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THE IMPACT OF FREEZING METHODS ON FUNCTIONAL AND TECHNOLOGICAL PROPERTIES OF SEMI-FINISHED RABBIT MEAT PRODUCTS

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ABSTRACT

During storage meat and semi-finished meat products, the decisive factor is the correct implementation of freezing process, because the physical, histological, biochemical, microbiological changes that occur at this time, affect the final quality of product after defrosting procedure. Accordingly, studies of the impact of traditional and shock-freezing methods on functional and technological properties of semi-finished rabbit meat products represent scientific and practical interest. The effect of freezing temperature of natural and minced semi-finished rabbit meat products on the duration of cold treatment process has been studied, and the regression equations of their relationships have been obtained and regression curves have been constructed. It has been established that unlike traditional method, by the type of semi-finished products, the duration of cold treatment by shock-freezing method is 3 – 3.5 times shorter. The optimal freezing parameters have also been selected. It has been shown that the use of shock-freezing method contributes to the reduction of mass losses of semi-finished rabbit meat products, and by the type of semi-finished products, they are 5 – 5.3 lower as compared to traditional method of freezing. The determination of functional properties has revealed that shock-freezing allows for increasing water binding capacity-by 23.2 – 31.9%, water holding capacity-by 20 – 25% and pH by 6.7 – 10.4%. There have been studied microbiological indicators of frozen semi-finished products and their changes during the storage process. It has been established that they meet the safety and hygiene requirements for meat products. The full results obtained indicate the advantage of shock-freezing method as compared to traditional methods, as well as point to the appropriateness of its use when selecting the cold treatment modes for semi-finished rabbit meat products.

Keywords: rabbit meat; shock freezing; semi-finished products; functional properties; microbiological indicators

INTRODUCTION

The most important problem of modernity is to meet the population's needs for high quality and safe food products.

With a view to preserving the quality of foodstuffs and their safe storing for an extended period of time, of particular importance is the use of modern refrigeration technologies and the development of rational regimes cold treatment **(Bolshakov, 2003; Feiner, 2010; Hip, 2007; Erlihman, 2010; Evans, 2008; Farouk, Wieliczko and Merts, 2004)**.

During storage meat and meat products, as well as other perishable food raw materials, the decisive factor is the correct implementation of freezing process, because the physical, histological, biochemical, microbiological changes that occur at this time, affect the final quality of product after defrosting procedure **(Rogov, Zabashta and Kazyulin, 2009; Vieira et al., 2009; Gambuteanu, Borda and Alexe, 2013; Chwastowska-Siwiecka et al., 2013; Swami, Raut and Rindhe, 2015; Wang, He and Li, 2018)**.

When refrigerating meat and semi-finished meat products, the decisive factor, coupled with a temperature, is the rate of freezing. The process of crystallization of moisture existing in product, the sizes of generated ice crystals, their distribution in tissues and, consequently, maintaining the integrity of the tissue's natural structure, as well enzymatic changes in tissue and recovery of primary properties in the process of defrosting, depend on the dynamics of cold penetration into the depth of product.

Resaerch investigations of various authors have confirmed that the increase in the sizes of ice crystals in the freezing process is directly linked to disruption of a cell structure of tissue, and the most share of disruption of tissue cells takes place during freezing at slow rate. However, in some of the works, it is noted that in the superfast freezing process, there also occur substantial mechanical destructions in the tissue **(Jo et al., 2014; Onishchenko, Zheliba and Zinchenko, 2011; Leygonie, Britz and Hoffman, 2012)**.

The quality of the frozen product is achieved by the dynamics of the decrease of product temperature. In this regard, attention should be given to meat, in which 60 – 75% of the total weight is liquid. Accordingly, the freezing and defrosting processes are based entirely on the state of a liquid phase of the product.

It is known that the freezing process using traditional method takes places at temperature minus 18 °C and at an air velocity of 0.1 $m.s^{-1}$. In the case of different cooling equipment and different products, the duration of the process is 2.5 – 5 hours. At that time, due to a low rate of freezing within a temperature range from 0 to -5 °C, 70% of mosture existing in product is transferred from the liquid phase into the solid phase, the crystallization process begins, and due to slow freezing, the crystals are getting larger, which is accompanied by a substantial disruption of a cell structure of tissue.

