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THE PROBLEMS OF MEAT PRODUCTS THERMAL TREATMENT

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Abstract. The main problems of meat products thermal treatment have been considered and analysed in the paper. Analysis of the existing research papers suggests that the main attention is devoted to the influence of temperature value and time of processing on the physical, chemical, microbiological and organoleptic indicators of the product. The influence on the protein and fat components of raw meat has been described as well as the changes in the meat product structure under the influence of temperature have been pointed out. The important impact of thermal treatment on the changes in proteins at heating, including solubility and hydration of the proteins, has been examined. The paper analyses the microbiota screening before and after thermal treatment. Special attention was paid to the impact of temperature on microbiota as it is an important indicator of a meat product safety. Methods and purpose of thermal treatments as well as the advantages and drawbacks of each method were considered. Formation of tastiness properties of the product depending on the methods and thermal cycling was emphasized. Submitted is the analysis of the factors that influence the product mass losses under the impact of high temperature. The dependence conditions of a meat product quality on the thermal cycle were also analysed. Attention is paid to alternative methods of thermal heating as well as their influence on ready product quality and safety. Substantial contribution of Odesa National Academy of Food Technologies to solving problems of the conventional thermal treatment of meat products was shown, same as a possibility of bringing a product to cooking readiness without application of high temperature. The main content of the paper includes analysis of the methods and thermal treatment cycles existing in the world and proves importance of the temperature control and cooking time which influence safety, quality and yield of the product.

Keywords: meat products, thermal treatment, safety, protein denaturation, cooking methods, cooking loss.

ПРОБЛЕМИ ТЕМПЕРАТУРНОГО ОБРОБЛЕННЯ М'ЯСНИХ ПРОДУКТІВ

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Анотація. У статті розглянуто та проаналізовано основні проблеми температурного оброблення м'ясних продуктів. Аналіз існуючих наукових робіт свідчить про те, що основна увага приділяється впливу величини температури та часу оброблення на фізико-хімічні, мікробіологічні та органолептичні показники виробу. Висвітлено вплив на білкову та жирову складову м'ясної сировини, а також зазначено зміни, які відбуваються в структурі м'ясного продукту під час дії температури. Розглянуто важливий вплив температурного оброблення на зміни білків при нагріванні, у тому числі на їхню розчинність та гідратацію. У статті проаналізовано скринінг мікробіоти до та після теплового оброблення. Особливу увагу приділено впливу температури на мікробіоту, оскільки це важливий показник безпечності м'ясного продукту. Розглянуто способи та призначення температурного оброблення, а також переваги та недоліки кожного. Показано важливість формування смакових властивостей продукту в залежності від способів та режимів теплового нагріву. Проведено аналіз факторів, які впливають на втрати маси продукту під час дії високої температури. А також, проаналізовано умови залежності якості м'ясного продукту від умов нагріву. Приділено увагу альтернативним способам температурного оброблення, а також їхній впливу на якість та безпечність готового продукту. Наведено вагомий вклад науковців Одеської національної академії харчових технологій у вирішенні проблем традиційного температурного оброблення м'ясних продуктів, а також можливість доведення продукту до стану кулінарної готовності без використання високих температур. Основний зміст статті містить аналіз існуючих у світі способів та режимів температурного оброблення та доводить важливість контролю температури та часу приготування, які впливають на безпечність, якість та вихід продукту.

Ключові слова: м'ясні продукти, температурне оброблення, безпечність, денатурація білка, способи приготування, втрати маси.

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Introduction. Formulation of the problem

The heat treatment is one of the key stages in the technological process of manufacture of the meat products. It characterizes a set of successive complex physical and chemical processes in the meat system aimed at fixing the shape and structure of the product, destruction of the vegetative microbiota, forming organoleptic parameters, and increasing the product's resistance to mildew and microbiological damage during storage [1,2].

The issue of the day is quality and safety of the product, the loss of nutrients, and the provision of organoleptic indicators acceptable to consumers.

Meat and meat products are the source of valuable nutrients, such as proteins, essential amino acids, polyunsaturated fatty acids, vitamins and minerals. Heat treatment results in conformational changes in the structure of the protein, the taste of the product, its smell, texture and appearance, as well as changes in the chemical properties of the ingredients.

The change in the components and properties of the finished products significantly differ and depends on the conditions of the process and the final temperature of the heating.

The main problem of the safety of meat products is the inactivation of microorganisms that are characterized by resistance to temperature action.

It should be noted that there may be a conflict between quality and product safety issues. Because under severe temperature conditions, the inactivation of microbiota and safety are ensured, however, the quality of the product significantly deteriorates.

The researches in various directions are devoted to the solution of this issue.

The purpose of the study is to determine the problems of heat treatment of meat products.

The research task is to monitor scientific works devoted to the influence of heat treatment on the quality and safety of meat products.

Analysis of recent research and publications

Physical and chemical changes of meat during heat treatment

The influence of heat treatment on a meat product is accompanied by change in its physical and chemical characteristics. As a result of the temperature effect, the meat acquires new typical flavor and aromatic properties, dense consistency and is usually better digested by the body. Depending on the conditions of the process and the final temperature of heating, the changes in the components and properties of the finished products differ significantly [3-5].

The physical and chemical changes occurring during the heat treatment include: thermal denaturation of protein substances; boiling and hydrothermal decay of the collagen; change of extractive substances and vitamins; change of structural and mechanical properties, moisture-binding ability; the formation of components of taste and aroma; color change; loss of product components in the environment; the death of the vegetative microbiota [4,6,7].

