M. Serdyuk, V. Kalitka, S. Baiberova // Eastern-European Journal of Enterprise Technologies. – 2014. – Vol. 5, Issue 11 (71). – P. 17–22. doi: 10.15587/1729-4061.2014.27584
21. Serdyuk, M. Zmina vmistu askorbinovoi kysloty v plodakh hrushi pry tryvalomu zberihanni z vykorystanniam antyoksydantiv [Text] / M. Serdyuk, N. Gaprindashvili // Pratsi Tavrijs'koho derzhavnoho ahrotekhnolohichnoho universytetu. – 2013. – Vol. 13, Issue 7. – P. 89–94.
22. Serdyuk, M. The study of methods of preliminary cooling of fruits [Text] / M. Serdyuk, D. Stepanenko, S. Baiberova, N. Gaprindashvili, A. Kulik // Eureka: Life Sciences. – 2016. – Vol. 3 (3). – P. 57–62. doi: 10.21303/2504-5695.2016.00148
23. Najchenko, V. M. Tehnologija zberigannja i pererobki plodiv ta ovochiv [Text] / V. M. Najchenko, I. L. Zamors'ka. – Uman': «Sochins'kij», 2010. – 328 p.