Today, the efficient freezing and shock-freezing technologies are considered to be a promising area among the methods of cold treatment of meat products. Unlike traditional method, shock-freezing, due to high rate and low temperature, reduces 3 – 5 times the duration of freezing, prevents the increase in the sizes of crystals, considerably reduces mechanical destruction of tissue and contributes towards maintaining the structure of biological membrane. In addition, shock-freezing impedes bacteria development and activity, has a conservative impact on the natural autolytic processes of destruction of the protein structures **(Filippov, Kremenevskaya and Kutsakova, 2014; Evans, 2008; Soroko and Usenia, 2011; Qian et al., 2018)**.

Thus, the lower the meat freezing and storage temperature, the less change in the tissue structure caused by moisture redistribution and the increase in the liquid phase concentration, which is reflected in binding capacity of water and the loss of cellular fluid and nutrients dissolved in this fluid.

It should be noted that there are limited scientific data in the literature on the impact of freezing conditions on technological and functional properties on rabbit meat semi-finished products.

Based on the above, the goal of our study is to investigate the impact of different conditions of cold treatment of rabbit meat semi-finished products on the duration of freezing process and the functional-technological characteristics of semi-finished products.

Scientific hypothesis

By shortening the duration of freezing process, the shock-freezing method improves the functional-technological characteristics of product, with respect to the traditional method.

MATERIAL AND METHODOLOGY

The studies were carried out in the laboratories of the Department of Food of Akaki Tsereteli State University. Research covered semi-finished products produced from rabbit meat of Californian breed (their average age was 130 days): 1 – piece of rabbit meat – fillet; 2 – minced, made by traditional recipe; 3 – minced semi-finished product enriched with a plant-based supplement. As a plant-based supplement there was used lentil puree in the amount of 25 – 30% by mass of meat. The mass of all samples was 100 g, and the thickness was 20 mm.

The semi-finished products were frozen using the following methods: traditional freezing (freezing temperatures – T = -18 °C, air velocity – V = 0.1 $m.s^{-1}$ and relative humidity – φ = 85%), intermediate freezing (freezing temperatures – T = -30 °C, air velocity – V = 0.1 $m.s^{-1}$ and relative humidity – φ = 85%), and shock-freezing (freezing temperatures – T = -30 °C, air velocity – V = 9.4 $m.s^{-1}$ and relative humidity – φ = 87%), The freezing was carried out in a chest freezer in the wardrobe (KLIMASAN) at -18 °C, at an air velocity of 0.1 $m.s^{-1}$ and in a shock-freezing fridge (ATTILA GN 1/1 – 600x400 mm) at -35 °C, at an air velocity of 9.4 $m.s^{-1}$.

The freezing temperature in samples was determined by contact thermocouple thermodynamics (DIGITAL MULTIMETER DT9208A, the measuring range -40 °C – 1370 °C, measurement error – 1.5%). The product was considered frozen, when the temperature of product was fixed at minus 10 °C.

The mass losses during freezing and thermic treatment, we determined by the mass difference after the cold and thermic treatment of samples, water binding capacity – by press method of Grau and Hamm, water-holding capacity – by the difference between the amounts of moisture existing in semi-finished product and moisture released during thermic treatment **(Antipova, Glotova and Rogov, 2004)**, the pH medium was determined by potentiometric method.

Organoleptic indicators were determined based on a 10-point system, according to the following characteristics: appearance, color, smell, taste, consistency and succulence.

During microbiological analysis, the quantities of mesophylic aerobic and facultative anaerobic microorganisms in rabbit meat were determined according to state standard "Food products. Methods for determining the quantities of mesophylic aerobic and facultative anaerobic microorganisms" – **GOST 10444.15-94 (1994)**; number of bacteria of intestinal bacillus was determined according to State Standard "Food products. Methods for the detection and determination of the number of bacteria of the Escherichia coli group (coliform bacteria)" – **GOST 30518-97 (1997)**; Salmonella was determined according to State standard "Food products. Methods for the detection of bacteria of the genus Salmonella" – **GOST 30519-97 (1997)**.

Statistic analysis

To analyze the test parameters (mass losses, water binding and Water holding capacity) of rabbit meat, is conducted a statistical analysis of the obtained data, the reliability of the obtained data was evaluated by the mathematical statistics method T-test using the Windows IBM SPSS Statistics software program (version 20.0). To describe the ordered sample, we used statistical functions of the average arithmetic value and average standard error.

Graphical interpretation of the results was made by using Microsoft Excel. In Table 1, Table 2, Table 3, Table 4, Table 5 and Figure 1, Figure 2, Figure 3 and Figure 4, there are presented the data of typical tests, and each value is an average of at least ten determinations.

