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# MECHANICALLY DEBONED POULTRY MEAT AND ITS ROLE IN RATIONAL AND EFFICIENT USE OF RAW MATERIALS

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***Abstract***

*The growth in poultry meat production is a worldwide trend. Industrial poultry meat processing is also developing with production of a wide range of products. The technology of mechanical deboning of poultry meat and carcass parts is widely used in complex non-waste production. Mechanically deboned poultry meat (MDPM) is believed to be of inferior quality and its use is restricted by certain rules in different countries of the world. At the same time, hand separated meat is accepted as conventional meat and is not subjected to any restrictions. Over the last decades, the technology and equipment have been created that allow approximating MDPM to the category "meat" in terms of quality characteristics and reducing risks in its use upon reduction of pressure in the process of its production. However, costs of new equipment that enables producing a product with higher quality do not provide the expected efficiency, and a positive effect will be achieved only in the case of clear legal solutions regarding separation of MDPM types and methods of their classification and identification. The volume of scientific publications concerning a solution to this problematic theme is significant and scientists from many countries search for approaches to its realization differently. The difficulty in finding a solution is caused by the multifaceted nature of the problem, the character of non-standardized raw materials, a type of equipment being used to obtain different MDPM types, and various methods of investigations. Nevertheless, the performed studies create conditions for improvement of the approach to classification of different MDPM types by the production method and maximum allowable threshold values of the main standardized parameters, assessment methods, detection of their characteristics and substantiation of terminology.*

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## Introduction

Poultry husbandry is a leading branch of production of animal husbandry products worldwide and is constantly increasing its outputs. According the forecasts presented at the 24th European Poultry Conference, poultry meat production should have reached 124.91 million tons in 2020 [1], but actually it accounted for 130 million tons already in 2019 [2]. Russia made a significant contribution to this quantity (5 million tons) and stably occupies the fourth place in the world by this indicator [3].

Radical changes have taken place in the world poultry husbandry over the last decades. As a result of the growth in production of poultry meat, it became a widely used raw material for further industrial processing. During last decades, the consumer demand shifted from whole carcasses to their parts and poultry meat products.

Equipment for deboning carcasses and their parts to obtain poultry pieces as well as to produce mechanically deboned poultry meat (MDPM) was designed with the aim of mechanization of labor-intensive processes and increase in efficiency of operations of meat separation from the bone fraction.

MDPM production volumes are growing in the world, including Russia. For example, about 15–20 thousand tons of mechanically deboned poultry meat out of 1,800 thousand tons of poultry meat in slaughter weight were produced in the country in 1990 [4]. In succeeding years, the MDPM use sharply grew due to its import from the USA and Europe. In 2002–2004, the import volume was 240–270 thousand tons annually. An increase in domestic poultry meat production, growth in its industrial processing into products, creation of the technical base of MDPM production using domestic and import equipment allowed producing and processing into products about 500–550 thousand tons of MDPM according to our estimates, which accounted for 14–15% of the total poultry meat production volume in agricultural enterprises. At the same time, resources (bone residue) for non-waste utilization of poultry raw materials have been created [5].

MDPM is widely used in industrial processing both in the poultry processing industry and meat industry. Due to its nutritional and functional characteristics, mechanically deboned poultry meat is suitable for production of a wide assortment of sausage products, frankfurters, nuggets and so on [6].

However, the process of MDPM production inevitably leads to changes in its chemical, physical, organoleptic and functional properties. The characteristics of mechanically deboned poultry meat are determined by a type and quality of the non-standardized raw material being processed that is sent to deboning (defect carcasses, different parts with skin or without skin) with different meat-bone index, as well as by parameters of its technological preparation, type of equipment for deboning, pressure in its working zone, condition of working bodies, content of calcium and bone inclusions, qualification of personnel, scheme of a technological process, the target parameter of quantity of produced products that ensures the balance between MDPM yield and quality in terms of functionality for further application [7,8,9,10].

According to the existing legislation of the majority of countries, the use of MDPM requires the mandatory indication of its presence on a product label as a separate component that is not included into the ingredient "meat". The development of new technologies based on the modern equipment for MDPM production under low pressure enabled making it closer to the characteristics of poultry meat, but does not allow obtaining the economic effect expected by producers.

Therefore, it is necessary to find the main criteria for its classification and determine under which conditions it can be assigned to the term "meat". In addition, the separate processing of its types depending on the content of wholesome components is expedient for rational use of raw materials intended for MDPM production.

Unfortunately, there are no clear boundaries for separation by quality of MDPM types compared to hand deboned meat, common terminology, methods for classification and identification. Different countries approach to this problem and search for ways of its solution differently.

The aim of this review is to analyze the state of regulatory normative rules for production of different types of mechanically deboned poultry meat in leading world countries, methods for their classification and identification, and determine ways for solving this problem in Russia based on the world scientific experience.

**Mechanically deboned poultry meat in national normative documents**

Previously, the term "mechanically deboned meat" was used in the USA and Europe to characterize MDM. Then, the term "mechanically separated meat" came to be regarded as more correct [11]. In Russia, the term "mechanically deboned meat" is officially used with indication of its type (chicken or turkey) and this term is analogous to the term mechanically separated meat[1]. Raw materials for MDPM are poultry carcasses with defects, carcass parts with previously removed meat in pieces (frames, back-shoulder part, wings, neck).

