Cryoprotective properties of functional mixtures in cooked sausage products

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Abstract

Introduction. It is studied the effect of the cryostabilizing mixture in the composition of cooked sausages on the formation and stabilization of their functional, technological, structural, mechanical, and sensory characteristics under conditions of long-term storage in a frozen state.

Materials and Methods. The sausage was prepared using a cryostabilizing mixture with a content of 2.0, 2.5, 3.0 and 3.5 %. The control sausage does not contain a cryostabilizing mixture. The cryostabilizing mixture comprised animal protein, bamboo fiber, wheat fiber and sodium alginate in a ratio of 1:0.5:0.5:0.5. The sausages were frozen at –18 °C for 30 days.

Results and discussion. The addition of the cryostabilizing mixture to minced meat systems significantly improves their moisture retention (by 9.7–17.3%) and fat retention (by 9.4–9.7%), and increases the stability of the systems by 15.7–16.5%. The use of a mixture of 2.5–3% provided better sensory characteristics, including greater juiciness and structure density. Weight loss during defrosting and heat treatment decreased by 10.24–14.67%, and water activity decreased by 0.048, which contributed to the shelf life of sausage products. The cryostabilizing mixture also reduces the cryoscopic temperature of meat systems by 2.82–4.52°C and improves the structural and mechanical properties of products after defrosting.

The most significant changes in sensory quality indicators: insufficient juiciness, fragility of the structure, lower yield, and higher losses during heat treatment by 6.18–7.25% were observed in control samples after freezing, storage for 30 days, and thawing.

The best structural and mechanical properties (penetration stress 27.37–27.63 Pa) were obtained for thawed samples of sausage products with the addition of a cryostabilizing mixture in the amount of 2.5%–3.5%. The consistency and density of such products almost did not differ from the consistency of chilled products, and single stratifications of the structure were visible in their section, but in a very small amount.

Conclusions. The study proved that the use of 2.5–3% cryostabilizing mixture improves the sensory and structural and mechanical properties of cooked sausages.

Introduction

One of the promising areas for minimizing negative changes in meat products during freezing is the use of cryoprotective food ingredients that prevent the formation of large ice crystals and tissue dehydration (Simakhina et al., 2024; Sun et al., 2022). It has been shown that a composite cryoprotective mixture in the amount of 3% reduces the cryoscopic temperature of minced meat systems by 2.09–2.81°C, reduces the mass fraction of frozen moisture by 1.7%, and reduces the water activity index by 0.031–0.067 (Shevchenko et al., 2020).

The mechanism of action of these ingredients is to reduce the number of crystallization centers, which is especially important for sausage products stored for a long time at low temperatures (minus 18 °C and below) (Tian et al., 2021). The expediency of using hydrocolloids (carrageenans, xanthan gum, guar gum, sodium alginate, etc.) in meat product technologies has been established to improve their functional and technological properties and sensory characteristics (Dromenko et al., 2021; Shevchenko et al., 2020). Such ingredients provide an increased yield of meat products, improve their consistency, and extend shelf life (Ramadhan et al., 2012; Stabnikova et al., 2022).

Cryoprotectants also help to reduce water mobility in minced meat systems, which affects the process of ice formation, increasing the plasticity of products and ensuring the stabilization of their quality characteristics after freezing (Keniyz, 2014; Lee et al., 2002). During the storage of frozen meat products, proteins are denatured and aggregated, which leads to the loss of their functional properties. This process is exacerbated by the formation of intracellular ice and changes in salt concentration during water freezing (Castro-Giraldez et al., 2014; Yancheva et al., 2014). The use of cryostabilizing ingredients allows to protect protein macromolecules from denaturation, maintaining their functional and technological properties, in particular, emulsifying and moisture-binding capacity (Sharpe et al., 2009; Tuan Pham, 2014).