Effect of heat treatment on the protein component

The most typical and fundamental change in the proteins of all tissues when heated is denaturation **-** the change in the natural properties of proteins, and simultaneous reduction of their solubility, and hydration. Proteins denatured by heating, easily aggregate and coagulate, consolidate with the release of water [3,4].

The denaturing effect of heat on meat proteins essentially depends on the conditions of heating: on the heating temperature, the duration of heat exposure, the presence or absence of residual moisture content, pH value of the medium, the bonds between proteins and other compounds in the structure of animal tissues [3,8].

The proteins included in the meat composition differ from each other by denaturation temperature. When heated, proteins denature in the appropriate range of temperatures, and each temperature in this range corresponds to a certain amount of denatured proteins [2].

Thermal denaturation of muscle proteins begins at a temperature of 30–35°C. When heated to 60–65ºC, about 92% of the salt-soluble proteins and up to 93% of water-soluble intracellular proteins denaturate, but even at a temperature of 100°C a small amount of protein substances remains in the native state [9].

The main protein of the muscles – myosin is the most sensitive to the action of temperature. In as little as 15-20 minutes, when heated to 37°C, it loses its enzymatic activity. In the structure of muscle tissue, the native property of myosin remains more stable. Its enzymatic activity decreases by 50% when heated at 40°C for 3 hours. When heated above 40°C, myosin is denatured completely [4].

Along with denaturation, there is an aggregation of polypeptide chains due to the occasional secondary salt and hydrogen bonds between protein molecules; the process of coagulation is in progress. The emergence of these bonds results in blocking polar groups and as a consequence decreases the hydrophilicity of denatured protein, reduces its solubility. The degree of coagulation changes increases with increased temperature and duration of heating, and the higher the degree of aggregation, the slower the protein digestion [6,9,10].

When heated to 58–65°C, in the presence of water the collagen protein is boiled, which is accompanied by a weakening and breakage of a portion of hydrogen bonds that hold polypeptide chains in the three-dimensional structure of the molecule [4,6].

Under the effect of heat treatment, the collagen change, namely, the decomposition to glutin and glutosis, results in increased collagen absorption and reduced strength of connective tissue and rigidity of the meat. However, the excessive collagen decay results in the separation of fibres of tissues [4].

After heat denaturation, the meat proteins are more easily subjected to enzymatic hydrolysis because internal peptide bonds become more accessible to enzymes, therefore the denaturated proteins are better digested. However, prolonged heating at high temperatures can increase the resistance of proteins to enzymes due to the development of post-denaturation changes [8,11].

During the heat treatment, the changes in myoglobin are of great importance, on which the color of the meat depends. Myoglobin denaturation occurs gradually and depends on the temperature and duration of heating. The connection between hem and globin decreases. Globin denatures, and gem turns into hemochrome – brown pigment. After denaturation, globin is able to form an adsorption compound with hemochrome. Hemochromes contain ferrous iron, which can easily be oxidized to ferric iron with the formation of hematins. When heated to the temperature at which the myoglobin is denatured, the color of the meat varies from red to gray-brown as a result of the formation of hemochromes and hematins. At a temperature of 60°C, the red color is preserved inside a slice of meat, at 60-70°C the meat assumes pink color, and at 70–80°C and above it becomes to a large extent gray-brown [4,12].

As a result of the temperature effect, the diameter of the muscle fibers decreases by 25–30%, and the thickness of the layers of the connective tissue decreases by 2–2,5 times, resulting in changes in the size of the product. At the same time, part of the water with dissolved substances is released into the environment. In case of boiling of salted meat products, depending on the temperature and time, about 10–15% of water contained in soft tissues is released. The amount of moisture loss in the product affects not only its rigidity, but also determines the yield of the product. In addition, during the heat treatment part of the amino acids breaks down and undergoes a reaction of melanoid formation, therefore too prolonged action of high temperature can reduce the nutritional value of the product. The nature and intensity of the changes depends on the amino acid, temperature and duration of the heating [13].

Influence of heat treatment on lipids

The heat treatment of meat raw materials causes the destruction of a complex intracellular colloidal system, which contains fat. A high temperature causes the destruction of fat cells, melting and coalescence of fat. The heating of the meat is accompanied by the melting down of fat and its partial emulsification. At the same time, certain volatile compounds connected with fats which give a specific flavor to meat are released [2].

With the increase in the duration of heating, the degree of emulsification and hydrolysis, as well as saturation of unsaturated bonds of fatty acid radicals increases. The heating stimulates the course of the oxidative-hydrolytic processes of fat and thus results in some reduction in the nutritional value of the product. The level of hydrolysis of fats with the formation of fatty acids is insignificant in case of moderate heating [6,7].

Due to the addition of hydroxyl groups at the place of double bonds as a result of the interaction of triglycerides with water, the hydroxy acids are partially formed. In addition, heating contributes to faster oxidative spoilage of fats during storage, especially for pork, which is accompanied by an increase in the number of peroxides and increase in thiobarbituric value. The lipid fraction of boiled pork is exposed to faster oxidative spoilage as a result of the absence of natural antioxidants [4,14].

The hydrolytic and oxidative processes occur under the influence of heat treatment in the fatty component,. As a result, this reduces the biological value of fats, as well as resulting in formation and accumulation of a number of toxic substances of cyclic fatty acids and peroxides, from which then aldehydes, ketones and low molecular weight compounds are formed. The depth of these processes depends on the method, temperature and duration of heating [9].

