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WATER-HOLDING AND WATER-BINDING CAPACITY OF MEAT AND METHODS OF ITS DETERMINATION

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Abstract
*The considered topic is of great interest for researchers and practitioners engaged in the development of technology and the production of meat food. In the review, the authors focus on theoretical aspects of the meat capacity to bind and hold water. The characteristic of the forms and strength of the water-to-meat bonds is given. The influence of the structural elements of muscle tissue on the meat capacity to bind and hold water is shown. The different opinions of the specialists are given in regard to the terms "water-binding" (WBC) and "water-holding" (WHC) capacity of meat, and the authors of this research expressed their own opinion. Basing on the analysis of publications, a characteristic is given to forms of water-to-meat bonds strength from the point of view of technological practice: there is tightly bound water, loosely bound available water (**immobilized**), and loosely bound excessive water (**free**). The article summarizes the material on the methods of determination of water-holding (water-binding) capacity of meat. It is shown that up to date there is no unequivocal answer about the choice of WHC determination method. To define WHC, it is recommended to subtract the WBC value obtained by one of the gravimetric methods from the value of the indicator obtained by one of the methods of external pressure. This problem requires further research, discussion of issues and methods for determination of water-holding capacity.*

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Introduction

The capacity of muscle tissue to hold or to lose water underlies all modern technologies of meat food production. Understanding the mechanisms of water supply and water maintenance allows direct regulating the functional and technological properties of raw meat materials in order to achieve the desired result. In meat and meat products water is the most important component that provides a significant impact on the organoleptic, structural-mechanical properties of raw materials, quality and storability of the ready-to-consume food products.

Modern knowledge about water-holding capacity of meat is based on fundamental researches of Hamm [1], Offer et al. [2], and Honikel [3,4]. However, the essence of water binding in the meat is not yet completely clear till nowadays.

In available publications there are differences in the approaches to the terms "water-binding" and "water-holding" capacity. So Hamm [1], Forelle et.al. [5], Honikel [3] believe that water-binding capacity is more related to potential capacity of raw meat to bind water, while Klima et.al. [6], Naveau et.al. [7] interpret the term "water-binding capacity" as the capacity of the food product exposed to heat treatment to bind and hold water. According to the authors there is a rather close correlation between these two indicators. Water-holding (water-binding) capacity of meat is understood as the difference between the water content in the sample before and after any processing (maturation, pressure, heat treatment, etc.). Pospic et.al. [8] consider the abbreviation of WHC as capacity of raw meat to hold water, and WBC — as capacity of thermally processed meat to bind water.

In domestic researches the term water-holding capacity, as a rule, is construed as capacity of native proteins (raw meat) to bind water, while water-binding capacity is construed as the amount of water bound by the food product, exposed to thermal processing [9,10].

According to the authors of this article, the concept of water-holding shall be understood as the capacity of native proteins in raw meat to bind water through peptide bonds and hydrophilic lateral groups of residues of protein macromolecules amino acids capable to hold the opposite-charged ions and water dipoles. In the long chains of fibrillar proteins (collagen) the terminal

groups create chemical bonds between the chains. While that the terminal groups form a three-dimensional spatial structure, which retains and immobilizes water inside the spatial lattice, thus contributing to the swelling of proteins. Polypeptide chains of globular proteins are rolled up in such a way that hydrophobic centers are oriented inwards the globe, and hydrophilic centers are located on its surface.

When meat is heated, denaturation and coagulation of myofibrillar proteins occurs, which leads to the loss of their biological specificity. In this case, the term water-binding capacity should be understood as the amount of water bound by the structure of the product exposed to heat treatment. Nevertheless, an analysis of the results of forms research and methods of retaining of water within the meat structure proves the presence of water not bound to the structural elements of cell, but still held in its structure. Consequently, the concept of "water-binding capacity" is also applicable to assess the properties of raw meat not exposed to heat treatment. Therefore, before discussing the issue of water holding, it is appropriate to consider the morphological structure of muscle tissue.

Characterization of water bonds in meat

It is known that the main structural element of muscle tissue is muscle fiber, which surface is covered with a sarcolemma. Inside the fiber there are myofibrils which occupy 60–65% of the cell volume. The muscle fibers are separated by layers of connective tissue — endomysium, which is connected to the sarcolemma. A group of muscle fibers forms the primary muscle bundle, surrounded by coat of connective tissue — perimysium. Primary muscle bundles are combined into the secondary bundles, to tertiary bundles and bundles of a higher order, which all together form the muscle. The muscle is surrounded by a coat — epimysium or fascia.