RESULTS AND DISCUSSION

In line with the target, using the different methods of freezing at the first stage of research, we determined the effect of freezing temperature of samples on the duration of their cold treatment. The results are shown in Figure 1A, Figure 1B, Figure 2A, Figure 2B, and Figure 3A, Figure 3B.

Figure 1A, Figure 1B, Figure 2A, Figure 2B and Figure 3A and Figure 3B illustrate that the process of cold treatment is significantly affected by the parameters, such as temperature and air velocity.

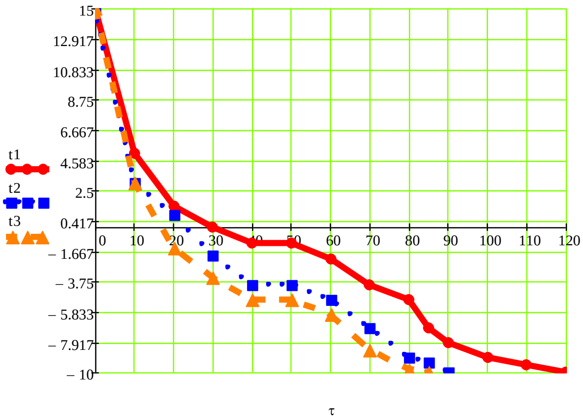

Figure 1A The effect of freezing temperature on the duration of freezing of semi-finished products during cold treatment by traditional freezing method.
Note: (T = -18 °C, V = 0.1 m.s^{-1}, φ = 85%),
1. fillet,
2. natural minced semi-finished product,
3. minced semi-finished product enriched with a plant-based supplement.

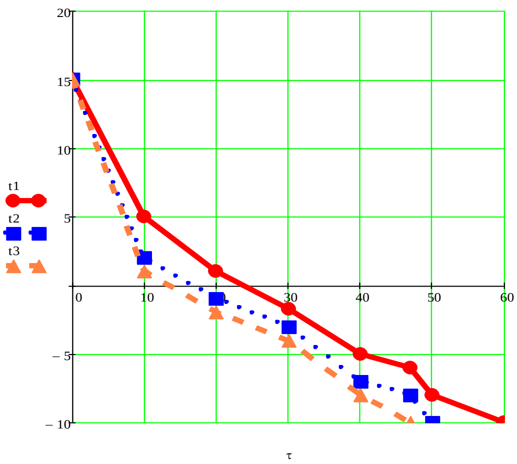

Figure 2A The effect of freezing temperature on the duration of freezing of semi-finished products during cold treatment by intermediate freezing method.
Note: (T = -30 °C, V =0.1 m.s^{-1}, φ = 85%),
1. fillet,
2. Natural minced semi-finished product,
3. minced semi-finished product enriched with a plant-based supplement.

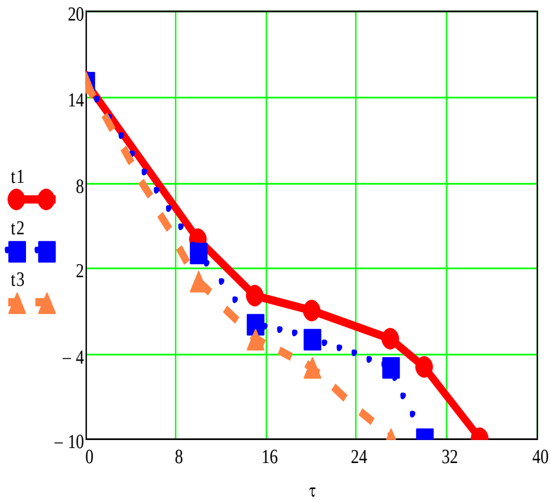

Figure 3A The effect of freezing temperature on the duration of freezing of semi-finished products during cold treatment by shock-freezing method.
Note: (T = -30 °C, V = 9.4 m.s^{-1}, φ = 87%),
1. fillet,
2. natural minced semi-finished product,
3. minced semi-finished product enriched with a plant-based supplement.