Change in the content of vitamins as a result of heat treatment

Heat treatment of meat results in decrease in the content of some vitamins as a result of their thermal inactivation and environmental losses. The amount of changes in the content of vitamins in meat when heated depends on their resistance to temperature, as well as on the conditions of meat processing, mainly on pH value and the presence of oxygen [3].

Even with moderate temperature regimes, the meat processing reduces its vitamin value, and at high temperature heating the vitamins are significantly destroyed (from 40 to 70%).

Depending on the heating conditions, the meat loses: 30–60% of thiamine; 15–30% of pantothenic acid and riboflavin; 10–15% of nicotinic acid; 10–15% of ascorbic acid [6].

Among the water-soluble vitamins, the least stable are vitamins B, and ascorbic acid (vitamin C); among fat-soluble vitamins the least stable are vitamin D. Vitamin A almost endures a temperature of up to 130°C. However, dry heating in contact with air, for example during frying, is accompanied by intense destruction of vitamin A and other vitamins, especially those that are easily oxidized, namely vitamin E and C [3].

Formation of taste and aroma of meat as a result of heat treatment

The specific taste and aroma of the finished meat product is caused by a number of soluble and volatile substances, most of which are formed during heat treatment. As a result of the conversion of carbohydrates (glucose, ribose and partially fructose), amino acids and nucleotides during the heat treatment, the compounds that cause the appearance of a characteristic odor are formed: aldehydes, ketones, volatile acids, sulfur compounds, amines and others [6].

Extractive substances play a decisive role in the formation of the taste and smell of the meat product. They accumulate as a result of the decomposition of high-molecular compounds. However, the amount of extractive substances decreases as a result of own disintegration under the effect of heating. The sensitivity of extractive substances to the effect of heating is different. Carnosine, lactic acid and choline break down by 10–15% [4,15].

The specific taste and aroma during heating of meat appears as a result of the interaction of amino acids with carbohydrates, i.e. as a result of the sugar-amino reaction. In this case, the sulfur-containing and other compounds that form the appearance of a characteristic smell and give color to the products are formed. As a result of the sugar-amino reaction, the aldehydes are formed – formaldehyde and methylglyoxal, as well as acetone, diacetyl, furfural, oxymethylfurfural, and methylfurfural [16].

The sugar-amino reaction is very slow in raw meat, but sharply accelerated during heating. At 60°C, the reaction occurs 20 times faster than at 37°C. The melanoid-forming process provides certain consumer characteristics of the product and affects its quality, but as a result of excessive heating, accumulation of toxic substances is observed, as well as a decrease in the nutritional value resulting from the transformation of amino acids [4,12].

Change in the structural and mechanical properties

Change in the properties of a meat product during heating depends on the change in the properties of its components, the chemical composition, the method and modes of heat treatment, the presence or absence of a protective coating. The properties of animal tissues change under the influence of two opposite factors, namely, the coagulation of proteins and collagen decay [4,6].

Denaturation-coagulation transformation of proteins affects the change of stable properties, hydrophilicity, size, loss of amino acids. Stable properties of animal tissues that are heated, depend on the degree of dehydration of the product. The development of coagulation changes is accompanied by a decrease in the moisture-binding capacity of protein substances and water loss. Hydrothermal disaggregation of collagen reduces strength and increases water absorption capacity [17].

The depth of development of denaturation-coagulation processes depends primarily on the temperature and duration of heating. With increased temperature, the product yield decreases and the losses of nutritionally valuable nitrogenous substances and fat are increased [16].

As the product is dehydrated during heat treatment, its rigidity increases, therefore products manufactured at lower temperatures are more delicate and homogeneous in terms of consistency and more toothsome [15].

Effect of temperature on microbiota of meat product

The meat and meat products are favorable environment for the development and long-term survival of numerous microorganisms that can cause spoilage of the food products and cause human illness when consuming substandard products [18].

In the process of preparing meat for heat treatment, it is contaminated by microorganisms that penetrate into it from various sources at all stages of the technological process of its cooking: from raw materials, in the preparation of meat (carcass cutting, breakdown into cuts, cleaning), salt pickling, mechanical processing, forming [19].

The life of organisms is more determined by temperature than any factor of the environment, due to the fact that all organisms are made of chemical components and all processes of life occur on the basis of chemical reactions subjected to the laws of thermodynamics [20,21].

The environmental temperature is one of the main physical environmental factors that determine the ability and intensity of the development of microorganisms. All microorganisms develop within certain limits of temperature. At the same time, there is a minimum, optimum and maximum temperature regime for growth for each microorganism: the minimum means the temperature below which the development of microorganisms does not occur; optimum means the best temperature for the development of microorganisms; maximum is a temperature above which the development of microorganisms does not occur. Temperature points of development of the microorganisms correspond to the optimum temperature of action of enzymes [19,21,22].

As a rule, the thermostability of microorganisms is associated with an optimal temperature of their growth. The ratio of microorganisms to a temperature exceeding the maximum for their development is characterized by the thermostability, which is different for certain species. The psychophilic microorganisms are most susceptible to heating, followed by mesophilic, and then thermophilic microorganisms. Spore-forming bacteria are more thermostable compared to non-spore-forming bacteria. As a rule, aerobic bacteria are less heat-resistant than anaerobic bacteria. As to the reaction of Gram bacteria, the trend is that gram-positive bacteria have higher thermal stability than gram-negative ones. In this case, cocci are usually more thermostable compared to non-spore-forming rod-shaped bacteria. Yeast and filamentous fungi are very sensitive to heating. At the same time, ascospores of yeast are only slightly more resistant to heating compared with vegetative yeast cells [21,23,24].

