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THE RATE OF THE TEMPERATURE DROP IN SWEET PEPPERS AT THE TECHNICAL STAGE OF RIPENESS DURING THEIR COOLING

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Abstract. The leading vegetables in Ukraine are cabbages, cucumbers, tomatoes, sweet peppers, and aubergines. More than 27 million tons of sweet pepper is grown in the world yearly, and only about 161,600 tons of it in Ukraine. However, it takes one of the leading places in vegetable growing, and it is a traditional and the most common type of the vegetable.

The article presents the results of research on the rate of the temperature drop in sweet peppers at the technical stage of ripeness during their cooling and warming. Fruits of the sweet pepper of the Sondela variety at the technical stage of ripeness, with a weigh of 375, 208, and 104 g, ripening and harvested at the same time, were taken for the experiments.

The studies have shown that the fruit temperature dropped most actively in the first 40–50 minutes of storage, and then the rate of cooling decreased, the decrease starting in the pepper fruit weighing the least. Fruits weighing 104 g, 68 mm in diameter, reached their optimum temperature (0.0°C) in 2 hours. The cooling of peppers weighing 208 g, 80 mm in diameter, was only 10 minutes longer. The temperature of the largest fruits became 0°C after 3 hours 40 min. The enthalpy of the fruits, too, slowed down rapidly. If the rate of the decrease in the enthalpy is the same, it will have a positive effect on maintaining an even temperature of storage of peppers. Besides, it will make it possible to avoid the external sweating caused by an uneven temperature of the fruits. Also, the cooling process is not smooth and uniform: the temperature remains the same for some time, and then it sharply decreases, in percentage terms, between the indices. These processes indicate the resistance of a plant organism to unfavourable temperature conditions of the environment.

Keywords: sweet pepper, cooling and warming rate, physical and thermophysical parameters of the sweet pepper, heat capacity, en- thalpy.

ШВИДКІСТЬ ЗНИЖЕННЯ ТЕМПЕРАТУРИ ПЛОДІВ ПЕРЦЮ СОЛОДКОГО ТЕХНІЧНОЇ СТАДІЇ СТИГЛОСТІ ПРИ ЇХ ОХОЛОДЖЕННІ

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Анотація. У статті представлено результати досліджень швидкості зниження температури плодів перцю солодкого технічної стадії стиглості при їхньому охолодженні та отепленні. Для дослідів використовували плоди перцю солодкого сорту Сондела у технічній стадії стиглості масою 375, 208 та 104 г, одного строку дозрівання і збирання.

Дослідження показали, що найбільш активно температура плодів знижувалась у перші 40–50 хв зберігання, а потім спостерігалось зниження темпів охолодження плодів починаючи з самого меншого за масою плоду. Свого оптимума (0,0°С) плоди масою 104 г і діаметром 68 мм досягли через 2 год, лише на 10 хв довше тривав процес охолодження плодів масою 208 г і діаметром 80 мм, у самих крупних плодів температура 0°С встановилась через 3 год 40 хв. Швидкими темпами знижувалась і ентальпія плодів. Однаковий темп зниження ентальпії позитивно буде відображатись на утриманні рівномірної температури зберігання плодів і усунення процесу їх зовнішнього відпотівання через нерівномірну температуру плодів. Також процес охолодження відбувається не плавно і рівномірно, а з затримкою температури деякий час на одному місці, а потім різким її зниженням у відсотковому вираженні між показниками. Ці процеси свідчать про опір рослинного організму несприятливим температурним умовам оточуючого середовища.

Ключові слова: перець солодкий, швидкість охолодження і отеплення, фізичні та теплофізичні параметри перцю солодкого, теплоємність, ентальпія.

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Introduction. Formulation of the problem

Fresh vegetables are living organisms. To preserve their vital functions after harvesting, certain conditions of the environment are needed, in particular, the optimum storage temperature, that is, the final cooling temperature that should be quickly reached. Cooling food products consists in lowering their temperature by means of heat exchange with the environment, without the formation of ice. When the product is placed in a refrigerating chamber with the optimum storage temperature preset, its cooling occurs theoretically according to

Fourier's law of thermal conductivity of solids in non-stationary conditions [1]. First, the surface layers are cooled, and then the cooling gradually spreads inside the product. After cooling the product for some time, the temperature in all of its parts is the same and equal to the ambient temperature. The rate of heat removal and the final temperature of cooling the products in many cases determine successful refrigerated storage, in particular that of products of vegetable origin. However, if the fruits are not cooled immediately to the optimum temperature, it can intensify the respiration of the fruits, and negative biological and microbiological processes. It leads to significant losses of the products and deterioration of its quality as a whole.