Regulation (EC) No 853/2004 of the European Parliament and of the Council of 29 April 2004 [12] laying down specific hygiene rules for food of animal origin understands by the term "mechanically separated meat" (MSM) a product that was "obtained by removing meat from flesh-bearing bones after boning or from poultry carcasses, using mechanical means resulting in the loss or modification of the muscle fibre structure" and contains calcium insignificantly exceeding its presence in minced meat, for which Commission Regulation (EC) No. 2074/2005 [13] established a limit of no more than 0.1% (=100 mg/100 g or 1,000 ppm) of a fresh product.

According to the existing Code of Federal Regulations of the USA [14], when sending to mechanical deboning carcass parts, in which most of meat is retained as well as whole carcasses of non-standardized poultry, mechanically separated meat can be classified as "ground chicken meat". If the initial raw materials are frames, pieces or part of carcasses, from which most of meat was removed by hand, this meat should be defined as "mechanically separated meat" *with allowable limits for the calcium content and sizes of bone particles*.

According to FSIS Directive 7160.1 (1.09.96) (UDSA, USA) [15], two criteria were established to define the term "meat produced by advanced meat/bone separation machinery and meat recovery systems": the maximum calcium content should be no more than 0.15% and "the bones emerging from the advanced recovery systems must be essentially intact and recognizable to assure that the bones are not being crushed, ground, or pulverized". It is expected that the content of bones and bone constituents (for example, marrow) in a product obtained using these systems would not be higher than expected in a product obtained by hand deboning. Such meat should be produced under the control of inspectors of Food Safety and Inspection Service (FSIS).

GOST R 52313–2005 "Poultry-processing industry. Food products. Terms and definitions"[2] defines "mechanically deboned poultry meat" as a food product obtained as a result of deboning of an eviscerated poultry carcass or its parts by the method of separation and representing finely comminuted mass with the normed quantity and size of bone tissue.

EAEU TR 051/2021 "On the Safety of Poultry Meat and its Processed Products" [16] slightly changed the term introducing several amendments and defined "mechanically deboned poultry meat" as a product of poultry slaughter obtained as a result of deboning by the method of separation of an eviscerated poultry carcass or its parts including necks or bones with pieces of flesh no less than 30%, consisted of minced muscle, fatty and connective tissues with the normed size and mass fraction of bone inclusions. They are stated in the active GOST 31490–2012[3].

[1] GOST R 52313–2005. "Poultry-processing industry. Food products. Terms and definitions" Retrieved from https://docs.cntd.ru/document/1200039098 Accessed March 02, 2023. (In Russian)

[2] GOST R 52313–2005. "Poultry-processing industry. Food products. Terms and definitions" Retrieved from https://docs.cntd.ru/document/1200039098 Accessed March 02, 2023. (In Russian)

[3] GOST 31490–2012. "Poultry meat of mechanical separation. Specifications" Retrieved from https://docs.cntd.ru/document/1200095720 Accessed March 02, 2023. (In Russian)

The normative document approved by the Order of the Ministry of Health of Ukraine [17] introduces the following term: "Poultry meat separated with the use of mechanical means" (MSMM), which applies to all meat separated mechanically (its two types). The term MSM (mechanically separated poultry meat) defines the mass obtained by the mechanical separation of flesh from bones. With that, the calcium content in the indicated mass should not differ significantly from its content in minced meat obtained by hand deboning. If the content of calcium in the obtained mass is significantly higher than that in minced poultry meat, the mass is called MDM (mechanically deboned poultry meat).

In the guideline of the Canadian Food Inspection Agency "Meat Processing Controls and Procedures" [18], two terms are introduced for meat obtained using mechanical equipment to separate meat and bones: mechanically separated meat (MSM) and finely textured meat (FTM). Mechanically separated meat (MSM) should contain no more than 0.027% of calcium for every 1% of protein, no bone particles with a size of more than 2 mm, the minimum protein content of 10% (14% for retail sale). Finely textured meat (FTM) used as ground meat should contain no less than 14% of protein, no more than 0.15% of calcium, should not have bone particles with a size larger than 1.5 mm and the maximum of 20% of the bone particles with a size larger than 1 mm. Bones coming from the separation equipment should be basically intact and recognizable to guarantee that bones were not crushed, ground or pulverized.

Technical Regulations on Identity and Quality of Mechanically Separated Meat (CMS) from poultry, beef and pork (Brazil) [19] introduces the following definition: by mechanically separated meat (CMS) is meant meat obtained by mechanical comminution and separation of bones of meat-producing animals intended for production of *certain* meat products from poultry meat. It is characterized by the following indicators: protein (minimum) 12%, fat (maximum) — 30%, calcium content (maximum) — 1.5% (dry matter), bone diameter — 98% should have a size (maximum) of 0.5 mm, width (maximum.) 0.85 mm, (maximum) –1 meq KOH/1 kg fat [19].

The international organization for food quality Codex Alimentarius Commission establishes for MSM recommendations only for the calcium content — no more than 1.5% on dry matter basis [20].

Analysis of national normative-technical documents of several countries that are the main MDPM producers show significant differences in assessment criteria for "mechanically deboned poultry meat". For example, requirements of the content in MDPM of protein mass fraction are in a range from 10% to 15%, fat from 12% to 30%, calcium from 0.1% to 2.75%, amount of bone inclusions from 0,35% to 1%, their size from 400 μm to 2 mm. There are also other differences and requirements indicated in the above-mentioned documents [12,13,14,15,16,17,18,19,20]. The reason for such differences in various approaches to the problem includes non-standardized initial raw materials, poultry age, a ratio of meat and bone tissues in raw materials, initial temperature, type and design of the deboning equipment, its technical condition, used pressure and so on.