The death of microbial cells occurs depending on the duration of the temperature effect; for example, a temperature which is slightly higher than the maximum, causes the phenomenon of “thermal shock”. Short-term “thermal shock” may not cause death of microorganisms, but in case of prolonged “thermal shock” the cells of microorganisms die [19].

When selecting the modes of heat treatment of the product, the time of thermal death is of full relevance. This is the time necessary to destroy an existing amount of microorganisms at a certain temperature. In accordance with this method, the time required for the destruction of all microorganism cells is determined. In this case, the temperature remains constant throughout this period. The point of thermal death, which is defined as the value of temperature necessary for the destruction of a certain number of cells in a fixed time, is less important. Death of microorganisms is defined as their inability to form visible colonies after a rather long-term incubation period [21,25].

The microbiotypes of fresh meat include approximately 30 genera of microorganisms, the most common of which are: gram-positive sticks *Clostridium spp., Bacillus spp., Brochothrix spp., Lactobacillus spp. and Listeria spp.; gram-positive cocci Pediococcus spp., Enterococcus spp., Lactococcus spp., Micrococcus spp. and Staphylococcus spp. gram-negative cocci and coli Aeromonas spp., Enterobacter spp., Citrobacter spp., Escherichia spp., Proteus spp., Salmonella spp., Yersinia spp., Pseudomonas spp., Shigella spp. and Campylobacter spp.* [23,26].

The heat treatment of meat products should ensure the death or a sharp reduction in the amount of vegetative microbiota [4,18].

The pasteurization is sufficient for the destruction of vegetative forms of microorganisms - heating to a temperature in the range of 72 to 80°C. By the end of the boiling process, in the depth of the product the temperature reaches 68–72°C depending on the type of product. Under the influence of high temperature in the process of boiling, the quantitative and group composition of the microbiota of meat product sharply changes. In this temperature mode all non-spore pathogenic and opportunistic microorganisms die: *E. coli* and *Proteus coli*, the most of saprophytic non-spore-forming microorganisms (cocci, lactic acid bacteria, yeast, etc.), vegetative forms and part of spores of spore-forming bacteria [14,27].

The total amount of microbes in 1 g of raw meat is tens of thousands or more. After boiling, 1 g of the product usually contain only hundreds of microorganisms. The spore forms of microorganisms are persistent to the action of high temperatures. Therefore, the remaining microbiota is represented by spore forms by 90% [6].

The level of residual microflora after the end of heat treatment depends mainly on the degree of initial microbiological contamination of raw materials and materials used in the manufacture of meat products; pH values of the medium, water activity, availability of preservatives; diameter and mass of the product; thermal treatment parameters [6,14, 18].

Pasteurizing effect

The effectiveness of heat treatment can be estimated based on the level of the resulting pasteurizing effect. It is calculated according to a method that is similar to the definition of the sterilizing effect in the canning industry [6].

In the meat product of a certain mass and diameter, the temperature in the central part is measured at all stages of heat treatment. However, it should be borne in mind that the development of microorganisms is stopped at a temperature higher than 54–55°C and the lethal effect of temperature on the microbiota begins. That is why the pasteurizing effect is calculated from the beginning of reaching this temperature at the center of the product until the end of the thermal effect. The lethal effect of heat treatment on microorganisms is determined not only by the temperature, but also the duration of exposure. The pasteurizing effect for meat products of various sizes is ensured by the duration of exposure of the microorganisms to the highest temperature. The temperature measurement starts at 54–55°C and above, and changes inside the loaf and duration of exposure are recorded each minute [6,23].

By using the experimentally found values of pasteurizing effect Reichert F-10/70, which characterize the degree of death of microorganisms within 1 minute of exposure to a certain temperature, the total pasteurization effect is calculated [6,21].

The value of the F-index is the total lethal effect on microorganisms in the process of raising the temperature of the product, achieving the required temperature at the center of the product, maintenance at this temperature and further lowering of the temperature at the center to values lower than the lethal ones [18,23].

As a result of excessive calculated pasteurization effect, the durability of the period of exposure of the product is reduced, in case of insufficient effect, the duration of heat treatment or temperature at the center is increased. This method makes it possible to perform comparative evaluation of the effectiveness of different modes of heat treatment, optimize existing parameters and predict the stability of finished products during storage [6,24].

Methods and purpose of heat treatment

Depending on the type of meat product, the different methods of heat action, their combination and modification are used. The chosen method of heat treatment shall correspond to the type of meat, the amount of connective tissue, the shape and size of the meat. The basic ones include: frying, smoking, boiling, and baking [1,28].

Frying and smoking are treatment of the meat product surface with smoke fume. Frying differs from smoking by short-term treatment at significantly higher temperatures of smoke fume. The frying temperature is 50–120°C until the temperature at the center of the product reaches 40-45°C. In the process of frying, the raw material is heated and partial development of denaturation-coagulation processes commences and the form of the product is fixed. In peripheral layers, the death of vegetative forms of microorganisms begins. The color developing reaction is also activated as a result of the decomposition of sodium nitrite, and as a result of the action of the smoke substances, the product acquires a typical smell and taste. During frying, there is a partial evaporation of weakly bound moisture, resulting in mass loss. Depending on the type of product, temperature, duration, the relative humidity of the air or air-smoke mixture during frying, the losses reach from 4 to 12% [1,2,13].