Studies have also confirmed the effectiveness of dietary fiber (wheat, plantain, etc.) in protecting minced meat systems from cellular degradation during freezing due to their hydrophilic properties (Castro-Giraldez et al., 2014; Tomaniak et al., 1998). In addition, polysaccharides, such as sodium alginate, due to their gel-forming properties, reduce the rate of water crystallization, which reduces osmotic drops and protects cells from destruction. The use of these components in sausage stuffing systems is a prerequisite for maintaining their quality and extending shelf life (Keniyz, 2014; Sapiga et al., 2021).

The effect of freezing on the quality of sausages is not well understood, and this requires additional research. It is necessary to substantiate the method of minimizing the negative effects of freezing on cooked sausages, to investigate the cryostabilizing ability of the mixture in model samples, and to assess its effect on the quality of sausages during long-term frozen storage.

The aim of research is to study the cryostabilizing ability of the mixture in the composition of cooked sausages for the purposeful formation and stabilization of their functional, technological, structural, mechanical and sensory characteristics under conditions of long-term storage in a frozen state.

Materials and methods

Cryostabilizing mixture

Composition of protein-polysaccharide cryostabilizing mixture: animal protein "ScanPro™ A-95" (Essentia) – a highly functional cold-brewed animal protein made from natural food pork raw materials by mechanical and heat treatment, dietary fiber: bamboo and wheat (Shandong Jianyuan Foods Co, Ltd.), sodium alginate (E401) (Shandong Jiejing Group Corporation) in a ratio of 1:0.5:0.5:0.5. The degree of hydration of the protein-polysaccharide composition was 1:6.

Recipe of the tested samples of cooked sausages

The sausages were made on the basis of pork (20%), chicken fillet (20%), minced chicken (20%), beef vein emulsion (20%) and lard (20%). In the production of minced meat for the cooked sausage test samples, the protein-polysaccharide mixture was added at 2.0, 2.5, 3.0 and 3.5% to replace the same amount of chicken fillet.

Preparation of sausage samples

The boiled sausage mince samples were ground with ice in a cutter to a temperature of 12 °C for 15 min, formed into a 55 mm diameter protein sausage casing, and heat-treated in a thermal chamber according to the heat treatment programme for boiled sausages in a natural protein casing. The finished sausage products were cooled to 12 °C for 8 h and frozen at minus 18 °C. The shelf life of the sausage samples at minus 10 °C was 30 days. The heat treatment of the experimental sausage samples, until the temperature in the centre reached 70–72 °C, was carried out before freezing and after defrosting. Defrosting was carried out at a temperature of 20±2 °C for 1.5–2 hours.

Methods for studying properties of cryostabilizing mixture and cooked sausages and optimizing their composition

The sensory parameters were determined in all samples before and after heat treatment: appearance, cut appearance, smell, taste, color, juiciness, and consistency (Savinok et al., 2017). Physicochemical (pH, moisture, protein, ash, fat content), functional and technological (emulsion stability, moisture binding capacity, emulsifying capacity, fat retention capacity, finished product yield), structural and mechanical (penetration stress), and water activity (a_w) parameters were also studied.

Sausage products were manufactured and tested in accordance with raw material restrictions that regulate the use of quality meat raw materials, permissible additives, moisture, fat, protein levels, and technological processes to ensure the safety and quality of sausage products.

Determination of the mass fraction of moisture. The mass fraction of moisture was determined according to the ISO 1442:1997 method used for meat and meat products. This method involves drying a sample of meat or meat product at a specific temperature to a constant weight. The weight loss of the sample during drying is considered the amount of moisture.

Determination of the mass fraction of fat. The mass fraction of fat was determined according to the ISO 1443:1973 method used for meat and meat products. The method involves the extraction of fat from meat or meat product using an organic solvent. After extraction, the fat is determined by measuring its mass.

Determination of the mass fraction of protein. The mass fraction of protein was determined by the Kjeldahl method "Agricultural food products. General guidelines for the determination of nitrogen content by the Kjeldahl method (ISO 1871:1975, IDT)".

Determination of the mass fraction of minerals. The mass fraction of minerals is determined by the gravimetric method after burning organic matter in a muffle furnace at a temperature of 500–700°C for 5–6 hours to a constant mass.