When using MDPM for meat product manufacture, the mandatory indication of its presence on a label as a separate component is necessary according to the international and national requirements. For example, Article XI (paragraph 110) of the TR CU "On the safety of meat and meat products" (TR CU 034/2013) [21] states that in the case of using mechanically deboned (finally deboned) meat in the manufacture of meat products, the information about its use shall be indicated in the composition of such products (for example, "mechanically deboned meat"). The similar requirement is in Article 12 (paragraph 106) of the EAEU TR 051/2021 "On the Safety of Poultry Meat and its Processed Products" [16].

In Europe, the sale of mechanically separated meat (MSM) as "meat" is also banned. If MSM is used as an ingredient of a product, it should be indicated in the list of ingredients as "mechanically separated meat". This rule also acts in other countries including the USA.

The foregoing analysis of the normative documents of several countries that dominate in the world by the share of mechanically deboned meat production shows that these documents reflect the search for the ways of increasing efficiency due to an improvement of MDPM characteristics.

Mechanically deboned meat (MDM) is usually regarded as low-quality and is used according to certain rules. It differs from hand separated meat by an increased risk of microbiological contamination, proportion of bone inclusions, their fractional composition, calcium and phosphorus content, chemical indicators (fat, protein, moisture) and by technological properties (water holding, water binding and emulsifying capacities).

At the same time, the biological value of MDPM protein is approximately the same as that of protein of hand deboned poultry meat and is predetermined by the amino acid composition. The deficiency of amino acids was not established in MDPM compared to chicken egg protein. It is necessary to note that part of connective tissue is separated from the muscle part of meat upon separation and enters the meat-and-bone residue. The relative biological value (RBV) determined using infusoria turned to be significantly higher ($P < 0.05$) compared to that of hand deboned meat in reference to casein [22].

The development of new modern technologies and equipment for mechanical deboning of meaty bones allows producing meat raw materials, which is difficult to distinguish from conventional minced meat; therefore, there are no objective reasons to classify all MDM as low-quality. This is stipulated in the normative documents of the USA [15], Ukraine [17] and Canada [18]. For example, according to the existing EU Regulations [13,23], MSM types are distinguished depending on whether low or high pressure was used in their production and are determined

according to the alterations in the bone structure and calcium content. The EU upper limit for the calcium content in low-pressure MSM is 100 mg/100 g (1,000 ppm), and MSM with the calcium content higher than this threshold is considered high-pressure MSM. Other terms are also used to define these types of meat: "soft and firm", "firm separation", and "soft separation", "Baader meat" [24,25].

The EU member states usually designate the pressure of up to $10^4$ kPa (equal to 100 bar) for low-pressure MSM and the pressure higher than $10^4$ kPa (up to $4 \times 10^4$ kPa or higher) for high-pressure MSM [26].

Nevertheless, classification of these values is not clearly determined and does not permit equating low-pressure MSM to the term "meat", although several European countries ignore this requirement. For example, the EU ban (Food Standards Agency — EFSA) to use low-pressure mechanically separated meat as a category "meat preparations" in the UK unlike existing EU norms led to significant economic losses, which amounted to £200 million according to the British Meat Processors Association. At the same time, the Food Standards Agency (FSA) declared that "there is no evidence of any increased food safety risks associated with DSM obtained by mechanical separation or the process by which it is produced" [27,28].

**Modern approaches to distinguishing MDPM types**

To straighten out approaches to distinguishing types of mechanically deboned poultry meat obtained on different types of equipment and on request from the European Commission, the Panel on Biological Hazards (BIOHAZ) of the European Food Safety Authority (EFSA) [26] carried out an expert examination of the published studies on the sanitary and hygienic risks associated with mechanically separated meat (MSM) from pork and poultry (high and low pressure) comparing them with non-MSM (fresh meat, minced meat and meat preparations) by criteria chosen as potential (chemical, histological, molecular, textural and rheological parameters). Mainly, the aim of the investigation was to determine whether it is possible to distinguish high-pressure MSM from low-pressure MSM and to establish whether low-pressure MSM is similar to hand deboned meat.

In several investigations, which compared meat of different types obtained by the method of low and high pressure, as well as hand deboning, the results were presented mainly on the basis of their histological assessment. It is quite difficult to distinguish low-pressure MSM and hand deboned meat using this method due to their similarity. Muscle structure of fibers is modified in hand deboned meat upon comminution or freezing and, therefore, it can be similar to meat obtained upon low pressure. With that, the presence of bones often can be higher in hand deboned meat depending on the experience of a boner and it also cannot be a reliable marker.

Indicators obtained by methods based on chemical and textural changes were contradictory as their levels in low-pressure MSM and hand deboned meat differed to such a degree by overlapping that they were not suitable for clear distinguishing.

Despite the large number of materials studied by EFSA, no individual parameter was chosen as an indicator of mechanical separation of minced meat types and it was concluded that there is no uniform method or approach that can be used to distinguish low-pressure MSM and hand deboned meat.

