Modern methods for cooling raw meat

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Abstract. Cooling of animal products occurs by lowering their temperature by means of heat exchange with the cooling medium, but without the formation of ice. Cooling ensures the preservation of high consumer properties of products (aroma, taste, consistency, color) with the least changes in them. In chilled products, at temperatures close to cryoscopic, during long-term storage, harmful microorganisms actively develop.

1. Introduction
The introduction of agricultural robotic systems (agrobots) and the development of autonomous agricultural systems based on them, required the development of models for their effective use in agriculture and the processing industry [1-3]. Currently, combined preservation methods make it possible to significantly increase the shelf life of perishable food products in a refrigerated state. During cooling, processes of heat and mass exchange between the product and the cooling medium take place, which causes evaporation of moisture from the surface of the product (shrinkage) and the transfer of heat from the product to the cooling medium.

In industry, the most common methods of cooling are carried out by the transfer of heat from the product by convection, radiation and as a result of heat transfer during phase transformation.

In accordance with the method of heat exchange, the following cooling systems are used for cooling: type of air conditioners (convective method); using liquefied gases (convective method); cooling with non-boiling liquids (conductive method); cooling with non-boiling liquids moving relative to the object (mixed method); vacuum, operating up to a pressure of 665 Pa (evaporation-condensation method).

2. The results and discussion
Modern directions for improving refrigeration processing are based on bringing the temperature of products to a level that is unfavorable for the development of microflora and ensuring their safety and reducing weight loss.

Specific cooling modes for each group of products are determined taking into account the cryoscopic temperature and in accordance with the peculiarities of their composition, properties, microstructure, biochemical processes, as well as intended purpose and economy.
Meat in the form of carcasses and half-carcasses to be cooled can be loaded into a continuous chamber synchronously with the operation of the conveyor in the animal slaughter and carcass cutting shop. Cooling of meat in the air is carried out in one-, two- and three-stage, as well as by software methods. Carcasses and half carcasses are conveyed sequentially along all overhead paths of the chamber with the help of a conveyor, the duration of passage along which must correspond to the duration of cooling. Continuous chambers are mainly used for the first stage of two-stage cooling.

The intensification of the process and a reduction in the duration of cooling is achieved by lowering the temperature and increasing the speed of air movement in the chamber.

In a one-stage method, the meat is cooled by lowering its temperature from the initial to the final 4 °C and is carried out in one chamber or in one stage. One of the disadvantages of this method is the long process duration, which is 28-36 hours for various types of meat.

In addition, due to significant moisture loss during cooling, the surface of carcasses and half carcasses is covered with a solid thick drying crust, which can subsequently swell, which increases the likelihood of microbial contamination and accelerates meat spoilage during storage. With an accelerated cooling mode, the temperature in the chamber is set close to cryoscopic, equal to 0 °C, and the air speed is at least 0.5 m / s.

Duration of cooling of beef, pork and lamb carcasses is on average 20–24 hours. The outlined tendency to decrease the temperature of the cooling air below the cryoscopic one and to increase the speed of its movement to 2 m / s is explained by the desire to intensify the cooling process. At the same time, additional energy consumption, in comparison with the traditional method, is quite justified, since the duration of the process is reduced, shrinkage is reduced and the productivity of the cooling chambers increases.

With the fast method, lowering the air temperature to −3 ... −5 °C and increasing its speed to 1.0–2.0 m / s reduces the cooling time of beef to 12–16 hours, pork to 10–3 hours. The reasons for holding back the intensification of one-stage cooling of meat by lowering the temperature and increasing the speed of air movement is the danger of freezing the product.

With a two-stage method, the temperature of meat carcasses and half-carcasses is lowered first in an intensive cooling chamber at a low air temperature t equal to −4... −15 °C, and its intensive circulation (1.0–2.0 m / s). The first stage of the process ends when the product surface temperature tn approaches cryoscopic t. The second stage of the process (aftercooling) is performed at a higher temperature of −1... −1.5 °C and an air velocity of no more than 0.1–0.2 m / s until the required temperature is reached in the center of the product. After further cooling, the temperature of the meat is equalized throughout the volume of the half carcass to the final temperature.