Determination of sensory characteristics of sausages. Sensory characteristics of sausages: the method is to assess the quality of sausage products according to five criteria: appearance, consistency, color in the cut, smell and taste. Each of these indicators is rated on a five-point scale, where 5 is excellent and 1 is unsatisfactory. The assessment is carried out by a group of experts who analyze the product according to the established parameters to determine its compliance with quality standards.

Determination of Water-Binding Capacity (WBC). The water-binding capacity of the research objects was determined using the Grau-Hamm press method, modified by Volovynska and Kelman. The method is based on the extraction of water from a 300 mg sample during a 10-minute pressing with a weight of 1 kg. The determination is carried out by measuring the size of the spot left on filter paper after the absorbed moisture is released. The outline of the spot from the pressed meat is drawn with a pencil. The size of the wet spot (outer) is calculated as the difference between the total area of the spot and the area formed by the meat (product). The WBC content is calculated using the formula:

$$WBC = \frac{(A - 8.4B) \times 100}{A}$$

where: WBC – the water-binding capacity, % of total moisture;

A – total moisture content in the sample, mg;

B – wet spot area, (cm^2).

Determination of emulsion stability. The emulsion stability (ES) of the coarse raw material was determined by heating at 80°C for 30×60s and cooling with water for 15×60s. Then, four 50 cm^3 calibrated centrifuge tubes were filled with the emulsion and centrifuged at a rotational speed of 500 s^{-1} for 5×60s. The volume of the emulsified layer was then determined. The stability of the emulsion was calculated by the formula:

$$ES = \frac{V_1}{V_2} \times 100$$

where:

V_1 – the volume of emulsified oil, cm^3;

V_2 – total volume of the emulsion, cm^3.

Determination of Emulsifying capacity. The emulsifying capacity (EC) was determined after centrifuging a mixture of oil, water, and emulsion at a rotation speed of 500 s^{-1} for 10×60 s. The volume of the emulsified oil was then measured, and the emulsifying capacity was calculated using the following formula:

$$EC = \frac{V_1}{V_2} \times 100$$

where: V_1 – volume of emulsified oil, cm^3;
V_2 – total volume of oil, cm^3.

Determination of the penetration stress. Penetration stress of the sausages was determined using a Brookfield DV1 digital viscometer by the depth of the indenter immersion in the test sample at 20°C. Three measurements were made on the open surface of the sample at a distance of at least 10 mm from the edge of the product and at the maximum distance from the points of other measurements so that the deformed part of the surface did not enter the measurement area, after which the penetration value was converted to the penetration stress value.

Determination of water activity. The water activity (a_w) of the model minced meat systems and sausages was determined using a rotronic Hygro Palm-23 analyzer. The cryoscopic temperature of the model minced systems and sausages was measured using the method of thermal analysis based on the construction of temperature change curves over time.

Results and discussion

Optimisation of the degree of replacement of meat raw materials with a cryostabilising mixture of animal proteins, polysaccharides and dietary fibers

In order to offset the negative effects of freezing on the functional and technological properties of low-functional meat raw materials and cooked sausages, as well as to prevent significant crystal formation and slow down the freezing process, the cryoprotective properties of a protein-polysaccharide mixture based on animal proteins, polysaccharides and plant fiber were investigated (Yancheva et al., 2014). Protein and vegetable fibers, such as bamboo and wheat, were chosen as cryostabilising components. Protein products, as high molecular weight substances, are able to reduce the growth rate of crystals and protect muscle cells from osmotic and temperature changes (Shevchenko et al., 2018). In addition, they can stabilise meat systems during storage.

Adding vegetable fiber to products subject to freezing and thawing can improve their texture, retain moisture and ensure consistent quality of the final product (Petracci et al., 2013). The sodium salt of alginic acid was used as a polysaccharide component. It is known that sodium alginate and bamboo and wheat fibres improve the consistency of food products, adsorb water, reduce weight loss, and enrich them with ballast substances (Yancheva et al., 2014). The principle of action of these substances is based on the formation of an amorphous structure in the food system, a decrease in the number of crystallisation centres and a decrease in the water activity index.