The EFSA recommended using the content of calcium and cholesterol in meat as well as a change in the muscle fiber structure as potential indicators of such difference [26].

In 2015, the English Food Standards Agency & DEFRA realized the project "An evidence based review of the state of knowledge on methods for distinguishing mechanically separated meat (MSM) from desinewed meat (DSM)" [27].

It was concluded based on the performed research and EFSA report that the study of differences can include a multivariate analytical approach with a decision tree as the best method. According to the authors' opinion, it should use calcium and fat levels, oxidation behavior, damage of nuclei, integrity of muscle fibers and a measure of texture. With that, it is necessary to determine categories, in which a sample corresponds to the high confidence limits and high certainty in the types of meat under study. It is also necessary to include overlap or "grey" areas and make a decision about their labeling for legislative purposes.

For future research, the project suggests taking into account the following:

- comparison of the residual material from hand deboning with that from machine deboning carried out depending on a type of meat remained on bones for correct assessment of a level of losses or modification of the muscle structure;
- use the histology method developed in the UK [30], which is similar to the method used in Germany [31], clearly distinguishes between low-pressure and high-pressure MSM and is suitable for measuring quality of a sample. It is necessary to develop this method for quantitative assessment supplying with high quality software for image analysis;
- investigation of microbial load in MSM production compared to hand deboned meat;
- formulation of clear requirements for types of comminuted meat that take into account not only losses or modification of fiber structure but also rheology as a measure of the property of the product itself;
- inclusion of inter-laboratory assessment for chosen methods.

The MACSYS project [32] on the "development of an objective method to perform quality classification of comminuted poultry meat" ended in 2016 was carried out within the framework of FP7-SME. It was financed by the EU and several companies. Three universities from Denmark (Kobenhavns Universitet, Aarhus Universitet) and

Germany (Max Rubner Institut), and seven private for-profit organizations (from Denmark, France, Spain, United Kingdom, Iceland) took part in the project.

The general goal of the MACSYS project was to overcome scientific and technical barriers linked with the development of efficient and objective solutions for quality classification of comminuted poultry meat. The main result of these investigations was an agreement on the common immune-histochemical method for quantitative assessment of muscle fiber degradation based on differentiation of their intact and non-intact membranes. This led to the other two main results of the MACSYS project: the cloud-based automated histochemical system of image analysis of intact and non-intact muscle fiber membranes and developed prototype based on near-infrared spectroscopy (NIRS) to measure muscle fiber destruction in comminuted poultry meat in real time, and this method should be calibrated against the immunohistochemical method [32].

The software for automated image analysis and fast acting device based on NIRS for objective quantitative assessment of the level of muscle structure degradation enables differentiating comminuted meat, classifying quality of MDM and also allows producers to obtain the economic benefit from this.

Another method was used to determine calcium — laser induced breakdown spectroscopy (LIBS). This method does not require sample preparation and is used for direct measurement of minerals in a sample, as well as for separation of samples with the very low level of calcium. With that, to obtain the representative sampling, it is necessary to determine the optimal number of measurements.

The project developers concluded that the positive effect will be achieved only if EU legislation is changed.

Raudsepp *et al.* [33] reported at the 61th International Congress of Meat Science and Technology about the results of investigations of histochemical methods based on staining of MDPM samples with Toluidine Blue, which is a well-proven method, and contemporary immunohistochemical labeling based on myosin and laminin, on which antibodies of comminuted chicken meat were applied to assess their potential in terms of objective detection of muscle tissue and its degradation. The researchers [33] concluded that the immunohistochemical method with myosin and laminin antibodies has a significant advantage as it uses fully automated equipment for visualization, ensures objective images with good representativeness for determination of the muscle tissue content and assessment of the degradation level in comminuted chicken meat. This method was used in the MACSYS project.

Since one of the main control parameters of MDPM is the calcium content as an indicator of residual bone, a method was proposed based on Raman spectroscopy to assess the calcium and ash content in bone and meat mixtures upon mechanical deboning of chicken meat and the partial least squares regression models were developed to predict their content [34].

Within the framework of the MPSQA project financed by the Ministry of Health of Italy, a study was carried out and a method was developed for identification of mechanically separated meat by irradiation of a sample coupled with electron spin resonance. Bone fragments were identified both in the samples of fresh meat with addition of different percentages of bones and in meat samples consisted of MDPM (chicken/turkey) obtained under low and high pressure [35].

**Development of the technical base of MDPM production**

To increase MDPM quality, measures are taken to improve equipment for its production upon reduced pressure with significant preservation of the meat structure.

In the middle of the last century, production of products from poultry meat increased along with the growth in its outputs. With that, a need emerged for the rational use of raw materials that are labor intensive for hand separation of meat from bones (frames, backs, necks, wings and so on) and not safe for working personnel. Creation of such equipment for these purposes allowed solving this task [6].

The initial use of equipment with high values of pressure in the working zone of separation (up to 200 bar and higher) for MDPM production allowed obtaining a product as finely comminuted paste-like mass with the presence of bone inclusions of different sizes, cartilages, increased calcium content, loss or modification of the muscle fiber structure of meat different from minced meat produced from raw materials in pieces [6,36].