Analysis of recent research and publications

A state's main task is providing the population with high-quality food products. This task requires an integrated approach, which begins with selection work, and is continued in the appropriate technologies of cultivation and collection of high quality products to be then preserved till they reach the consumer. The problem of preserving fruits and vegetables is always relevant. It is considered in works by V.A. Koltunov, O.P. Pris, K.V. Kostetska, V.F. Yalpachik [2-6].

The pepper is an economically valuable culture, popular in many countries. Its global commercial production is about 27 million tons, with an area of over 1.7 million hectares involved. 57% of this area is in Asia [7]. In Ukraine, according to the State Statistics Service, in 2017, 161.6 thousand tons of sweet pepper fruits was grown, with an average yield of 11.3 t/ha, although it is one of the key crops in vegetable growing [8].

A pepper fruit is a false berry containing 2–5 seed pockets, with a thickness of the flesh 1.0–8.0 mm. There is a wide variety of shapes of the fruits. According to the international classification UPOV (International Union for the Protection of New Varieties of Plants), a fruit can be, in its longitudinal section, flat, round, heart-shaped, square, rectangular, trapezoidal, triangular, narrow-angled, humpy-like. There are also intermediate forms [9]. The weight of the fruits depends on the variety and ranges from 5 to 200 g. They are classified as small (25 g), medium (25–45 g), and large (more than 45 g) ones, as well as thin-walled (1–2 mm), of medium wall thickness (3–4 mm), and thick (more than 4 mm). The dry matter content varies within 7.40–13.2%, sugar within 2.1–7.44, ascorbic acid within 105.7–270.0 mg/100 g [10].

There is no comprehensive experimental data on the physical and thermophysical characteristics of sweet pepper fruits of different ripeness degrees. In our opinion, researchers have avoided studying these issues, since the fruits themselves are different on the same plant, depending on the variety, the conditions of cultivation, and the degree of ripeness. Each variety has a genetically determined matrical and trophic variability of qualities. That is why, of the sweet pepper's physical properties, the following are worth studying: the weight and volume of the fruit, the volume of the seed cavity, the weight of the seed, seed stalk, and pulp, the thickness of the pericarp, the length and diameter of the fruit, its structural and mechanical properties. Thermophysical indicators of food products include heat capacity, heat content, heat and temperature conductivity. All these indices are necessary for scientifically grounded methods of storage. From this point of view, sweet pepper fruits have never been investigated.

In terms of thermophysics, cooling food products is removing heat from a body to be cooled in which there are no internal sources of heat, but juicy fruit and vegetable products are not such bodies. The amount of heat withdrawn from the cooled body can be determined by different methods. One of them is based on Fourier's law and consists in determining the heat transferred by thermal conductivity from the internal mass of the body and its outer surface that contacts the cooled medium.

The second method is based on Newton's law of cooling (the Newton-Richmann law) and consists in determining the heat transferred by the outer surface of the body to the cooled medium.

The third method of calculating the heat removed from the cooled body is the mass multiplied by the heat capacity and by the difference of the initial and final temperatures of the cooled body.

$$Q = G \cdot C(t_i - t_f), \text{ кJ} \quad (1)$$

where G is the product weight, kg

C is mass specific heat, kJ/kg•°C

t_i and t_f are the initial and final temperatures of the cooled body, °C [1].

In technical calculations of food cooling, it is the third method that is mostly used, as discussed in the works [1,2,6,11-13]. In the course of cooling, biochemical and microbiological processes slow down. Temperature is the major factor affecting the vital activity of fruit and vegetables after harvesting and during storage.

Thus, cooling is a complex process of heat and mass transfer, which should be considered as an integrated process of heat transfer. The efficiency of cooling and storing fruit and vegetables, including sweet peppers, at different stages of ripeness, depends on external and internal factors. Pepper fruits should be cooled immediately after harvesting in the appropriate phase of ripeness, as a delay with this process does not only shorten the shelf life of this juicy product, but also worsens the saleability and merchandising properties of the fruits. Thus, rapid cooling of sweet pepper fruits to the optimum storage temperature is a topical problem, and its solution could extend the term of consuming them fresh.