Study of chemical composition and functional and technological properties

In order to develop recommendations for the use of the mixture as a cryostabilising ingredient, the chemical composition and functional and technological properties (FTP) of model minced meat systems with different levels of its use were investigated. The results of the study are presented in Table 1.

Table 1

Chemical composition and functional and technological properties of model minced meat systems using the mixture (n=3)

Indicators	Samples				
	Control	Prototypes with the mixture, %			
		2.0	2.5	3.0	3.5
Mass fraction of moisture, %	72.03±3.14	71.47±3.35	71.50±3.40	71.67±3.39	71.56±3.41
Mass fraction of moisture protein, %	10.04±0.23	10.21±0.41	10.26±0.28	10.30±0.31	10.31±0.19
Mass fraction of fat, %	14.16±0.81	14.64±0.77	14.62±0.71	14.43±0.79	14.54 ±0.78
Mass fraction of carbohydrates, %	3.01±0.01	2.91±0.01	2.85±0.01	2.82±0.01	2.81±0.01
Mass fraction of ash, %	0.76±0.02	0.77±0.02	0.77±0.01	0.78±0.02	0.78±0.02
pH	6.13±0.14	6.15±0.21	6.16±0.17	6.17±0.19	6.17±0.07
Water-binding capacity, %	78.05±3.62	79.11±3.14	79.85±3.6	80.10±3.7	81.14±3.5
Water retention capacity, %	70.90±3.05	74.35 ±3.16	75.17±3.1.	76.01±3.0	76.79±3.0
Fat retention capacity, %	68.78±3.28	76.40±3.2	76.52±3.1	77.63±3.4	77.57±3.4
Emulsifying capacity,%	69.80±3.24	79.90±3.3	79.86±3.1	79.91±3.3	79.88±3.4
Emulsion stability, %	87.30±3.15	89.40±3.3	92.95±3.1	96.40±3.2	96.06±3.5
Penetration stress, Pa	117.25±0.75	24.87±0.95	27.37±1.06	27.54±1.08	27.63±1.07
Yield of the finished product, %	117.58±3.1	118.16±3.1	119.30±3.3	120.78±2.1	121.08±2.3

The introduction of the mixture into minced meat systems as a cryostabilising ingredient has a positive effect on increasing the moisture retention (by 3.45–5.89 %) and fat retention (by 7.62–8.79 %) capacities of model meat systems, which improves the structure of model samples of cooked sausages. When the gelling temperature of the selected polysaccharides approaches the denaturation temperature of meat proteins, water separates from the proteins and is absorbed by the protein-polysaccharide complexes. This creates stable protein-polysaccharide complexes.

An important indicator that determines the quality characteristics of cooked sausages is the stability of minced systems. This indicator characterises the content of bound water and fat in the meat system (Sharpe et al., 2009). The results of the study indicate an increase in the stability of the meat minced systems of the experimental sausage samples by 2.1–8.76 % compared to the control sample.

When determining the losses after heat treatment of cooked sausage samples, it was found that a higher yield (121.08 %) was characteristic of samples with a mixture of 3.5 %.

The most significant changes in sensory quality indicators (insufficient juiciness, fragility of the structure, lower yield, higher losses during heat treatment by 14.66–14.75 %) were observed in control samples after freezing, storage for 30 days and defrosting.

Study of sensory properties

According to the results of the sensory study of model samples of cooked sausages, it was found that the use of the developed cryostabilising mixture does not lead to noticeable changes in the sensory properties of meat systems. The best score, in comparison with the control sample, was given to sausage samples with a mixture content of 2.5–3.0 %, which were characterised by greater juiciness and structural strength, while samples with a mixture content of 3.5 % had too dense a consistency, were not juicy enough and had a worse taste (Figure 1).