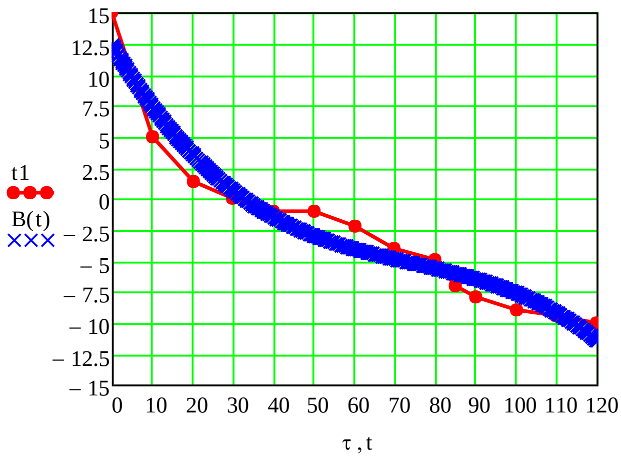

Figure 1B The effect of freezing temperature on the duration of freezing of semi-finished products during cold treatment by traditional freezing method.

b := regress (τ , t1, 3)
correlation coefficient
corr(τ , t1) = –0.961

$$b^T = \begin{pmatrix} 3 & 3 & 3 & 14.619 & -1.061 & 0.022 & -1.806\times 10^{-4} \end{pmatrix}$$

Regression coefficient
B(t) := interp(b , τ , t1, t)

$$a := \mathrm{line}(\tau , t1)\quad a = \begin{pmatrix} 10.857 \\ -0.379 \end{pmatrix}$$

the equation of the regression line

$$f(y) := a_0 + a_1 \cdot y$$

Diagram of the approximation dependencies

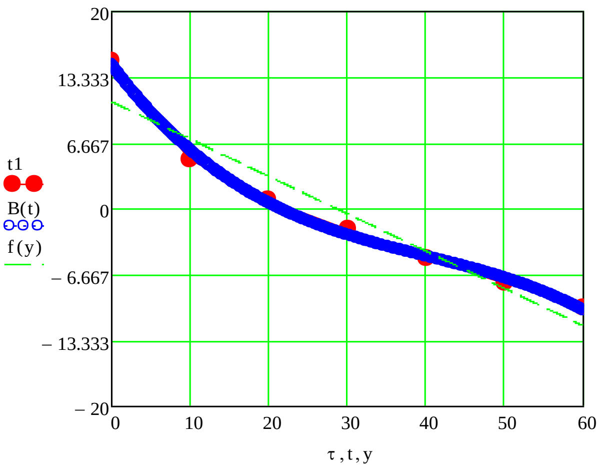

Figure 2B The effect of freezing temperature on the duration of freezing of semi-finished products during cold treatment by intermediate freezing method.

b := regress (τ, t1, 3)

correlation coefficient

$$b^T = (3\ \ 3\ \ 3\ \ 15.165\ -1.631\ 0.061\ -9.975\times 10^{-4})$$

$$a = \begin{pmatrix} 10.857 \\ -0.379 \end{pmatrix}$$

Regression coefficient

B(t) := interp(b, τ, t1, t)

a := line(τ, t1)

the equation of the regression line

$f(y) := a_0 + a_1 \cdot y$

Diagram of the approximation dependencies

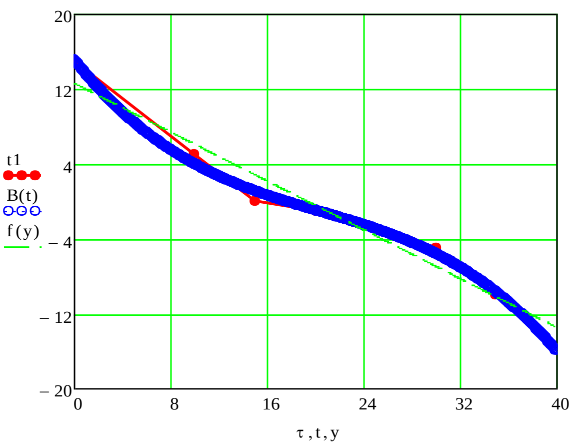

Figure 3B The effect of freezing temperature on the duration of freezing of semi-finished products during cold treatment by shock-freezing method.

We selected the value of reliability $p = 0.05$. In particular, the duration of freezing process in the case of shock-freezing is shortened relative to traditional method: 85 minutes off for rabbit meat fillet, 60 minutes off for natural minced semi-finished product, and 58 minutes off for minced semi-finished product enriched with a plant-based supplement. The difference between the freezing durations of different samples is explained by the different structures and compositions of samples.

A similar trend is reported in the data obtained by other authors **(Tsikin, 2012; Yablonenko, 2008; Ali et al., 2015; Jo et al., 2014)** in freezing similar semi-finished products produced from studied beef and pork, while in the case of rabbit meat, the obtained data are much better. This can be explained by the low content of fat in rabbit meat, the amount of which affects the duration of freezing.