For smoking of meat products, several temperature regimes are used: 18–20°C – cold smoking and 35–50°C – hot smoking. Cold smoking is used in the production of fermented products, and hot smoking is applied for manufacture of semi-smoked, boiled-smoked and smoked-baked products. The smoking process is accompanied simultaneously by heat and mass transfer and moisture exchange, resulting in evaporation of the part of the moisture from the product, dehydration of the product and acquiring of typical organoleptic characteristics. In addition, penetration of some fractions of smoke into the product, especially phenolic and organic acids, which have a high bactericidal and bacteriostatic effect, and the dehydration of the product results in depression of the development of putrefactive microbiota, and as a result increases the stability of products during storage. The mechanism of smoking consists of two phases: precipitation of smoke substances on the surface and their transfer from the surface of the product. At the same time, the speed of the first phase depends mainly on the temperature of the smoking (the higher it is, the more sediments are deposited), the concentration (density) of smoke and the speed of its movement [1,15].

Boiling is the process of heating meat products in a medium of saturated steam by hot air or in water in order to bring them to a state of cooking readiness, complete the formation of organoleptic indicators, and increase storage stability. The boiling is accompanied by a number of typical physical and chemical changes, the main of which are: thermal denaturation of soluble protein substances; boiling and disaggregation of collagen; change in the state and properties of fats; change in structural and mechanical properties; change in organoleptic parameters; the death of vegetative forms of microorganisms. The combination of the abovementioned processes determines the quality of finished products [13,18].

Boiling at constant temperature of water or steam is the most common method of heat treatment of meat products. This method is based on the effect of the heat carrier, the temperature of which does not change from the very beginning of the boiling process. Typically, the temperature is from 74 to 80°C, since temperatures above 80°C results in significant mass losses after heat treatment. Boiling at constant temperature is completed when the desired temperature is reached at the center of the product (usually from 69 to 72°C). The disadvantage of the process is a slightly higher loss of mass of peeled products than with other methods of heat treatment [14].

Stepwise boiling assumes that at the first stage the product is exposed to steam or water at a temperature of about 60°C for a certain time, about 1 hour. Then the temperature is raised to 70°C and the product is maintained for a certain time. Finally, the temperature is brought to 74–80°C and the boiling is continued until the desired temperature is reached at the center of the product. Often, the steam acts as the heat carrier. The advantage of stepwise boiling is that the mass loss is lower, because the stepwise boiling takes place a little slower than boiling at constant temperature. But the disadvantage is a longer process. The use of this method is rational for large-size products [1,13].

In case of delta-boiling, the treatment of the product begins at a temperature of 60–65°C. The difference between the temperature of the heating medium and the center of the product must be at least 25°C; 30°C is more often used. When the specified temperature difference is reached, the temperature of the heat carrier is increased, while the temperature at the center of the product increases with the same speed. When the temperature of the heating medium reaches a set value, then it is maintained at a given level, and the temperature at the center continues to rise until a set value ranges of 69–72°C is reached. The advantage of delta-boiling is the highest yield of the finished product compared with other boiling methods, which is 2–4% less. The disadvantage is a longer boiling process compared to the previous ways [1].

Baking is a heating process that is carried out by hot air or air-smoke mixture. In contrast to boiling, the heating takes place in several stages, with constant increase in the temperature of the heating medium from 70°C to 150–180°C. Baking and boiling have similar physical and chemical processes that occur in the product. However, baking has some specific features. As a result of contact of the surface of the product with the heating medium, an intense short-term evaporation of moisture occurs and the surface sealed layer is formed, which prevents further loss of moisture from the product. Therefore, the baked product has a larger yield. The temperature of the outer layer rises, and as a result, chemicals are formed that have a specific pleasant aroma and taste. The process with formation of the substances that cause a sense of flavor and taste begins at 105°C and increases with rise of temperature. In addition, the pasteurizing effect of heating is more pronounced, which contributes to extension of the shelf life of finished products [2,14].

During heat treatment, the meat changes its nutritional qualities, including texture, color and taste, and also increases its ability to digestion and absorption in the human body. The degree of these changes depends on the amount of heat to which the product is exposed, and on the heating rate. The ability to control these variables determines when the meat becomes more delicious and useful after cooking [29].

For the consumer, the nutritional value, tenderness, juiciness and taste are the main factors influencing the choice of the finished meat product. Therefore, the constant aim of the meat industry is to seek improvements in meat production technology that provides and improves these desired sensory characteristics, and manufacture of a product that is safe to consume [30].

One of these improvements is long-term low temperature treatment (LTLT). The method involves heating of the product to a low end temperature with the use of increased heating time. The cooking temperature is often close to 60°C or lower and the product remains isothermal for a long time. The meat product cooked in this way has high quality, excellent sensory characteristics, it is tender and toothsome [30-32].

One of the most popular forms of LTLT preparation is the technique of cooking meat in vacuum packaging Sous Vide [32,33].

The Sous Vide method is one of the ways of heat treatment and bringing the product to a cooked readiness state. The essence of the method is that the products are packed in a vacuum, then exposed to heat treatment, cooled and stored in the refrigerator. The advantages of using Sous Vide are as follows: vacuum packaging minimizes moisture loss, the resulting products are toothsome and tender, since the meat is cooked in its own juice. The products have high nutritional value. However, the disadvantage of the Sous Vide method is a danger of the development of pathogenic microorganisms, since the product is exposed to mild heat treatment and does not contain preservatives [1,34,28].