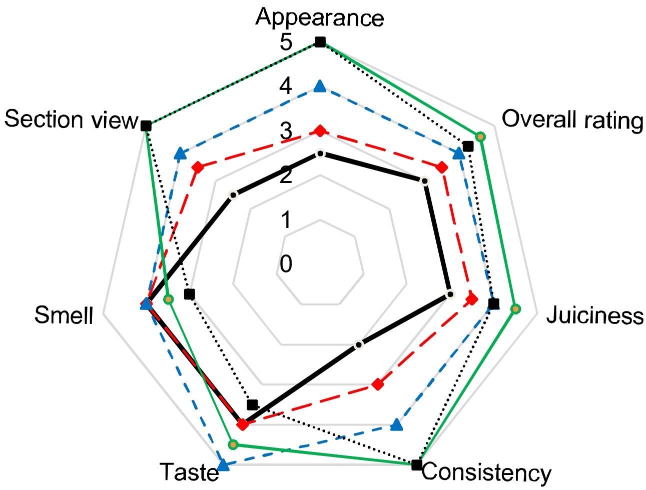

Figure 1. Quality profiles of cooked sausage samples by sensory characteristics and recipe composition

Study of mass loss after heat treatment

When determining the mass loss of heat-treated model samples of cooked sausages, it was found that the use of a cryostabilising mixture in the amount of 2.0 to 3.5 % in their composition can reduce mass loss regardless of the type of processing. Thus, the weight loss of the experimental samples of cooked sausages after defrosting and heat treatment was reduced by 10.24–14.67 %, respectively, compared to the control sample (Table 2).

Table 2

Weight loss of heat-treated model minced sausage systems with cryostabilising mixture (n=3)

Type processing	**Weight loss, %,**				
	Control	**Samples with mixture content, %**			
		2.0	**2.5**	**3.0**	**3.5**
Heat treatment before freezing	29.33 ±1.12	20.25 ± 0.93	17.50 ±0.78	16.23 ±0.78	16.42 ±0.79
Freezing	2.64 ±0.12	1.96 ±0.09	1.76 ±0.07	1.65 ±0.08	1.66 ±0.08
Heat treatment after defrosting	33.68 ±1.39	23.44 ±1.14	20.49 ±0.98	18.93 ±0.92	19.02 ±0.90

Thus, it can be concluded that the use of a cryostabilising mixture in an amount of 2.5–3 % can reduce the amount of frozen moisture to a minimum during the storage period stipulated by the technology at a temperature of minus 18 °C.

Determination of water activity and cryoscopic temperature

The preservative effect of the freezing process is aimed at reducing the water activity a_w , which contributes to the shelf life of meat systems (Sharpe et al., 2009). The use of the cryostabilising mixture as a cryostabilising ingredient in the model minced boiled sausage systems also reduces the water activity index a_w by 0.048 compared to the control sample. The dynamics of changes in the water activity index of meat minced systems and the cryoscopic temperature of heat-treated cooked sausage samples after 30 days of storage are shown in Figure 2.

A decrease in the temperature of the onset of moisture crystallisation in minced meat systems and, accordingly, a change in the nature of the process of water crystallisation in the cellular structure of muscle tissue at an increased content of the cryostabilising mixture in the experimental samples also causes a decrease in the water activity index a_w (Keniyz, 2014; Tuan Pham, 2014).

The obtained results confirm the expediency of using a cryostabilising mixture in the amount of 2.5–3 % as a composition of ingredients whose actions are aimed at cryoprotecting minced meat systems from the effects of low temperatures and reducing the water activity index a_w.

The protein-polysaccharide mixture also helps to reduce the cryoscopic temperature of minced meat systems by 3.82–4.52 °C and increases the moisture retention capacity by 3.45–5.89 % compared to the control sample, which has a positive effect on the quality of finished products.