Qualitative indicators of products (structure, storage stability and yield) are especially affected by the moisture content in them. Thus, at the next stage of research, we studied the functional-technological properties of samples: mass losses, water binding and water holding capacity of the study samples: mass losses, water connectivity and water retention capacity.

Table 1 and Table 2 outline the data on mass losses of the test samples under various cold treatment conditions and after thermic treatment.

The tables indicate that mass losses are as minimal in both cases of cold treatment and further thermic treatment, while using a shock-freezing method, and respectively, they are: for fillet – 0.7% and 9.5%; in the case of natural minced semi-finished products – 0.85% and 11.4%; while for minced semi-finished products enriched with a plant-based supplement – 0.75% and 10.2%.

In addition, under shock-freezing conditions, mass losses in minced rabbit meat semi-finished products are higher than in fillet, in particular, by 21.4%. In natural minced semi-finished products, while in minced semi-finished products enriched with a plant-based supplement, mass losses are 7.1% higher than in fillet, which is explained by a larger content of "free water" in fillet.

For their part, mass losses in fillet during shock-freezing are five times lower than during freezing by traditional method, while in minced semi-finished products – by 5.29 and 5.33 times, respectively. After thermic treatment of the test samples, the same data are reduced by 1.72, 1.58 and 1.69 times, respectively (Table 2).

It is well known that mass losses after thermic treatment of semi-finished products are linked to water binding capacity, while the organoleptic indicators of the finished products (succulence, consistency, appearance) depend on water holding capacity of semi-finished products.

Water binding and water holding capacities of the test samples in different freezing conditions are shown in Table 3 and Table 4.

The Table 3 and Table 4 illustrate that water binding and water holding capacities of the test samples are better in shock-freezing conditions.

The figures in tables illustrate that water binding and water holding capacities of the test samples are better in shock-freezing conditions. In comparison with traditional freezing method, water binding capacity of fillet has increased by 31.9%, while water holding capacity has increased by 25%, in natural minced semi-finished products – by 23,2% and 20%, respectively, and in minced semi-finished products enriched with a plant-based supplement – by 24,5% and 20,9%, respectively.

The better functional and technical indicators obtained by shock-freezing method show that of ice crystals formed during the fast freezing process have a minimal impact on a cell structure of rabbit meat tissue, at that time, no structural destruction of tissue and biological membranes is happening, so water crystals destroy the structure of tissues, there is a change of hydrophilic properties of tissue and destruction of the protein-water colloidal systems, resulting in reduced water binding capacity **(Tsikin, 2012; Yablonenko, 2008)**.

In addition, as compared with other semi-finished products, higher water binding and water holding capacities of minced semi-finished products enriched with a plant-based supplement, is presumably explained by the fact that water is held due to a substantial amount of starch and fiber fetlock existing in a plant-based supplement **(Tavdidishvili et al., 2018)**.

The obtained data on water binding and water holding capacities of the test samples are in line with similar data obtained by other authors during the freezing of beef, pork and poultry meat. For example, according to **Tsikin (2012)**, the lowest water binding and water holding capacities were found in those samples, which were frozen at minus 30 °C and at an air velocity of 9.4 $m.s^{-1}$.

We have also studied the variation of pH medium of minced semi-finished rabbit meat products during different modes of freezing (Figure 4).

As shown in Figure 4 the pH medium value for both samples, in all freezing conditions is within the required limits, and besides, under shock-freezing conditions, its value is 6.7 – 10.4% higher, indicating the advantage of this method.

At the next stage of the study, we studied the organoleptic indices of frozen minced semi-finished products after their thermic treatment. The results are presented on the profilograms (Figure 5 and Figure 6).

At the same time, the organoleptic indices of minced semi-finished rabbit meat products are enriched with a plant-

The profilograms show that the organoleptic indices of both samples of minced semi-finished products are better than under shock-freezing conditions.

At the sme time, the organoleptic indices of minced semi-finished rabbit meat products are enriched with a plant-based supplement are better than the organoleptic indices of natural minced semi-finished products, particularly, their higher succulence is explained by relatively higher water holding capacity of minced semi-finished products enriched with a plant-based supplement ability.

We have determined microbiological indicators of the test samples frozen by various methods (Table 5).