The problem of mass loss during the heat treatment

The loss of the mass of the product during the heat treatment is important in meat production technology. The mass loss is an important physical parameter of the quality of a meat product, which determines the composition and taste characteristics and also affects its value. Increase in the temperature in the center of the product increases the loss of moisture, and, consequently, the mass of the product itself. The actual amount of losses depends on the method of heat treatment and the amount of connective tissue in the meat. The correlation between the duration of heating and losses when bringing the product to the cooked readiness state is not linear, since losses are determined by a combination of cooking time and heating speed. Low temperature treatment results in lower product losses compared to cooking at normal temperatures. An increase in temperature in the range of 75–90°C by 1°C causes an increase in mass losses by an average 0.37%, in the temperature range of 65–75°C – by about 0.25% of losses, and when heated from 55 to 65°C – by 0.14% [1,35].

The heat treatment of duck meat at a temperature of 100°C till the achievement of a different final temperature of the product proves that increase in the temperature in the product center increases the mass loss. As at final temperature of 40°C the losses make up 3.34%, at 50°C – 3.86%, at 60°C – 3.33%, at 70°C – 3.65%, at 80°C – 4.07%, at 90°C – 5.68%, and at a temperature of 95°C the mass loss is 5.74% [36].

With the increase in the proportion of connective tissue in the product, the mass loss increases in case of heat treatment. However, the higher the temperature in the center of the product, the smaller the difference in losses between the types of tissues. At a temperature of 80°C and above, there is a slight difference in the mass loss of product mass between the method of heat treatment and the different amounts of connective tissue [1,34].

The conducted studies [37] demonstrated the dependence of the mass loss of chicken steak on the heat treatment method. The marinated chicken steak was brought to a temperature of 75°C in the center of the product by the following treatment ways: boiling in a water bath at a temperature of 100°C for 22 minutes; baking in a convection oven for 20 minutes at 120°C; grilling at a surface temperature of 150°C for 14 minutes with turning every 2 minutes; treatment in a microwave oven for 10 minutes; steaming with the use of superheated steam at 250–380°C for 5 minutes. The greatest losses were observed during boiling and baking. As the mass losses increase with increase in temperature and time of treatment. Products cooked using superheated steam had the slightest mass loss [37].

During the heat treatment of colt steaks at the temperature of 70°C at the center of the product, the greatest mass losses of the product were in treatment by microwave oven: 32.49 ± 6.41%. The smallest mass losses were in grilling treatment: 22.45 ± 5.51% and frying: 23.73 ± 2.87%. During the baking, the losses were 26.71 ± 3.51%. The parameters of heat treatment are as follows: grilling at 130–150°C for 5 minutes on each side; in a microwave oven for 3 minutes; frying at 170–180°C with the addition of refined olive oil for 8 minutes; baking at 200°C for 12 min [38].

Mass loss of product depends on the age of the animal. Studies conducted [39] in 3 age groups of cattle have proven that mass loss rises with increasing age. With age of the animal, the proteins of the meat are characterized by weak moisture-binding properties.

In the manufacture of restructured products, the mechanical treatment of raw materials affects the loss of mass of the product. During tumbling for 2 hours, the mass loss of the product was the largest and comprised 5.41 ± 0.47%. During the mechanical treatment for 4 and 6 hours, the losses were lower and amounted to 3.90 ± 0.40% and 3.22 ± 0.57% respectively. The results demonstrate that with increasing time of tumbling the loss of mass of the product is reduced [40]. In addition, the weight of the restructured meat product is affected by the size of the slices of meat of which the product is composed. The product made of 2–3 cm slices has less weight loss than a product with a meat of 4-5 cm grinding degree. In addition, the appearance and overall taste properties were much better in a restructured product that consisted of 2–3 cm slices [41].

Alternative methods of heat treatment

In recent years, consumer demand for health-friendly meat products with a minimum processing and no chemical additives is growing. Indeed, the meat and meat products are one of the main foodstuffs of the population, which provides the necessary nutrition for a person for years. The food safety and shelf life are often closely linked to the presence of microorganisms and other phenomena, such as biochemical reactions, enzymatic activity and structural changes that have a significant impact on consumers' perception of the food quality. The alternative ways of treating the meat product are designed in such a way that they are gentle, energy-saving, environmentally friendly, have an excellent appearance and taste, while eliminate pathogenic microorganisms and microbiota which causes spoilage of product [42-44].

The application of high pressure for the treatment of meat raw materials is an alternative technology for the manufacture of meat products. The high pressure treatment is applied to extend the shelf life of fresh and cooked food without alteration or with minimal effect on organoleptic parameters and nutritional value. This technology ensures the same standards of food safety as thermal pasteurization and satisfies the demands of the consumers [43].

Currently, the research scientists and specialists in the meat industry demonstrate considerable interest in using high pressure treatment as a technology for non-thermal pasteurization and sterilization of meat products. Unlike traditional heat treatment, the high pressure acts instantaneously and uniformly throughout the product, regardless of size and composition. Therefore, the cooking time of the product can be reduced, and the cost of production is reduced [42,45].