The purpose of the research was to determine the rate of temperature decrease in sweet pepper fruits of the technical stage of ripeness to the optimum in refrigerators, and the intensity of its increase during its presale preparation, depending on their physical and thermophysical characteristics.

To achieve this purpose, it was necessary to find out:

– physical and thermophysical characteristics of sweet pepper fruits at the technical stage of ripeness, of various visual dimensions;
– the rate of decrease in the temperature of sweet pepper fruits at the technical stage of ripeness to the optimum in refrigerators, depending on the weight and size;
– the intensity of the temperature increase of sweet pepper fruits at the technical stage of ripeness, depending on their weight and size during their warming, as part of their presale preparation;
– the change in the specific heat, or enthalpy, of sweet pepper fruits at the technical stage of ripeness during the temperature change.

Research Materials and Methods

For the research, cube-shaped sweet pepper fruits of the Sondela variety were taken at the technical stage of ripeness, ripened and harvested in the same period, grown in the same field in chernozem soils (Uman district, Cherkasy region). The temperature of the fruits before cooling was the same as that of the environment. The temperature inside the fruits was measured with an electronic thermometer WT-2. The temperature in the cooling chamber was 0°C, it was being registered in its change over time, but we ranked it in tables every 10 minutes.

The dry matter was determined by drying until a constant weight, according to DSTU ISO 751:2004, and soluble solids according to DSTU ISO 2173:2004, were reached.

Indicators of the weight and dimensions were studied by means of scales of medium accuracy tolerance, GOST (State Standard) 29329, and Vernier callipers of the 1st grade of precision, GOST 166. Other physical and thermophysical proper- ties of the sweet pepper were studied in accordance with the guidelines [12].

The physical density was determined (ρ_f, kg/m^3) by the formula (2), by the ratio of the weight of a fruit to the amount of the liquid displaced from a graduated glass container in which the fruit was placed, thus establishing its volume.

$$\rho_f = \frac{m}{V_1 - V_2} \quad (2)$$

where m is the weight of a sample, kg;

V_1 is the volume of the liquid, m^3;

V_2 is the volume of a sample in the liquid, m^3.

The true density (ρc) is the density of the product with no gas inclusions. It is determined by the formula (3), kg/m^3.

$$\rho_c = \frac{267000}{267 - n_c} \quad (3)$$

where n_c is the dry matter content of sweet pepper fruits.

There is dependence between food porosity (P), true density, and physical density (4):

$$P = \frac{\rho_c - \rho_f}{\rho_c} = (1 - \frac{\rho_f}{\rho_c}) \quad (4)$$

The bulk weight of the fruits was found by weighing them in a container of a certain volume, by the formula (5), t/m^3:

$$t = m_{mp} - m_m / V_m \quad (5)$$

where m_{mp} is the weight of the measuring container of a certain volume, with peppers, kg m_m is the weight of the measuring container of a certain volume, kg;

V_m is the volume of the measuring container, m^3. The void space (K) was calculated by the formula (6),%:

$$K = \left(1 - \frac{t}{V}\right) \cdot 100 \quad (6)$$

where ι is the bulk weight of the stack or pile of the product, t/m^3; V is the product density, t/m^3.

The heat capacity (C) was determined by the formula (7), kJ/kg • °C:

$$C = 4{,}19 - 0{,}028\, n_c \quad (7)$$

where n_c is the dry matter content of sweet pepper fruits.

The coefficient of thermal conductivity (λ) was determined by the formula (8), W/ m•°C:

$$\lambda = \frac{\rho_f}{\rho_c}(0{,}57 - 0{,}004 n_c) + (1 - \frac{\rho_f}{\rho_c}) \quad (8)$$

The thermal conductivity coefficient (a) was determined basing on the dependence (9), m^2/s: For the specific heat content, or enthalpy (ε), there is the formula (10), kJ/kg • ° C:

$$a = \lambda / C \cdot \rho_f \quad (9)$$

$$\varepsilon = C \cdot \Delta t \quad (10)$$

where C is heat capacity;

Δt is the temperature difference of the product before and after cooling.