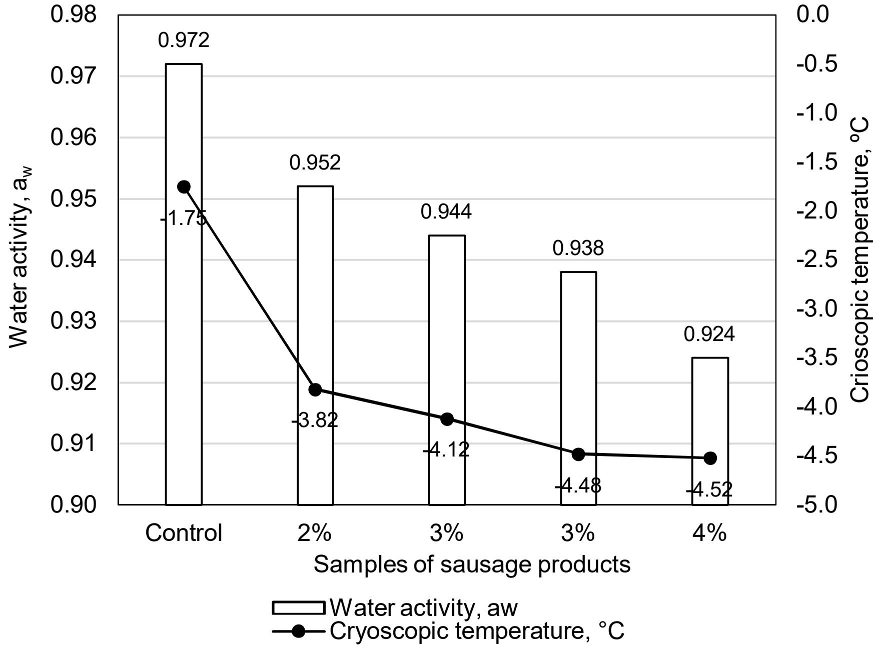

Figure 2. Dynamics of changes in the water activity index in minced meat systems and cryoscopic temperature of heat-treated samples of cooked sausages after 30 days of storage

Impact of cryostabilising mixtures on the quality of sausage products

According to the results of optimizing the composition of cooked sausages (Table 1), the range of the content of the cryostabilizing mixture in minced meat systems as a cryostabilizing ingredient is in the range of 2.5 to 3 %, which increases the moisture retention (by 3.45–5.89 %) and fat retention (by 7.62–8.79 %) capacities of model meat systems and improves the structure of model samples of cooked sausages. The crystallization process helps to retain moisture in meat products during heat treatment. This allows the product to retain its juiciness and texture, as the water that is usually released when proteins are heated does not escape from the product but is absorbed by the polysaccharides. The results of the study characterize the ability of meat systems to absorb and retain moisture during heat treatment (Tuan Pham, 2014). The determination of losses during heat treatment of model minced meat systems showed that a higher yield is typical for samples with the use of a cryostabilizing mixture in the range of 2.5 to 3 %. This effect can be explained by better retention of immobilized moisture during the heating process due to the capillary effect characteristic of dietary fiber and the high processing properties of thermostable proteins (Keniyz, 2014; Yancheva et al., 2018). The most significant changes in sensory quality indicators (insufficient juiciness, fragility of the structure, lower yield, higher losses during heat treatment by 14.66–14.75 %) were observed in control samples after freezing, storage for 30 days and thawing.

When water freezes, the concentration of soluble compounds in aqueous solutions of meat systems changes. This, in turn, affects changes in pH and the strength of ionic interactions in the layer close to the protein molecule. This phenomenon is a consequence not only of dehydration and aggregation, but also of the breakdown of glycogen remaining in the meat before freezing and the formation of lactic acid (Petracci et al., 2013; Yancheva et al., 2018).

Role of cryostabilising mixture in the process of cryopreservation

The use of cryostabilising mixtures in minced meat systems before the freezing process, due to its hydrophilic properties, can reduce the negative impact of physical and chemical factors and protect meat systems from cell destruction during cryopreservation. In addition, cryopreservation can slow down oxidative processes, prevent denaturation of proteins, molecular complexes and pigments, and deflavour the raw materials.

The research proves the functional, technological and cryostabilising properties of the cryostabilising mixture based on the selected ratio between highly functional animal protein, sodium alginate, bamboo and wheat fibre, which increases the moisture retention, fat retention and emulsifying capacity and forms the stable properties of model minced meat systems and cooked sausages.