At the Odessa National Academy of Food Technologies, Department of "Technologies of Meat, Fish and Seafood", the studies were conducted to improve the technology of poultry meat products using high pressure. The optimal modes of bar-treatment (pressure 225 MPa, duration$20 \cdot 60^1$ sec) have been established for extending the shelf life of fresh poultry meat up to 10 days, i.e. 2 times longer without deterioration of the quality of chilled meat [46, 47].

The scientists have determined the mode of athermic treatment for obtaining a finished product made of poultry meat, which has a yield of the finished product 35% higher than after the heat treatment. The product is made by means of bar-treatment, which has a shelf life of 4 times greater than a product manufactured in accordance with traditional technology. Products made using the high pressure have a higher biological and nutritional value due to lower loss of protein and B vitamins [48,49].

The modern consumer wants to consume products that contain less salt and no chemical preservatives. High pressure treatment has the potential as an additional technology to reduce salt content and increase shelf life without deterioration of the organoleptic parameters [43].

The scientists of Odessa National Academy of Food Technologies studied the possibility of using high pressure to intensify the process of pickling of meat raw material. Optimum regimes are pressure of 220 MPa during $25 \cdot 60^1$s, while pickling process is implemented by 40% faster compared with the traditional method due to a violation of the integrity of muscle fibers [46].

High pressure can be used for preservation of the food. Preservation of meat is a constant struggle against microorganisms that cause product spoilage and can be dangerous to health. This method provides inactivation of vegetative microorganisms and enzymes without significant changes in the organoleptic parameters that can be observed during heat treatment. However, spores of some pathogens are stable even at very high pressure (1000 MPa) [44,50].

Treatment of the product at 400–600 MPa is effective in struggle against the most of the major food pathogenic microorganisms (*E. coli*, *L. monocytogenes*, *Salmonella spp*., *S. aureus*, and others) that are present in various meat products [44,51].

For complete inactivation of microorganisms in the meat product, the heat treatment is applied in combination with high pressure. The bacterial spores that are resistant to pressure at low or moderate temperatures can be completely inactivated by treating products under pressure at high temperatures. [52]. This method of treatment is an alternative to the traditional sterilization process. The inactivation of the spores can be achieved by the careful choice of the pressure, temperature and time of treatment. Researches in this direction continue [42,53].

In order to prolong the shelf life, the high pressure is used after packaging the finished product. This eliminates the microbiota that has repeatedly penetrated into the product after its bringing to cooked readiness. Also, the combination of active packaging and high pressure treatment is used for this purpose. Natural antioxidants and antimicrobials are added to the polymeric packaging, followed by exposure of the product to high pressure [54]. The recent studies have demonstrated that the use of active packaging in combination with high pressure is a promising approach for the complete elimination of food pathogenic microorganisms in meat products under refrigeration conditions [42].

High-pressure treatment was recognized as one of the best non-thermal impacts for bringing the product to cooked readiness, extending the shelf-life and solving the problem of the safety of meat products without changing the sensory and nutritional properties. But due to high pressure alone, the cooked meat products are spoiled quickly because of the high value of water activity and high pH, which promotes the intensive and rapid multiplication of microorganisms that cause spoilage [42].

The application of high pressure can negatively affect the color and texture of the product and, as a result, its commercial attractiveness. Changes in color and texture are observed in meat as a result of denaturation of proteins under the influence of temperature, and the pressure increases the solubility of myofibrillar proteins resulting in change in structure [45].

The combination of high pressure and heat treatment was used to produce ham. Since the product is manufactured only under pressure, it can not be similar to a boiled ham, which is familiar and desirable to the consumers. Samples that were only treated with high pressure were pale and had a milder texture than the samples manufactured using traditional technology. Therefore, for the production of boiled ham that meets the organoleptic needs, the raw material was heated at a temperature of 53°C and then subjected to a pressure of 500 MPa. However, the technological process with the use of combined treatment was longer, and the yield of the product was lower, compared with samples that were exposed only to high pressure [45].

High-frequency heating has a great potential in the food industry to become an alternative way of heat treatment. It involves radio frequency and ultrahigh-frequency irradiation. The disadvantage of heat treatment is the slow heat conductivity from the heat carrier to the center of the product. This, in turn, requires longer processing, energy costs, and also results in changes in the outer layer of meat, which can potentially lead to a decrease in the quality of the product [44].

The radio frequency and ultrahigh-frequency irradiation are modern methods based on the use of electromagnetic energy and able to provide a fast and even distribution of heat in the product. Therefore, they are promising methods of heating in the meat industry [55].

Unlike other methods of heat treatment, the high-frequency irradiation can convert electrical energy into heat directly within the product itself, which then absorbs the produced heat. Therefore, thanks to high-frequency heating, it is possible to achieve uniform heating and greater efficiency in the manufacture of meat products [56].

The main difference between the radio frequency and microwave irradiation is the wavelength. The wavelength of radio frequency irradiation is greater, which provides a great depth of penetration into the product. Therefore, the radio frequency heating is more efficient for food products with large diameter [55].

The high-frequency heating has been used in the food industry for many years to defrost the food. Recently, this technology is used for pasteurization of meat products. By comparing the treatment of the product by means of boiling and radio frequency irradiation, it can be said that both methods were effective in reducing microbial contamination, but due to high-frequency heating the effect was achieved faster [57].

In the manufacture of products, the taste, color, and structure are important for the consumer. The product manufactured by means of high-frequency heating has a solid consistency in comparison with the sample produced by means of heat treatment, where the steam acts as heat carrier. However, the cooking time with high-frequency heating was significantly lower [44].