Results of the research and their discussion

The UNECE Standard FFV-28:2016, which deals with selling sweet peppers and their quality control, classifies the fruits into three commercial grades and stipulates their standardisation by the diameter of their maximum cross-section or by their weight. If the fruits are standardised by their size, the difference between them must not exceed 20 mm. If the fruits are standardised by their weight, they are divided into three groups: 1 – weighing up to 180 g, with a tolerance of 30 g for the items in a pack; 2 – weighing 180 to 260 g, and with a tolerance of 80 g for the items in a pack; 3 – comprising fruits weigh- ing more than 260 g, without any restrictions. That is why, in this work, different fruits were selected for studying, out of all the three groups, namely those weighing 104, 208 and 375 g. For them, physical and thermophysical parameters are given, as presented in Table 1.

Table 1 – Physical and thermophysical characteristics of sweet pepper fruits at the technical stage of ripeness

Parameter	Group 1, fruits weighing up to 180 g	Group 2, fruits weighing 180 to 260 g	Group 3, fruits weighing more than 260 g
Physical			
Weight of the fruit, g	104.0	208.0	375.0
Fruit volume, cm^3	133.0	270.0	489.0
Pericarp thickness, mm	5–6	6–7	7–8
Fruit length, mm	68.0	101.0	110,0
Diameter of the fruit, mm	68.0	80.0	115,0
Content of dry soluble substances,%	2,8	3.4	3.5
Dry matter content,%	3.40	4.00	4.25
Specific weight, t/m^3	0.78	0.77	0.77
Bulk weight, t/m^3	0.41	0.42	0.43
Void space,%	47.3	45.6	43.9
Physical density, kg/m^3	778.2	771.6	766.3
True density, kg/m^3	1012.9	1015.2	1016.2
Porosity, fraction of 1	0.23	0.24	0.25
Relative density of the pericarp	0.78	0.77	0.77
Thermophysical			
Specific heat, kJ/kg•°C	4.09	4.08	4.07
Coefficient of thermal conductivity, W/m•°C	0.66	0.66	0.66
Coefficient of temperature conductivity, m^2/s	0.000207	0.000210	0.000213

The uniformity and stability of the temperature field of a group of products is a requirement for successful storage. It cannot be met without determining thermophysical parameters. The data in Table 1 demonstrate how diverse in quality are the fruits collected from one field, by all the physical characteristics of different groups of fruits. The dimensional physical specifications determined for the sweet pepper describe a group of products in some aspects and are the basis for the formation of the specific and bulk weight, void space, physical density of sweet pepper fruits. The most important criterion used to determine thermophysical parameters is not the temperature, but the content of dry substances. The sweet pepper fruits we examined at the technical stage of ripeness contained 3.40 to 4.25% of dry matter, and, respectively, the specific heat content was 4.09 to 4.07 kJ/kg•°C, depending on the weight of the fruits. So, the smaller the fruits are, the greater their specific heat capacity. When determining the heat and temperature conductivity, it is necessary to take into account the physical and the true densities that reflect the degree of porosity of the raw material.

The influence of the temperature on the heat capacity, the heat and temperature conductivity of fresh fruit can be neglected, but this is impossible for the enthalpy. Tables 2–4 show the rate of the temperature drop and the change in the enthalpy when sweet pepper fruits of different weight and diameter, at the technical stage of ripeness, are cooled.

Table 2 – The rate of the temperature drop, and the change in the enthalpy when cooling sweet pepper fruits weighing 104 g, 68 mm in diameter, at the technical stage of ripeness

Cooling time, min.	Temperature drop, °C	Dynamic difference		Enthalpy drop, (ε, kJ/kg•°C)	Dynamic difference	
		°C	%		ε	%
0	18.1	-	-	74.1	-	-
10	13.8	4.3	23.8	56.5	17.6	23.8
20	7.4	6.4	46.4	30.3	26.2	46.4
30	6.8	0.6	8.1	27.8	2.5	8.1
40	6.7	0.1	1.5	27.4	0.4	1.5
50	6.0	0.7	10.4	24.6	2.9	10.4
60	3.6	2.4	40.0	14.7	9.8	40.0
70	2.6	1.0	27.8	10.6	4.1	27.8
80	2.6	0.0	0.0	10.6	0.0	0.0
90	2.0	0.6	23.1	8.2	2.5	23.1
100	1.0	1.0	50.0	4.1	4.1	50.0
110	0.3	0.7	70.0	1.2	2.9	70.0
120	0.0	0.3	100.0	0.0	1.2	100.0

The data in Table 2 show that cooling the fruits of group 1 weighing up to 180 g to a temperature of 0°C takes 2 hours. At +18°C, the heat content of sweet pepper fruits of group 1 was 74 kJ/kg•°C. It means that, when cooling the pepper fruits to the optimum temperature, it is necessary to remove 74,100 kJ of heat from 1 ton of the product.