Microbiological analysis was carried out on the presence of mesophylic-aerobic and facultative anaerobic microorganisms, salmonellas and bacteria of intestinal bacillus. It has been established that in test samples, the quantities of mesophylic aerobic and facultative anaerobic microorganisms varied from $3.4 \cdot 10^2$ to $2.4 \cdot 10^3$ $CFU.g^{-1}$ (colony forming $unit.g^{-1}$) that does not exceed sanitary norms and rules.

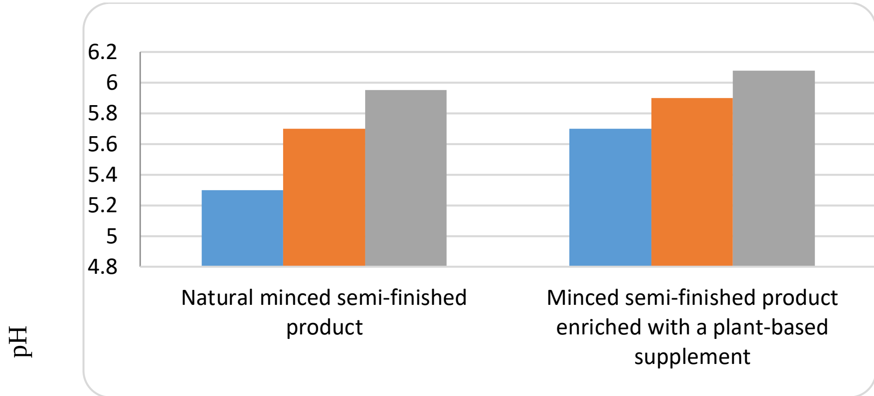

Figure 4 Change in the value of pH medium in minced semi-finished rabbit meat products in various modes of freezing.

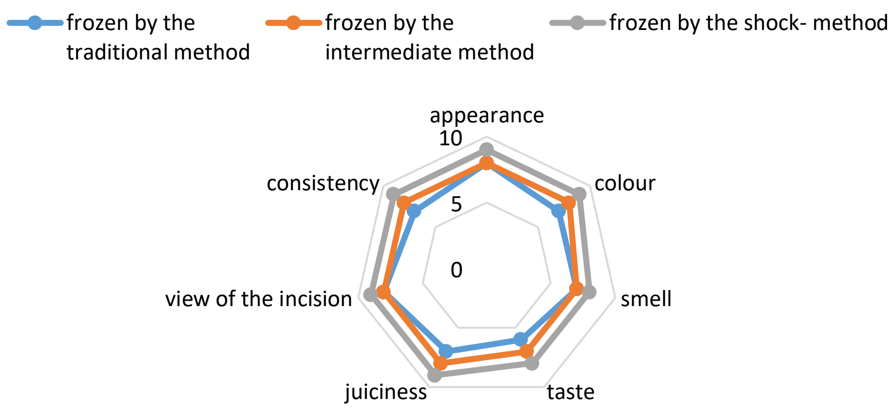

Figure 5 Profilogram of organoleptic indices of frozen natural minced semi-finished products after their thermic treatment.

Figure 6. Profilogram of organoleptic indices of frozen minced semi-finished products enriched with a plant-based supplement after their thermic treatment