The study of the possibility of using high-frequency heating for meat pasteurization and sterilization is still ongoing because of its potential in the production of storage-stable meat with a short treatment time and uniform heating.

The application of *ultrasound technology* in the food industry is deemed to be a new technology capable of accelerating the production process without compromising the quality of products. The use of ultrasonic vibrations makes it possible to improve the quality of the meat. The ultrasound can influence on meat in two ways: to break the integrity of muscle cells and to stimulate enzymatic reactions. Under the action of ultrasound, there is a partial mechanical damage to the fibers of muscle and connective tissues and favorable conditions for the action of enzymes of meat are created, therefore the acceleration of chemical processes in tissues and the autolysis process proceeds faster [58, 59].

The ultrasonic treatment has the ability to improve the heat transfer process, which is a key requirement in the manufacture of meat products. A product exposed to ultrasound during manufacture has a larger mass yield, since the use of high intensity ultrasound increases the moisture-binding properties of the proteins [58,60].

The antimicrobial effect is observed when using ultrasonic treatment. The effectiveness of the high intensity ultrasound on the microbiote depends on the time of contact with the microorganisms and their type, the mass of the product, its composition and treatment temperature. An ultrasound of 20 to 100 kHz generates high pressure and temperature gradients and destroys cell membranes and DNA, which results in the death of microbial cells [44,58,61].

The researches conducted by the scientists indicate the difference in the effect of ultrasound treatment on gram-positive (Staphylococcus aureus and Bacillus subtilis) and gram-negative (Pseudomonas aeruginosa and Escherichia coli) microorganisms [62,63]. The gram-positive bacteria are more resistant to ultrasound, since the cell wall structure is thicker due to the layer of peptidoglycans, which protect the cell from the treatment [64,65]. In addition, the microorganisms that generate the spores Clostridium and Bacillus showed great resistance to the ultrasound treatment compared to vegetative cells. These bacteria are more resistant both to heat treatment and to the action of ultrasound [66].

The application of ultrasound to inactivate microorganisms is more effective in combination with other physical methods of meat product processing. The combination of ultrasound treatment and steam has resulted in effective influence on microbiota, namely Campylobacter, Enterococcus faecium, and Bacillus subtilis spores. The steam treatment which had a temperature of 90–94ºC and ultrasound treatment of 30-40 kHz during 10 seconds reduced the Campylobacter by three logarithmic units [67]. The researches of the foreign scientists prove that antimicrobial properties of ultrasound increase at 60–70°C, since the cellular structure of the microorganisms at these temperatures is more susceptible to the physical effects, improving the efficiency of ultrasound treatment [68].

Sound treatment is applied in the production of animal fat. According to the traditional technology, the removal of fat from soft fat-containing raw materials is carried out by means of heat treatment. As a result of temperature effect, the quality of the fat deteriorates. Using ultrasonic treatment, the fat can be removed without heat treatment and without deterioration of its quality. Such technology involves grinding of fat-containing raw materials to which 30% of salted water is added with a temperature of 40°C and ultrasonic treatment during 20-30 min. The yield of fat from soft fat-containing raw materials is 60-75%, and the yield of fat from bones is up to 15% [59].

Ionizing irradiation in the meat industry is applied to inactivate the microbiota in the meat and finished products for several dozens of seconds without significant deterioration of the organoleptic parameters. This eliminates the need for the use of chemical compounds, the action of low or high temperatures for suppressing microorganisms and extending the shelf life of meat products [49,69].

The advantages of ionizing *irradiation* as compared with heat treatment: high efficiency of inactivation of microorganisms, decreased mass loss, and lower energy consumption [70].

The disadvantages of ionizing irradiation are the fact that the loss of nutrients, change in color and odor is possible, and it mat result in the oxidation of lipids in meat. To reduce the disadvantages, it is necessary to decrease the dose of the irradiation [44].

In the United States of America, a dose of 4.5 kGy for a chilled meat is allowed, up to 7 kGy for frozen meat and up to 3 kGy for poultry. However, for EU countries the restrictions are more severe and only dried aromatic herbs, spices and vegetable seasonings may be subjected to the irradiation [44].

The works of scientists record that the irradiation dose up to 4.5 kGy effectively reduces microbial contamination and is safe for people's health [71-73]. However, the consumers are worried about the consumption of products that were exposed to irradiation.

Every year, numerous studies are conducted to find new and improve existing technologies for the production of quality products. They are aimed at achieving maximum safety, prevention of re-contamination of the product, rational use of raw materials, energy saving and reducing environmental pollution. By combining and effectively using the methods of processing of the meat, it is possible to achieve manufacture of the products that will meet all the requirements of modern society.

Conclusion

On the basis of the foregoing, one can state that the temperature, duration and method of heat treatment are important in the manufacture of all meat products. Excessive heating can result in unwanted changes in the chemical composition of the product, decrease in its quality and biological value, deterioration of organoleptic parameters and increase and loss of mass. Based on the results of the studies of foreign researchers and scientists of Odessa National Academy of Food Technologies, it follows that the temperature, method and duration of treatment shall be only minimal and meet the specifics of the composition and properties of the meat product.

We believe that the prospects for further study of the problem are review of the existing hard temperature treatment regimes from the standpoint of scientific substantiation, which may enable to improve the organoleptic and technological parameters with a guarantee of microbiological safety without changing the technology and formulations.

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