For fruits weighing more than 180 g – in our study, the ones weighing 208 g and being 80 mm in diameter

(Table 3), – it took 130 minutes to cool them down to 0°C. The process of heat removal was more intensive in the first 20 minutes, when the fruits were being cooled down by 5.1 and 3.2°C, respectively, every 10 minutes.

Table 3 – The rate of the temperature drop, and the change in the enthalpy when cooing sweet pepper fruits weighing 208 g and being 80 mm in diameter, at the technical stage of ripeness

Cooling time, min.	Temperature drop, °C	Dynamic difference		Enthalpy drop, (ε, kJ/kg • °C)	Dynamic difference	
		°C	%		ε	%
0	18.5	-	-	75.4	-	-
10	13.4	5.1	27.6	54.6	20.8	27.6
20	10.2	3.2	23.9	41.6	13.0	23.9
30	9.2	1.0	9.8	37.5	4.1	9.8
40	7.3	1.9	20.7	29.8	7.7	20.7
50	5.6	1.7	23.3	22.8	6.9	23.3
60	5.4	0.2	3.6	22.0	0.8	3.6
70	4.0	1.4	25.9	16.3	5.7	25.9
80	2.5	1.5	37.5	10.2	6.1	37.5
90	2.5	0.0	0.0	10.2	0.0	0.0
100	2.0	0.5	20.0	8.2	2.0	20.0
110	1.2	0.8	40.0	4.9	3.3	40.0
120	0.4	0.8	66.7	1.6	3.3	66.7
130	0.0	0.4	100.0	0.0	1.6	100.0

The dynamics of the temperature drop and of the enthalpy in large sweet pepper fruits weighing more than 260 g (group 3), – in our case, the ones weighing 375 g, 115 mm in diameter, – is as follows. They need more than 3 hours of cooling, in particular 220 minutes (Table 4). The heat content of the largest and heaviest fruits was 75.3 kJ/kg•°C at +18°C. That is, when putting them into storage, 75,300 kJ of heat will be brought in with 1 ton of peppers, which is 1,200 kJ more compared to the smallest fruits.

Table 4 – The rate of the temperature drop, and the change in the enthalpy when cooling sweet pepper fruits weighing 375 g, 115 mm in diameter, at the technical stage of ripeness

Cooling time, min.	Temperature drop, °C	Dynamic difference		Enthalpy drop, (ε, kJ/kg • °C)	Dynamic difference	
		°C	%		ε	%
0	18.5	-	-	75.3	-	-
10	15.9	2.6	14.1	64.7	10.6	14.1
20	13.2	2.7	17.0	53.7	11.0	17.0
30	11.8	1.4	10.6	48.0	5.7	10.6
40	10.9	0.9	7.6	44.4	3.7	7.6
50	9.7	1.2	11.0	39.5	4.9	11.0
60	8.6	1.1	11.3	35.0	4.5	11.3
70	8.1	0.5	5.8	33.0	2.0	5.8
80	7.6	0.5	6.2	30.9	2.0	6.2
90	6.8	0.8	10.5	27.7	3.3	10.5
100	6.4	0.4	5.9	26.1	1.6	5.9
110	6.3	0.1	1.6	25.6	0.4	1.6
120	5.5	0.8	12.7	22.4	3.3	12.7
130	5.2	0.3	5.5	21.2	1.2	5.5
140	4.9	0.3	5.8	19.9	1.2	5.8
150	4.8	0.1	2.0	19.5	0.4	2.0
160	4.4	0.4	8.3	17.9	1.6	8.3
170	3.9	0.5	11.4	15.9	2.0	11.4
180	3.2	0.7	17.9	13.0	2.8	17.9
190	2.3	0.9	28.1	9.4	3.7	28.1
200	1.2	1.1	47.8	4.9	4.5	47.8
210	0.5	0.7	58.3	2.0	2.8	58.3
220	0.0	0.5	100.0	0.0	2.0	100.0