By the principle of action, such units are classified into two types: batch-type (hydraulic) system and continuous (screw type and belt-drum). The equipment of the latter two types is mainly used to produce mechanically deboned poultry meat. MDPM production was mainly ground on the one-stage technology with the use of one unit of equipment. Upon using screw presses, the obtained mass usually has paste-like appearance with a high degree of comminution. This type of equipment is characterized by an impact of high pressure on raw materials with destruction of its structure and separation of soft fraction from it; with that, pressure of no less than $300 \times 10^5$ Pa is required for meat deboning [37].

At the same time, a belt-drum unit with the flexible elastic belt (Baader type) exerting soft impact on raw materials (up to 5 atm.) upon its corresponding adjustment allows obtaining a product with appearance of a granular minced meat (a degree of granularity depends on the diameter of drum holes) that is equal in quality to the requirements for the category "meat".

When studying "firm" and "soft" (Baader meat) separation of MDPM obtained on different equipment, the selected quality parameters (hydroxyproline, calcium, content of bone particles and their histological features) were compared. The average values of the hydroxyproline content, which characterizes an amount of collagen tissue in MDPM,

were more than two times higher (335.44 mg.100 $g^{-1}$) compared to those in Baader meat (140.73 mg.100 $g^{-1}$). More pronounced differences were revealed between the indicators in mechanically deboned products and those in poultry meat, mainly in breast muscles (32.62 mg.100 $g^{-1}$ in pectoral muscle and 124.90 mg.100 $g^{-1}$ in thigh muscle). Upon "firm" separation, the calcium content was 7.9 times higher, respectively. The average content of bone particles was 0.27% ("firm" separation) and 0.034% ("soft" separation). The results of the studies show that Baader meat was analogous to fresh poultry meat in terms of its properties [38]. Similar data were obtained when studying properties of Baader meat from chicken furcula (wishbone) [39].

In the process of MDPM production, the two-stage technology came into use. Under this technology, meat removal under low pressure of up to 20 atmospheres takes place at the first stage and under high pressure (more than 100 atm.) at the second stage. The work of the press — meat deboner enables obtaining part of a product that approximates the category "meat" (meat mass of large dispersity) under low pressure and producing part of MDPM with lower quality as a paste-like mass on the subsequent machine with high pressure. The one-stage and two-stage technologies are practically equal in terms of product yield. With that, the pressure can be regulated achieving different yields and quality indicators of a product.

German scientists carried out comparative studies on the mechanical deboning of parts of poultry meat using the two-phase system TWD8/Mado, modified separator POSS (drum sieve with a hole diameter of 3 mm) and original separator POSS (0.6 mm plates) [38]. The first two methods are characterized as methods of soft pressing; the third method gives meat of paste-like consistency (meat from a tough separator). As histological data show, the two-phase system TWD8/Mado gives the final product that is equivalent to minced meat in terms of quality provided that raw materials do not contain bones with a small amount of attached meat. With that such MDPM is recommended to use as fresh processed meat reviewing its legal classification as defined in Regulation (EC) No 853/2004 [12].

At present, different countries carry out work on producing MDPM of different grades on a single unit of equipment.

The All-Russian Scientific Research Institute of Poultry Processing Industry (ARSRIPPI) has received a patent on the method for separation and division of mechanically deboned meat by quality simultaneously on a single unit in the process of movement of raw materials through the multizone filter with holes of different diameters according to zones (from 4.0 to 0.5 mm) and creation of different pressure of pressing in the process of movement of raw materials along the filter (from 0 to 85 atm.). Additional processing of the secondary product on a separator is not required when using this method. The samples of the equipment were created, tested and showed positive results [40].

Testing of the screw press with the four-zone filter on keel bones of broiler chickens [41] enabled obtaining in the first two zones meat particles with a size of 3.5–2.5 mm, 85–75% of volumetric muscle tissue, including 70%-80% with the preserved structure, a size of bone inclusions of 150–200 μm; in the third and fourth zones, meat particles with a size of 1.5–0.1 mm and lower and a size of bone inclusions of 150 and less than 100 μm were obtained. A significant preservation of meat structure in the first and second zones, production of its two types (close to minced meat in terms of quality with a possibility to assign it to the category "meat" and MDPM) on a single unit allows expecting its further improvement.

Ukrainian scientists studied an effect of technological aspects of production using a screw-type press equipped with the perforated filter sleeve having a hole diameter of 3.0 mm on the quality characteristics of low-pressure MDPM [42]. Histochemical studies of this meat type showed in the micrographs the dominant presence of comminuted muscle tissue with the intact structure and less significant presence of fatty tissue (similar to minced meat from hand deboned poultry meat), as well as the presence of bone marrow fragments and bone inclusions in the structure. It was found by chemical methods that upon the same yield, the content of total protein and fat in low-pressure MDPM approximately corresponded to minced meat from hand deboned poultry meat. The content of calcium was not higher than the norm (0.07%) established by regulatory documents. Macrostructural analysis demonstrated that the linear dimensions of the bone inclusions basically did not exceed 1.0 mm, and the sizes of incidental inclusions were less than 2 mm. These data served as an evidence base for identification of low-pressure MDPM obtained in the experiment.

The performed studies showed that it was possible to obtain low-pressure MDPM close to hand deboned meat in terms of quality using several technical means. With that, it is necessary to recognize such MDPM at the official level as the category "meat" with agreed deviations.

**Methods for detection of falsification of raw materials and products with MDM**

The presence of MDM in meat and sausage products is subjected to declaration. Due to the economic benefits, however, unfair producers more and more often replace expensive raw materials with cheaper and allow inclusion of MDM into meat product recipes without indication on a label. Nowadays, the existing methods have been improving and new methods have been developing to detect falsification.