The use of two-stage cooling reduces the duration of the process in the intensive cooling chamber by 2–3 times, which equally increases their productivity. Compared to the traditional one-step method, shrinkage is reduced by 20-30%. A rapid decrease in the surface temperature of meat to 0-1 °C slows down the development of microflora, which ensures high stability of raw materials during storage. In addition, the meat has a good presentation due to the formation of a thin drying crust and preservation of a bright color.

A relatively new method of cooling: air at elevated pressure; hydroaerosol; vacuum; using electrophysical methods; snow-like carbon dioxide; deep in the environment of inert gases.

Hydroaerosol cooling was originally used only for cooling plant materials – vegetables, fruits, herbs and flowers. Now it is used to cool meat in carcasses, half-carcasses and quarters, poultry, as well as sausages.

Hydroaerosol cooling is carried out by irrigating the surface of the meat half with the help of nozzles with finely dispersed water with a temperature of 9 °C. Within 3 hours, the temperature in the thigh of the half carcass decreases from 35–37 °C to 22–24 °C, and on the surface – to 10–12 °C. Additional cooling to the final temperature is carried out in chambers at an air temperature of 0... −1 °C for 10–13 hours. The total cooling time does not exceed 16 hours. With this method of cooling, weight loss is reduced, but at the same time the surface of the meat is moistened, which significantly reduces its shelf life.
The hydroaerosol cooling method can be carried out in a chamber with intensively circulating air at a relative humidity of up to 100%. To prevent spoilage of meat, bactericidal substances are added to the water. The process is intensified due to evaporative cooling from the surface of the half carcasses and is twice as economical in energy consumption as traditional air cooling.

Abroad, meat and meat products are cooled in a liquid droplet medium with a temperature of –8…–15 °C, created by a propylene glycol solution. Compared to air cooling, the efficiency of this method is 2–3 times higher.

Electrophysical method of cooling meat products, in which cooling is carried out using electrically charged liquid drops, treatment with ionizing gases, electroconvective cooling, etc.

The use of ionizing gases allows you to maintain high quality, reduce product shrinkage and increase the shelf life of semi-finished meat products by 1.3–1.5 times, as well as reduce the energy costs of production.

With electro-convective cooling, the density of the heat flux from the cooled product significantly increases (for different types of meat - by 1.1–1.8 times). With an increase in the electric field voltage, the maximum of the heat removal shifts to an earlier stage of the process and decreases in time by about two times, which is very significant, since the greatest mass loss occurs in the first half of the cooling process. Shrinkage due to electrical forces preventing moisture from evaporating from the product surface is reduced by 10–20 percent.

For cooling poultry meat from the point of view of sanitary conditions of production, the safest are the irrigation and combined (irrigation – immersion, irrigation – immersion – air treatment, irrigation - air treatment) cooling methods. The irrigation cooling method virtually eliminates cross-contamination of poultry carcasses and reduces the amount of moisture absorbed by them to 3%, which is below the acceptable level of 7 percent.

With the combined method of cooling (irrigation-immersion), gutted carcasses are pre-cooled by irrigation with water for 10–15 minutes, depending on the type of bird, and then recooled to a temperature in the thickness of the pectoral muscles of 0–4 °C by immersion for 25–35 minutes in a bath with ice water. Pre-irrigation reduces the total bacterial contamination of the carcass surface by 70% of the original.

The amount of moisture absorbed by the carcasses can also be reduced by partially conducting the final stage of additional cooling in an air cooling chamber. The advantage of this method is that during air aftercooling from the product not only moisture obtained at the stage of water cooling is removed, but at the same time additional heat removal occurs during its evaporation.

The combined hydro-aerosol-evaporative method of cooling poultry realizes the advantages of modern water and air cooling (irrigation – air treatment). This method provides for a combination of blowing cold air onto the carcasses with periodic application of droplet-liquid moisture of a certain degree of dispersion to their surface using nozzles.

Compared to the air cooling method, the cooling rate in the hydroaerosol-evaporative method is higher due to the evaporation of sprayed moisture, the product does not shrink. In the case of using this method as the first stage of lowering the temperature of carcasses before freezing, the loss of juice during defrosting of poultry meat decreases and does not exceed 1.8 percent.