Among all the experimental samples of chilled and heat-treated sausage products, the greatest changes in sensory quality indicators (after freezing, storage for 30 days and defrosting) were observed in the control samples after defrosting and heat treatment, which were characterised by insufficient juiciness fragility of the structure, deterioration of consistency due to the formation of large moisture crystals, which destroyed the consistency of the product during freezing, contributed to the stratification and deterioration of the product structure during defrosting and affected the decrease in yield and higher losses by 2.9– 3.1 % higher losses during heat treatment. However, the experimental control samples in the chilled state, before freezing, had better taste properties compared to the taste properties of the samples with the addition of the cryostabilising mixture in the chilled and thawed state. This confirms that the addition of sodium alginate can worsen the taste properties of sausage products, so its use should be well justified and optimally selected in terms of dosage.

Reasonability of use

The best structural and mechanical properties were observed in the thawed samples of sausage products with the addition of a cryostabilising mixture in the amount of 2.5 % and 3 %. The consistency and density of such products were almost the same as those of products that were not subjected to freezing, and single stratifications of the structure were visible in their section, but in a very small amount.

Thus, the results obtained confirm the feasibility of using a cryostabilising mixture in the manufacture of sausage products as a substance whose action is aimed at stabilising sausage minced systems and their cryoprotection against low temperatures during storage in the frozen state of such products at low sub-zero temperatures.

Thus, there are two promising areas for the use of the cryostabilising mixture in the production of cooked sausages to be stored frozen for a long time:

- stabilisation of functional and technological properties of meat raw materials and minced systems;
- cryostabilisation of minced meat systems when using cooked sausages for long-term storage in the thawed state.

Conclusions

1. The use of a cryostabilising mixture with a selected ratio between highly functional animal protein, sodium alginate, dietary fibers of bamboo and wheat fibre can stabilise the sensory and structural and mechanical properties of cooked sausages, help reduce weight loss during heat treatment and increase their yield.
2. The protein-polysaccharide mixture reduces the cryoscopic temperature of minced meat systems by 3.82–4.52 °C and increases the moisture retention capacity by 3.45–5.89% compared to the control sample, which has a positive effect on the quality of finished products.
3. Due to the cryoprotective effect of the ingredients of the cryostabilising mixture in the composition of minced meat systems in the amount of 2.5–3%, the water activity index a_w decreases by 0.048, which helps to extend the shelf life of sausage products of meat systems.
4. Due to their hydrophilic properties, animal protein, sodium alginate, dietary fibres of bamboo and wheat fibre can reduce the harmful effects of physicochemical factors and protect the minced systems of cooked sausages from cell destruction during cryopreservation, so they can be used in the production of cryostabilising mixtures for meat products.

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References

Castro-Giraldez M., Balaguer N., Hinarejos E., Fito P.J. (2014), Thermodynamic approach of meat freezing process, *Innovative Food Science & Emerging Technologies*, 23, pp. 138–145, https://doi.org/10.1016/j.ifset.2014.03.007

Dromenko O., Potapov V., Yancheva M., Onishchenko V., Bolshakova V., & Inzhyyants A. (2021), Research into the hermophysical characteristics of muscle and adipose tissues in the freezing–thawing process, *Food Science and Technology*, 15(3), https://doi.org/10.15673/fst.v15i3.2120

Keniyz N.V. (2014), *Technology of frozen semi-finished products using cryoprotectants*, Palmarium Academic Publishing, Saarbrücken,

Lee Ch. M., Lian P. (2002), Cryostabilization of unwashed fish mince, *Fisheries Science*, 68, pp. 1355–1358, https://doi.org/10.2331/fishsci.68.sup2_

Petracci M., Bianchi M., Mudalal S., Cavani C. (2013), Functional ingredients for poultry meat products, *Trends in Food Science & Technology*, 33(1), pp. 27–39, https://doi.org/10.1016/j.tifs.2013.06.004

Ramadhan K., Huda N., Ahmad R. (2012), Freeze-thaw stability of duck surimi-like materials with different cryoprotectants added, *Poultry Science,* 91(7), pp. 1703–1708, https://doi.org/10.3382/ps.2011-01926

Savinok O., Novgorodska N., Ovsienko S. (2023), Development of technology of cooked sausages with a changed fatty acid composition for military personnel in the armed forces of Ukraine, *Eastern-European Journal of Enterprise Technologies*, 6(11(126)), pp. 24–32, https://doi.org/10.15587/1729-4061.2023.292777