Detection of bone inclusions in the multi-component meat products (sausages and other products) produced with MDM using the method of their gravimetric determination by chemical treatment of samples broadens possibilities of revealing falsification of these products as the level of qualitative and quantitative expertise [43].

To detect meat product authenticity, protect consumers from falsification of products due to the presence of non-declared MDM, histological methods are actively used with staining sections of samples with hematoxylin and eosin, and trichrome blue along with the investigation of technological properties, content of ash, bones, cartilages and calcium [44].

The investigations performed based on the histological methods for detection of unauthorized inclusions in meat sausage randomly collected on Iranian markets by staining sections with hematoxylin and eosin, Masson's trichrome, periodic acid- Schiff/Alcian blue and Verhoeffe/Van Gieson allowed revealing a wide spectrum of unauthorized tissues including dense connective tissue, cartilages, bones, skin, smooth muscles and blood vessels. The researchers believe that histological methods, especially Masson's trichrome staining are practical methods for routine assessment of possible falsification [45].

To detect MDM in meat products, invasive destructive methods are mainly used. At the same time, the Czech researchers developed a new non-invasive method for detection of bone fragments as accompanying structures of MDM based on X-ray micro computed tomography (μCT). Bone tissue detected on the basis of higher density using μCT was confirmed by the image analysis and histochemical method with alizarin red staining. The method allows analyzing bone fragments in meat products with a possibility of determining parameters of their shape [46].

A study based on the application of computed tomography using a computed tomography analyzer (CTAn) was carried out to detect the presence of bone inclusions in sausage products with MDPM. On the basis of its results, characteristics of bone and cartilage inclusions in the experimental samples were determined. It was concluded that it is possible to use this method for microstructural analysis of food products to ensure quality of production or reveal food falsifications [47].

On the request of the European Food Safety Authority (EFSA), a study was performed to identify meat products with MSM using a liquid scintillation counter of ultra-low levels of the 90Sr activity concentrations in combination with other parameters: 88Sr, Ca and ash percentage via the multivariate approach. The accuracy of this method ensured the correctness of identification (87%) higher than in the reference method (Ca level; 76%). According to the authors' opinion, this is a new approach to identification of products with MSM [48].

To reveal non-declared MDPM presence in sausage products, an analysis was developed and approved based on pseudo-MRM–LC–MS/MS, which uses peptides specific to intervertebral discs and cartilages assigned to collagen II alpha 1. This method allowed detecting MDPM in real samples of the unknown composition upon its content of up to 10% in meat [49].

Wubshet *et al.* [34] reported about the first use of Raman spectroscopy as a fast tool for assessment of the calcium and ash content in bone and meat mixtures with mechanically deboned poultry meat. This analysis allows detecting much lower quantities of MDPM (10%) in commercially available meat samples compared to all currently established standard methods, such as microscopy, calcium detection and liquid scintillation counting (20%) or total reflection X-ray fluorescence (TXRF) method (40%). In addition, the method has another advantage as it enables abandoning thorough biochemical and chemical characterization of a sample material (lipids, proteins, ash, calcium, carbohydrates and so on) because high specificity of pMRM-transitions allows selective detection of MDPM specific marker peptides.

Electron spin resonance (ESR) spectroscopy is widely used for identification of irradiated meat and fish that contain bones [35]. This is associated with the characteristic signals obtained upon bone irradiation. When executing the MPSQA project (Italy), an innovative analytical method for MDPM identification after irradiation was developed as this type of meat products contains bone fragments. Ashing of samples allowed achieving the full removal of interfering signals. Bone fragments were identified both in the samples of fresh meat with addition of different percentages of bones and in the meat samples consisted of low-pressure and high-pressure MDPM (chicken/turkey).

Sarakatsianos *et al.* [50] studied the use of inductively coupled plasma/mass spectrometry to detect and differentiate the content of high-pressure mechanically deboned meat (MDM) in meat products. Of all tested elements, barium had a clear tendency of dependence of its concentration on the content of bone particles in MDM, which enabled detecting the presence of MDM in processed meat products by its correlation with the barium concentration.

With that, large variations among batches of mechanically deboned chicken meat that depended more on its processing rather than on initial raw materials will require consideration for this factor when improving methods for detecting falsification [51].

### State of production regulation and quality and safety control of MDPM in Russia

GOST 31490–2012[4] applies to mechanically deboned poultry meat (chicken and turkey) intended for industrial processing. According to this document, mechanically deboned meat should correspond by the organoleptic and physico-chemical parameters to the following main requirements: it should be viscous finely ground paste-like mass in terms of appearance with the moisture mass fraction no more than 70%, protein no less than 12%, fat no more than 18%, calcium no more than 0.26%, bone inclusions in reference to mass of mechanically deboned meat no more than 0.6% with their specified differentiated sizes.

[4] GOST 31490–2012. "Poultry meat of mechanical separation. Specifications" Retrieved from https://docs.cntd.ru/document/1200095720 Accessed March 02, 2023. (In Russian)

Quality indicators also include norms of the presence in MDPM of the quantity of volatile fatty acids, fat peroxide value (% of iodine), acid value (mg KOH/g fat), mass fraction of total phosphorus (%).