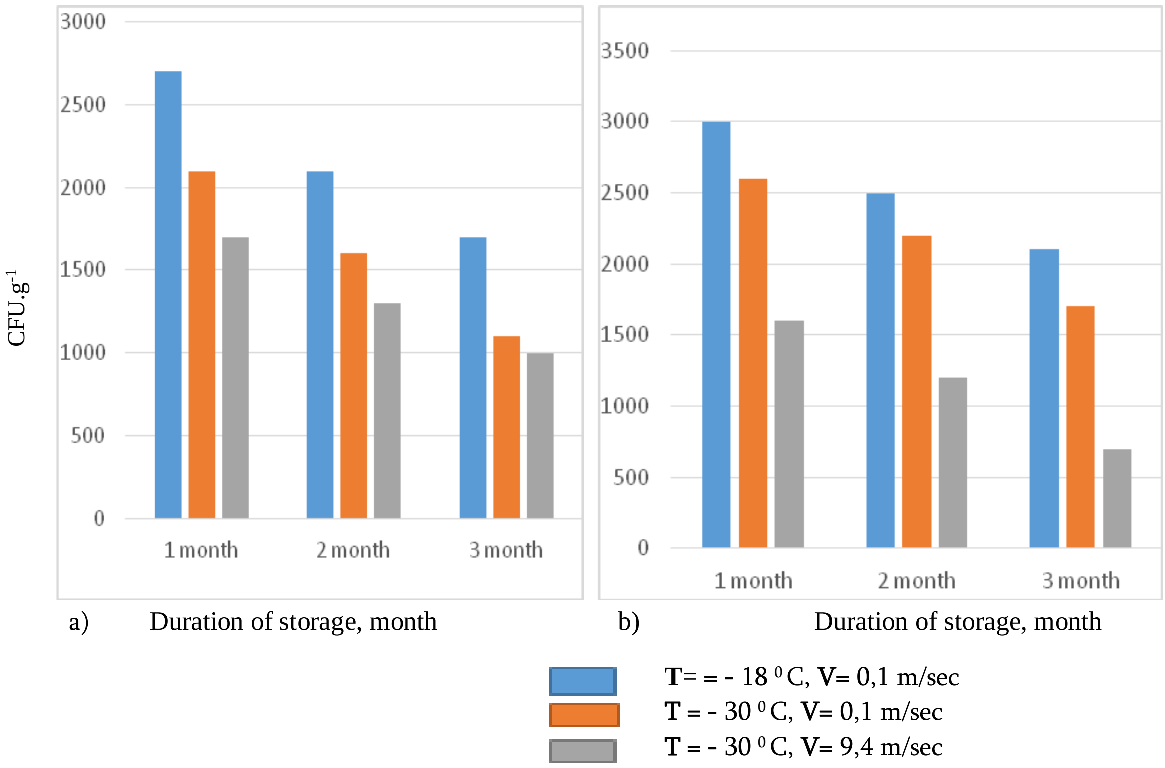

Figure 7. Changes in mezophilic-aerobic and facultative-anaerobic microorganisms ($CFU.g^{-1}$)during the storage process: a) in natural minced semi-finished products; b) in minced semi-finished products enriched with a plant-based supplement in various modes of freezing.

Table 1 Mass losses of rabbit meat fillet and minced semi-finished products under various freezing conditions.

Semi-finished products of rabbit meat	Change of mass after freezing, %		
	T = -18 ^{0}C, V = 0.1 m.sec^{-1}	T = -30 ^{0}C, V = 0.1 m.sec^{-1}	T = -30 ^{0}C, V = 9.4 m.sec^{-1}
Fillet	3.5	1.6	0.7
Natural minced semi-finished product	4.5	2.15	0.85
Minced semi-finished product enriched with a plant-based supplement	4.0	1.8	0.75

Table 2 Mass losses of rabbit meat fillet and minced semi-finished products frozen under various conditions after thermic treatment.

Semi-finished products of rabbit meat	Change of mass after thermic treatment, %		
	T = -18 ^{0}C, V = 0.1 m.sec^{-1}	T = -30 ^{0}C, V = 0.1 m.sec^{-1}	T = -30 ^{0}C, V = 9.4 m.sec^{-1}
Fillet	16.4	13.0	9.5
Natural minced semi-finished product	18.0	14.5	11.4
Minced semi-finished product enriched with a plant-based supplement	17.2	14.0	10.2

Table 3 Water binding capacity of rabbit meat fillet and minced semi-finished products under various freezing conditions.

Semi-finished products of rabbit meat	Change of water binding capacity from the total mass, %		
	T = -18 °C, V = 0.1m.sec^{-1}	T = -30 °C, V = 0.1 m.sec^{-1}	T = -30 °C, V = 9.4 m.sec^{-1}
Fillet	47	55	62
Natural minced semi-finished product	56	60	69
Minced semi-finished product enriched with a plant-based supplement	57	63	714

Table 4 Water holding capacity of rabbit meat fillet and minced semi-finished products under various freezing conditions.

Semi-finished products of rabbit meat	Change of water holding capacity, %		
	T = -18 ^{0}C, V = 0.1 m.sec^{-1}	T = -30 ^{0}C, V = 0.1 m.sec^{-1}	T = -30 ^{0}C, V = 9.4 m.sec^{-1}
Fillet	52	60	65
Natural minced semi-finished product	60	63	72
Minced semi-finished product enriched with a plant-based supplement	62	65	75

Table 5 Microbiological indicators of the test samples frozen by with different methods and their changes during the storage process.