Our studies (Table 2–4) showed that in sweet pepper fruits at the technical stage of ripeness, placed in a refrigerator where the temperature was 0°C, in the first 10 minutes, the temperature dropped by 3–5°C. After 20 minutes, the temperature decreased from the initial one by 10.7°C in the fruits weighing 104 g, 68 mm in diameter, by 8.3°C in the fruit weighing 208 g and with a diameter of 80 mm, and by 5.3°C in the fruit weighing 375 g, 115 mm in diameter. The most active temperature drop inside the fruits was recorded in the first 40–50 minutes of storage, and then the cooling of the fruits was slowing down starting with the lightest one. Further on, the temperature of the fruits dropped more slowly and reached its optimum (0.0°C) in 2 hours. The same value was observed in the fruit with a weight of 208 g and a diameter of 80 mm. In the largest fruits, the temperature 0°C was reached in 3 hours 40 minutes. As for the weight of the fruits, a pepper fruit has most of its mass in its skin, and the middle of the fruit is a chamber almost empty. So, the walls of the fruits being of the same thickness, the internal cooling varied but slightly with different fruits. It should be noted that the cooling process is not smooth and uniform: the temperature remains the same for some time, and then it sharply decreases, in percentage terms, between the indices. These processes indicate the resistance of a plant organism to unfavourable temperature conditions of the environment.

The drop in the enthalpy was rapid in the fruit with a weight of 104 g, a diameter of 68 mm, and a length of 68 mm (Table 2), that is, in the one that was significantly shorter than the other two fruits, thus being only 133 cm^3in volume, compared to 489 cm^3 of the largest, and 270 cm^3 of the medium one (Table 1). The largest fruit reached zero in 220 minutes, and the other two in about 2 hours. The same enthalpy drop rate will have a positive effect on maintaining a uniform temperature of fruit storage and will help avoid their external sweating caused by uneven fruit temperature.

Before selling sweet peppers, the temperature in the storage chambers is raised to warm the fruits.

The warming of cooled foods is the process of raising the temperature to the limit that prevents the condensation of moisture on their surface during the preparation for selling and transportation. The temperature of the ambient air is raised gradually, the ratio between its temperature and humidity being taken into account. The air dew point should all the time stay below the product's surface temperature. Thus, when warming, it is necessary to regulate constantly the temperature and relative humidity of the air. Warming is carried out in chambers equipped with air conditioning devices. However, as a rule, in vegetable storehouses with artificial cooling, there are no special warming chambers. That is why, one should carefully monitor the intensity of the temperature increase in sweet peppers that differ markedly in size and weight, and are stored in bulk, in containers or consumer packaging. When condensation appears, or at the first signs of microorganisms developing during warming, one should apply germicidal ultraviolet irradiation or ozone treatment with circulating air, etc. Our storage facilities, either with artificial cooling or without it, do not have such equipment.

The sharp increase in pepper fruits' temperature contributes to the formation of condensation on the fruits, which, if they sell slowly, can significantly intensify the respiration and trigger undesirable microbiological processes. That can result in the product's losing its marketable appearance, change in its consumption properties due to the spoilage of the fruits. That is why, the gradual warming of fruits is important for preserving their marketability and all merchandising properties.

We studied the rate of the increase in the temperature of sweet pepper fruits belonging to different groups according to their weight. We also calculated the change in their heat content during this process (Tables 5–7).

Table 5 – The rate of the change in the temperature and enthalpy during the warming of sweet pepper fruits, 104 g in weight, 68 mm in diameter, at the technical stage of ripeness

Warming time, min.	Increase in temperature, °C	Dynamic difference		Change in enthalpy, (ε, kJ/kg • °C)	Dynamic difference	
		°C	%		ε	%
0	0.1	-	-	0.4	-	-
10	3.4	3.3	97.1	13.9	13.5	97.1
20	6.8	3.4	50.0	27.8	13.9	50.0
30	10.2	3.4	33.3	41.8	13.9	33.3
40	13.4	3.2	23.9	54.9	13.1	23.9
50	15.5	2.1	13.5	63.5	8.6	13.5
60	16.8	1.3	7.7	68.8	5.3	7.7
70	18.3	1.5	8.2	74.9	6.1	8.2

Warming fruits weighing 104 g, 68 mm in diameter, to +18°C, takes 1 hour 10 minutes, while their cooling takes 2 hours.

Fruits weighing up to 260 g (Table 6), – in our case, the ones weighing 208 g, 80 mm in diameter, – returned to a temperature of 0 to 18°C in 1 hour 40 minutes, that is, compared to peppers weighing up to 180 g, their warming is 30 minutes faster.