It is not permitted to use raw materials with the mass fraction of fleshy tissues of less than 30% for production of mechanically deboned meat.

According to the GOST, the following restriction is introduced: raw materials in a form of poultry carcasses and/or their parts should be obtained directly in an enterprise that performs cutting and deboning of chilled poultry carcasses and/or their parts. At the same time, several production facilities were created in Russia, including in large holdings, where raw material production for MDPM and MDPM production are located at different sites, which contradicts to this GOST, although it is possible upon correspondence to the time of delivery, necessary temperature regimes and sanitary rules.

The GOST does not take into account new technical possibilities of producing MDPM of different types, and new scientifically based criteria for dividing such products for MDPM of different quality are required. In addition, its narrower specifications by parameters are necessary due to possible significant variations of MDPM by the protein and fat content depending on a type of initial raw materials.

Several interstate standards specify methods for controlling various indicators of MDPM. For example, according to GOST 31466–2012[5] approved based on the investigations carried out by ARSRIPPI [52], determination in MDPM of the calcium mass fraction is carried out by flame atomic absorption spectrometry, sizes of bone inclusions by the microscopic method, mass fraction of bone inclusions and mass fraction of bone inclusions, which size is higher than the specified (normed) value, by the gravimetric method.

To assess quality of meat raw materials and meat products and their correspondence to the normative document, including MDPM, the method[6] is used, which is based on identification in histological preparations of animal and plant components in different types of canned meats and meat products according to their microstructural features as well as on the determination of the ratio of muscle and connective tissues in meat raw materials. General staining of sections is performed with hematoxylin and eosin, staining for detection of fat with Sudan III and Sudan IV, staining for detection of starch with Lugol's solution. Semi-quantitative assessment of one or another component can be also carried out using either ocular-micrometer or ocular inserts attached to light microscopes.

The existing normative document used to reveal product falsification is based on the fast histological method for identification of animal and plant structural components of the compositions in different types of meat and meat products[7]. It enables revealing the presence of unenvisaged components and the correspondence of the real composition of a sample to the existing documentation or to the composition indicated on a product package.

At the same time, it is necessary to search for a method to detect not only semi-quantitative but also quantitative parameters of differences between MDPM types upon its using for objective assessment of the presence in products.

**Improvement of the organizational forms of MDPM production and processing**

Today, processing of poultry carcasses and their parts sent to mechanical deboning is performed on practice using several schemes. The main scheme among them includes the following: poultry slaughter, MDM production and its processing into products are carried out in the same enterprise — poultry processing plant. The next scheme is production of MDM from purchased raw materials in a specialized enterprise with the following product shipping to a customer. Several processing enterprises purchase raw materials for MDPM from poultry processing plants and produce it for their own needs.

The most effective production with lower allowable risks is MDPM production according to the first scheme. With that, it is possible to control each factor that determines its quality at each previous stage of processing. Production or purchase of MDPM in a specialized enterprise leaves producers relatively few possibilities to influence their own part of the process as an effect of other factors was applied at earlier stages (breeding, slaughter or preliminary deboning of meat from poultry carcasses). MDPM production operations that are disrupted in time and space negatively affect quality characteristics of products and their microbiological safety [53]. Furthermore, certain producers violate recommended time for raw material processing and overstate the yield of the final product. To avoid this, producers and consumers of MDPM need to apply maximum integration of production chain links, strictly adhere to production instructions and temperature regimes, ensure robust logistics and reciprocal control of production.

The next important specific feature of MDPM production is linked today with its production volumes, first of all in large enterprises. Appearance of enterprises with daily production volumes from 60 to 400 tons of poultry meat in Russia and assignment of a significant part of poultry meat for semi-prepared products and finished products create a possibility of separate processing of poultry carcass parts into MDPM after preliminary mechanical or hand deboning with different initial quality characteristics of raw

[5] GOST 31466–2012. "Products of processed poultry meat. Methods of determination of mass fractions of calcium and dimensions and mass fraction of bond particles" Retrieved from https://docs.cntd.ru/document/1200096477 Accessed March 02, 2023. (In Russian)

[6] GOST 31479–2012. "Meat and meat products. Method of histological identification of composition" Retrieved from https://docs.cntd.ru/document/1200097485 Accessed March 02, 2023. (In Russian)

[7] GOST 31796–2012. "Meat and meat products. Fast histological method of identification of composition structural components" Retrieved from https://docs.cntd.ru/document/1200100067 Accessed March 02, 2023. (In Russian)

materials. The calculations of the author show that upon cutting into parts broiler chicken carcasses in an amount of 50 tons and sending to mechanical deboning 4–5 tons of breast parts after preliminary separation of fillet from them, it is possible to obtain 2.8–3.5 tons of MDPM close to the initial raw materials in terms of quality. A producer obtains a product with higher quality and value when processing these raw materials separately from others.

Previous research [54] notices an effect of quality of produced MDPM from separately deboned carcasses of broiler chickens, layer hens and their parts on quality of the final products. Chemical and histological analyses (sections were stained with hematoxylin and eosin according to Mayer) showed their significant differences in terms of the content of total protein, lipids, moisture, cartilages, bones, connective, lipid and lymphoid tissues. For example, the average content of lipids was the lowest in the neck samples (4.87%). It was higher in back samples (7.74%) and whole carcasses (9.51%), while the highest content was found in wings (11.56%). Such complex investigations give a reliable insight into the raw material composition, its effect on the final product quality and prospects for the rational use.