microbiological indicators	Name of Product					
	fillet		natural minced semi-finished products		minced semi-finished products enriched with a plant-based supplement	
	before freezing	after freezing	before freezing	after freezing	before freezing	after freezing
Frozen by the traditional method (T = -18 ^{0}C, V = 0.1 m.sec^{-1})						
Number of mesophilic-aerobic and facultative-anaerobic microorganisms, cfu.g^{-1}, (colony-forming unit per gram), less than	$2.4*10^3$	$1.7*10^3$	$3.6*10^3$	$3.2*10^3$	$4.0*10^3$	$3.4*10^3$
E. coli group bacteria, in a 0.001 g sample	have not been identified	have not been identified	have not been identified	have not been identified	have not been identified	have not been identified
Pathogenic microorganisms, including *Salmonella*, in a 25 g sample	have not been identified	have not been identified	have not been identified	have not been identified	have not been identified	have not been identified
Frozen by the intermediate method (T = -30 ^{0}C, V = 0.1 m.sec^{-1})						
Number of mesophilic-aerobic and facultative-anaerobic microorganisms, cfu.g^{-1}, (colony-forming unit per gram), less than	$2.4*10^3$	$1.3*10^3$	$3.6*10^3$	$2.7*10^3$	$4.0*10^3$	$3.0*10^3$
E. coli group bacteria, in a 0.001 g sample	have not been identified	have not been identified	have not been identified	have not been identified	have not been identified	have not been identified
Pathogenic microorganisms, including *Salmonella*, in a 25 g sample	have not been identified	have not been identified	have not been identified	have not been identified	have not been identified	have not been identified
Frozen by the shock- freezing method (T = -30 ^{0}C, V = 9.4 m.sec^{-1})						
Number of mesophilic-aerobic and facultative-anaerobicmicroorganisms, cfu.g^{-1}, (colony-forming unit per gram), less than	$2.4*10^3$	$0.7*10^3$	$3.6*10^3$	$2.1*10^3$	$4.0*10^3$	$2.0*10^3$
E. coli group bacteria, in a 0.001 g sample	have not been identified	have not been identified	have not been identified	have not been identified	have not been identified	have not been identified
Pathogenic microorganisms, including *Salmonella*, in a 25 g sample	have not been identified	have not been identified	have not been identified	have not been identified	have not been identified	have not been identified

The established value of bacteria of intestinal bacillus (coliform) was not in 0.01 g sample, and met the hygienic requirements of microbiological safety, but pathogenic microorganisms including *salmonella*, have not been detected in 25 g samples, which also complied with microbiological safety norms and indicates safety of product. The data in Table 5 also confirm that the method of shock-freezing reduces the contamination of semi-finished products by mezophilic-aerobic and facultative-anaerobic microorganisms.

We have explored the changes in microbiological indicators of the test samples frozen under different conditions during the storage process, after 1, 2 and 3 months, respectively (Figure 7).

It has been established that during this period, no coliform bacteria and *salmonella* were found in the test samples, while the dynamics of changes in mezophilic-aerobic and

facultative-anaerobic microorganisms showed that, in the cases of all freezing methods, their value is reduced and is minimal when using the shock-freezing method.
Thus and so, studies have shown that method of shock-freezing allows for shortening the duration of freezing process, as compared to the traditional method, as well as for improving the functional-technological characteristics of product

CONCLUSION

With a view to preserving the quality of semi-finished rabbit meat products storing for an extended period of time, there have been studied various methods of their cold treatment. The advantage of shock-freezing method over the traditional methods has been justified and its rational parameters have been selected as follows: air temperature – not higher than -30 °C, air velocity – 9.4 m.sec^{-1} and relative humidity – 85%; the temperature in the depth of semi-finished product after freezing -10 °C.

The effect of freezing temperature on the duration of cold treatment process has been studied and the regression equations of their relationships have been obtained and regression curves have been constructed. It has been established that unlike traditional method, shock-freezing method reduces 3 – 3.5 times the duration of freezing of semi-finished rabbit meat products.

It has been shown that when using the shock-freezing method, mass losses of semi-finished rabbit meat products are minimal and are 5 – 5.3 lower as compared to traditional method of freezing.

Shock-freezing method allows for improving the functional properties of semi-finished rabbit meat products: by the type of semi-finished products, water binding capacity has increased by 23.2 – 31.9%, water holding capacity – by 20 – 25% and pH – by 6.7 – 10.4%.

There have been studied microbiological indicators of frozen semi-finished products and their changes during the storage process. It has been established that they meet the safety and hygiene requirements for meat products.

The full results obtained indicate the advantage of shock-freezing method as compared to traditional methods, as well as point to the appropriateness of its use when selecting the cold treatment modes for semi-finished rabbit meat products.

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