Table 6 – The rate of the change in the temperature and enthalpy during the warming of sweet pepper fruits, 208 g in weight, 80 mm in diameter, at the technical stage of ripeness

Warming time, min.	Increase in temperature, °C	Dynamic difference		Change in enthalpy, (ε, kJ/kg • °C)	Dynamic difference	
		°C	%		ε	%
0	0.1	-	-	0.4	-	-
10	0.7	0.6	85.7	2.9	2.4	85.7
20	2.7	2.0	74.1	11.0	8.2	74.1
30	5.6	2.9	51.8	22.8	11.8	51.8
40	8.4	2.8	33.3	34.3	11.4	33.3
50	12.0	3.6	30.0	48.9	14.7	30.0
60	13.5	1.5	11.1	55.1	6.1	11.1
70	14.7	1.2	8.2	59.9	4.9	8.2
80	16.0	1.3	8.1	65.2	5.3	8.1
90	17.3	1.3	7.5	70.5	5.3	7.5
100	18.4	1.1	6.0	75.0	4.5	6.0

The most rapidly the fruits warm up in the first 40–50 minutes (Tables 5 and 6), namely by 2–3°C every 10 minutes. As a temperature of 12–13°C was achieved in the fruits, the process began slowing down more actively.

The largest fruits needed the longest time, both to cool down and to warm up, – about 3 hours (Table 7).

Table 7 – The rate of the change in the temperature and enthalpy during the warming of sweet pepper fruits, 375 g in weight, 115 mm in diameter, at the technical stage of ripeness

Warming time, min.	Increase in temperature, °C	Dynamic difference		Change in enthalpy, (ε, kJ/kg • °C)	Dynamic difference	
		°C	%		ε	%
0	0.1	-	-	0.4	-	-
10	0.6	0.5	83.3	2.4	2.0	83.3
20	1.8	1.2	66.7	7.3	4.9	66.7
30	3.2	1.4	43.8	13.0	5.7	43.8
40	4.8	1.6	33.3	19.5	6.5	33.3
50	6.2	1.4	22.6	25.2	5.7	22.6
60	7.5	1.3	17.3	30.5	5.3	17.3
70	8.4	0.9	10.7	34.2	3.7	10.7
80	9.5	1.1	11.6	38.7	4.5	11.6
90	10.6	1.1	10.4	43.2	4.5	10.4
100	11.4	0.8	7.0	46.4	3.3	7.0
110	12.1	0.7	5.8	49.3	2.8	5.8
120	12.8	0.7	5.5	52.1	2.8	5.5
130	13.6	0.8	5.9	55.4	3.3	5.9
140	14.5	0.9	6.2	59.0	3.7	6.2
150	15.6	1.1	7.1	63.5	4.5	7.1
160	16.8	1.2	7.1	68.4	4.9	7.1
170	18.2	1.4	7.7	74.1	5.7	7.7

The data in Tables 5–7 indicate that during the warming of sweet pepper fruits, the temperature rises more actively than it drops while cooling them. A plant organism does not resist the temperature rise, but actively renews its physiological, biochemical, and physical functions. It tries to recover from the state of deep cooling and stress. But after the warming, the pepper fruits should be sold out quickly, as, after such a stress, they cannot recover completely, especially such heatloving ones as sweet peppers.

Conclusions

Basing on the results of the physical study of sweet pepper fruits and their dry matter content, thermophysical parameters for the fruits of the technical stage of ripeness are calculated, which should be taken into account during fruit storage when creating and maintaining the optimum temperature by removing the heat with the help of circulating air.

Cooling is a complex process of heat and mass transfer, which should be considered as a process of conduction of heat. The intensity of the temperature drop in the pepper fruits depends on their weight, diameter, variety, and dry matter content. Fruits weighing up to 180 g cool down in 2 hours, while in fruits weighing over 260 g, a temperature drop to 0°C takes 1 h 40 minutes longer. The warming of sweet pepper fruits is faster than cooling and depends on their weight, too, so they should be sorted by weight, size, and other characteristics when put into storage.

Our data on the regularity in the enthalpy content, depending on the rate of cooling and warming the pepper fruits, completely corresponds to the previous studies. It adds to the theory, as well as to the improvement of the technology of juicy raw materials storage.

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