When using the hydroaerosol-evaporative cooling method (irrigation-air treatment), the correct choice of process parameters is required, taking into account the influence of various factors. Excessive moistening of the carcass and its minimal shrinkage are achieved only if the masses of moisture sprayed on the carcass and evaporated from its surface are approximately equal. To ensure a high rate of cooling, save drinking water and prevent the washing out of nutrients from the carcasses, it is desirable that all the moisture sprayed by the nozzles remains on the surface of the carcasses and is retained on it without draining.

It should also be borne in mind that with intensive evaporation of moisture from the surface of the product, it becomes possible to form a snow coat on the surface of the evaporator of the air cooler, which will require frequent defrosting and reduce the performance of the device as a whole. Maintaining the temperature of the cooling air not lower than 0 °C removes the problem of the formation of a snow coat.
on the evaporator of the air cooler, but leads to an increase in the duration of the cooling process. At the same time, an excessive drop in air temperature can lead to freezing of the surface of the product and deterioration of its quality.

When choosing the parameters of the hydro-aerosol cooling process, the following recommendations should be followed:

- irrigation with water should be carried out for 5–7 s, while the mass of sprayed moisture is 5–10 g per carcass (depending on its size). Longer irrigation is impractical, since moisture begins to drain from the surface of the product;
- the carcass is blown with cold air at a speed of 2.5–4 m / s until the sprayed moisture has completely evaporated. Since with each subsequent stage «spraying – blowing» the surface temperature of the carcasses decreases and the moisture evaporates more slowly, the duration of blowing from stage to stage must be increased.

At each stage, except for the last, the recommended temperature of the cooling air is 0 °C, at the last –4…–7 °C. With intensive evaporation of moisture from the surface of the carcasses at the first stages, the use of a cooling air temperature of 0 °C avoids the formation of a snow coat on the evaporator of the air cooler. At the same time, a sufficiently high product temperature ensures a high cooling rate at these stages. Lowering the air temperature at the last stage to –4…–7 °C allows maintaining a high cooling rate at the final stage of the process. The low surface temperature of the carcasses during this stage results in little evaporation of moisture and therefore low formation of frost on the surface of the air cooler evaporator. At low temperatures and a relatively short duration of the last stage of cooling, moisture does not freeze on the surface of poultry carcasses.

To cool carcasses to the required average volumetric temperature of 4 °C, 3–4 stages «spray-blowing» with a total duration of 35–70 minutes are required, depending on the size of the carcass. With air cooling with the same parameters of the process, its duration is increased by 1.5 times.

It should also be noted that after hydroaerosol-evaporative cooling, poultry carcasses acquire an even white color, a rounded shape, and there is practically no loss of soluble proteins.

The main advantages of the hydroaerosol-evaporative method of cooling poultry carcasses are as follows:

- the consumption of water for cooling is reduced;
- there is no cross-contamination of poultry carcasses with microorganisms;
- in the hydro-aerosol cooling apparatus, to ensure the operation of the nozzles, the installation of a circulating water supply system is not required;
- the total cooling time is reduced;
- the frequency of thawing of the heat exchange surface of the air cooler decreases;
- improving the sanitary and hygienic conditions of the production process of refrigeration processing;
- the quality and presentation of the products increases.

3. Conclusion

The hydroaerosol method of cooling beef, pork and lamb carcasses is twice as economical as the traditional air method and bactericidal substances are added to the water to prevent meat spoilage.

The irrigation method of chilling poultry carcasses takes longer and eliminates cross-contamination of poultry carcasses and reduces the amount of moisture absorbed by them by up to 3 percent.

The combined cooling method at the immersion cooling stage adsorbs less moisture on the surface of the carcasses.

In the combined hydroaerosol-evaporative method of cooling poultry, the loss of juice during defrosting of poultry meat decreases and does not exceed 1.8 percent.
Global food security risks require the development of a new generation of intelligent technologies that combine agrobots, highly sensitive sensors with artificial intelligence technologies, which will increase agricultural productivity while reducing the negative impact on the environment [1].

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