In [55], which assessed quality of the poultry raw material sent to mechanical deboning, the main indicator for classification was its protein content and key factor was its quality. The protein mass fraction in the raw material with account for meat pieces on bones serves as a basis for detecting its quantity, while the nutritional and biological value serves for detecting quality indices: meat/bone, fat/protein, tryptophan/oxyprolin, proportion of complete protein in%, a ratio of complete protein to incomplete, energy value of raw materials, kkal/100g. The calculated values of the above-mentioned indices of raw material groups taken from large production batches of different suppliers showed their significant differences. For example, a ratio of the complete protein proportion to the incomplete protein proportion was the highest (3.26) for keel bone, which indicates the highest quality of raw materials among all compared types (2.43 times higher than in necks, 3.1 times higher than in frames and 65.2 times higher than in wings). With that, the study revealed significant differences in quality of raw materials represented by different parts of carcasses and less significant differences between batches of raw materials of the same type supplied by different producers.

Based on the data obtained, the authors propose using such raw material types as keel bones, backs and necks to produce MDPM of differentiated quality and use it for new products.

Abaldova *et al.* [56] proved the difference in chicken meat quality by the amino acid composition and the biological value depending on the carcass part, deboning method (hand or mechanical) and separation pressure (low or high) compared to hand deboned meat. For example, the total protein content in MDPM from keel bone was 4.7% lower than in hand deboned fillet, but 20.1% higher than in whole carcass which indicates its higher quality. When using low pressure, the content of pure protein (without connective tissue protein) in MDPM from keel bone was significantly higher than in the control (by 12.7%) and in fillet (by 3.3%), but it was lower by 9.7% when using high-pressure separation.

Similar results were obtained upon separate processing of turkey raw materials into MDPM using screw press with the six-zone filter with different diameters of holes in zones [57].

It is possible to increase the yield of high quality MDPM by improving criteria of its assessment by types [58]. With that, it is important to coordinate a type of the initial raw materials with the desired quality of the obtained MDPM as well as the produced final product. The process of meat removal with consideration for categorization of incoming meat-and-bone raw materials (pork) at the input stage is typical for foreign processors [59]. Therefore, there has been a long-standing need for classification of raw materials by quality characteristics with consideration for their morphological composition (meat-bone index, content of protein and fat) already at the input stage for the efficient use of MDPM.

**Conclusion**

Mechanically deboned poultry meat is widely used in significant volumes worldwide and in the national practice to produce sausages and other products. Quality characteristics of MDPM have been actively studied upon its production using the equipment with high pressure in the working zone. With that, the product had an appearance of paste-like mass with the destroyed structure, the presence of bone inclusions of different sizes and cartilages, increased content of calcium and several other inclusions that distinguished it from hand deboned poultry meat. The term “mechanically deboned poultry meat” is used for its definition.

Over the last decades, the technology and technical means for MDPM production have been improving worldwide. The equipment with low pressure has been designed and is used, which allows obtaining a product with quality approximating that of hand deboned meat. Boundaries for division by quality of all MDPM types compared to hand deboned poultry meat, conventional terminology, methods for their classification and identification are not clearly defined. Scientists from different countries search ways for solving these tasks.

At present, scientific studies are carried out widely in the world on the whole spectrum of indicators of new MDPM types produced under different pressures compared to hand deboned meat (content of calcium, barium and cholesterol, damage of muscle tissue and so on) and products of its using. Conditions are being created for improving classification of different MDPM types by method of production and maximum allowable threshold values, standardized parameters, determination of their characteristics, methods for assessment and substantiation of terminology.

Similar problems are also relevant to our country. With the appearance of domestic equipment and use of import equipment for MDPM production that allow production of low-pressure MDPM, the existing normative base requires correction and addition.

Based on the international and domestic scientific research, it is necessary to:

- substantiate the most objective parameters of quality characteristics of mechanically deboned meat based on poultry type (meat and egg chickens, turkey), their parts and pressure upon its production (destruction of the meat structure, presence of calcium, bone inclusions, their sizes as well as bone marrow, iron, cholesterol and so on), determine limits of maximum allowable values of destruction of the muscle tissue structure, the content of calcium and bone inclusions in low-pressure MDPM that is close in quality to hand deboned poultry meat, as well as to perform their comparative microbiological assessment;
- develop new and improve existing methods for detecting objective criteria of quality characteristics of MDPM based on physico-chemical, histological investigations and others, both arbitration and express analyses;
- classify MDPM depending on pressure upon its production, take into account changes in the sphere of production organization, actualize the national normative base;
- develop methods for controlling falsification when using MDPM for product manufacture (above norms specified in a recipe).

Creation of such a normative base will allow the rational use of poultry meat raw materials, increase in production efficiency and creation of conditions for active introduction of new technique for these purposes.

There has also been a long-standing need for classification of raw materials coming for processing by their quality characteristics with regard to the morphological composition, meat-bone index, protein and fat content already at the input stage to increase MDPM quality.

It is necessary to pay attention to improvement of the equipment design both for the one-stage and two-stage technology for MDPM production toward formation of feedback between the finished product, initial raw materials and pressure in the process, which will enable increasing its quality characteristics.

Producers and consumers — processors of MDPM should pay attention to the logistics schemes of movement along the life cycle linking its parameters with quality of the final product.

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