Savinok O., Pastyukov S., Kuzelov A., Shepelenko D. (2017), Sensory and functional parameters of sausages with reduced sodium nitrite content, *Scientific Works of University of Food Technologies*, 64(1), pp. 32–40.
Simakhina G., Naumenko N., Kaminska S. (2024), Changes in vitamin content and sensory characteristics of frozen wild berries during storage, *Ukrainian Food Journal*, 13(1), pp. 60–75, https://doi.org/10.24263/2304-974X-2024-13-1-5
Sapiga V., Polischuk G., Buniowska M., Shevchenko I., OsmakT. (2021), Polyfunctional properties of oat β-glucan in the composition of milk-vegetable ice cream, *Ukrainian Food Journal*, 10(4), pp. 691–706, https://doi.org/10.24263/2304-974X-2021-10-4-5
Stabnikova O., Danylenko S., Kryzhska T., Shang F., Duan Z. (2022), Effects of different phosphate content on the quality of wheat bran chicken sausage, *Ukrainian Food Journal*, 11(4), pp. 588–600, https://doi.org/10.24263/2304-974X-2022-11-4-8
Sharpe A.A., Azarov N.G., Yankova E.D., Bliznyuk A.A. (2009), The effect of freezing on the functional and technological properties of meat systems, *Food Science and Technology*, 2(7), pp. 12–14.
Shevchenko I., Skochko A. (2018), Advantages of using proteins in the production of truncated semi-finished products, *Food and Environment Safety*, 12(3), pp. 272–277.
Shevchenko I., Polishchuk G., Kotliar Y., Osmak T., Skochko A. (2020), Prospects of using the crystobilizing protein-polysaccharide composition to manufacture semi-finished chopped meat products, *Food Science and Technology*, 14(1), pp. 134–141, https://doi.org/10.15673/fst.v14i1.1642
Skochko O., Druhoveiko V., Shevchenko I., Maslikov M. (2018), The study of cryoprotective properties of protein-polysaccharide mixtures in the composition of chopped semi-finished products, *NAUKh Scientific Papers*, 24(5), pp. 203–207.
Tomaniak A., Tyszkiewicz I., Komosa J. (1998), Cryoprotectants for frozen red meats, *Meat Science*, 50(3), pp. 365–371, https://doi.org/10.1016/S0309-1740(98)00043-6.
Tian J., Walayat N., Ding Y., Liu, J. (2022), The role of trifunctional cryoprotectants in the frozen storage of aquatic foods: Recent developments and future recommendations, *Comprehensive Reviews in Food Science and Food Safety*, 21, pp. 321–339, https://doi.org/10.1111/1541-4337.12865
Tuan P.Q. (2014), Freezing time formulas for foods with low moisture content, low freezing point and for cryogenic freezing, *Journal of Food Engineering*, 127, pp. 85–92, https://doi.org/10.1016/j.jfoodeng.2013.12.007
Sun X., Wu Y., Song Z., Chen X., (2022), A review of natural polysaccharides for food cryoprotection: Ice crystals inhibition and cryo-stabilization, *Bioactive Carbohydrates and Dietary Fibre*, 27(100291), https://doi.org/10.1016/j.bcdf.2021.100291
Xiong Y.L., Mikel W.B. (2001), Meat and meat products, *Meat Science and Applications*, pp. 351–369, https://doi.org/10.1201/9780203908082.pt4
Yancheva M., Zheleva T., Pogozhych N., Hrynchenko A. (2014), Cryoscopy research of solutions of food ingredients of polysaccharide nature, *Eastern-European Journal of Enterprise Technologies*, 2(12), pp. 84. https://doi.org/10.15587/1729-4061.2014.23513
Yancheva M., Dromenko E., Potapov V., Hrynchenko O. (2018), Study of influence of freezing-defrosting on thermophysical properties of meat systems, *EUREKA: Life Sciences*, 1, pp. 32–38, https://doi.org/10.21303/2504- 5695.2018.005370.