From publications [11,12] it is known that the meat contains approximately 85% of water. This water is part of myofibrils, localized between myofibrils and connective tissue coat — endomysium, between the muscle fibers bundles and the surrounding connective-tissue coat, and between the individual bundles of muscle fibers. The remaining 15% are located in extracellular space. Hamm [13] found that various components of muscle tissue are capable to hold water in various degrees. The water held by myofibrillar proteins accounts for about 50%, by sarcoplasmic proteins — about 3%, and non-protein components of the sarcoplasm hold about 47% of water.

According to the electrostatic theory of Hamm [14], the amount of bound water is determined by the "clean" charge of proteins which repels the adjacent groups of protein molecules with negative charge; also the amount of bound water is determined by swelling of myofibrils and partial destruction of actomyosin complexes, which increases the water-binding capacity of meat.

The water, which is part of the undecomposed meat tissues, is heterogeneous in its physical and chemical properties, and its role is not the homogenous also. There are two forms of water in meat — bound and free. Bound water, according to Collins et al. [15] is mainly bound by polar groups of protein macromolecules, which is explained by the special structure of the water molecule itself. Such water is characterized by a number of specific properties: it has smaller volume, freezes at a lower temperature, chemically inert and is unable to dissolve substances. The water like this accounts for about 0.1% of the total water content in meat.

Water molecules have capacity to bind to each other with hydrogen bonds. Although these bonds are weak, they are very numerous, thus they together provide a significant impact on the structures which they get bound to. N-region of one water molecule, with negative charge, is attracted by the positive area of the other water molecule.

Much larger amount of water (from 5% to 10% of the total content) is in a less organized form and is less tightly bound with protein molecules [16,17]. Due to the presence of hydrophilic centers of proteins of the electrostatic field, water dipoles are oriented around them, forming this way adsorptionally bound water. Depending on the size of the charge, hydrophilic centers are able to hold from 2 to 4 water dipoles, not counting the water of diffusion layers. The force of interaction between active protein groups and water molecules depends on the distance between them, as well as the availability of the group itself in the molecule structure. The water dipoles, which are located close to the polar group, are bound with it quite firmly with the help of van-der-vials forces. When the dipole of water is removed from the polar group, the force of their interaction weakens. The number of subsequent layers can be as many as several dozen, forming a solvate coat around hydrophilic colloids and protein molecules in general. In the last layers, water molecules can move from the outer layer to hydrate layer and vice versa, forming this way the so-called "diffusion layer" [16].

Unlike polar groups, non-polar groups of protein macromolecules repel polar water molecules, creating an arched structure around a non-polar group.

According to Zayas [17], some amino acids possess the capacity to bind water. For example, aspargin and glutamic acids can bind from 4 up to 7 water molecules. Myosin protein also has a high capacity to bind water due to its being rich in these amino acids.

The forms of adsorption binding of water are divided into two types: binding of water with charged protein groups — ion adsorption, and binding of water with uncharged groups — molecular adsorption.

Water molecules bound and held by polar groups of proteins contribute to the preservation of the spatial structure of the protein macromolecules and make up **tightly bound water.** The share of tightly bound water is limited

by the number of cross-line actomyosine bridges and the strength of the relationship between actin and myosin and z-lines. Moreover, according to Clark et al. [18] the so-called costameres prevent the swelling of myofibrils. The costamers are the structural and functional components of the transversus stripe (barred) muscle tissue that connect the muscles with the cell membrane (sarcolemma) and provide a structural base. These bonds between the adjacent myofibrils and cell membrane consist of several proteins, which include desmin, philamin, sinamine, dystrophin, talin and vinculin [8]. Therefore, it can be assumed that water-binding capacity also depends on the structure of muscle tissue.

Water, located outside this adsorption layer formed by the electrostatic interaction by Pospiech et.al. [8], is considered as unbound, although it is immobilized in the structure of the muscles and also determines the water-binding capacity of meat.

Free water is not bound with protein and serves as a solvent for organic substances and minerals. This water freezes at a temperature of about 0 °C and drips out from the tissue easily. Free water is held in capillaries, the space between the proteins and inside them. This water is loosely held in meat and its volume depends on the size of the capillary space between myofibrils.

Offer et al. [16] proposed an alternative hypothesis of the formation of water-binding capacity of proteins (osmotic theory). According to this theory the uneven distribution of ions in the aqueous phase and on the surface of the actomyosin lattice creates an osmotic force that draws water into the system. The factor of swelling is limited by the cross bridges in actomyosin lattice.

The theories stated above of the formation of water-binding capacity were considered and discussed in numerous publications, including the research of this capacity with the help of nuclear-magnetic resonance. However, some issues regarding the theoretical side of this problem have always remained unsolved.

Honikel [19] defines five ways to bind water with proteins:

— extremely strong binding of water with proteins by electrical bonds;
— binding of water with polar groups of actin and myosin;
— immobilization of water in myofibrils structure, depending on pH value;
— immobilization of water in sarcoplasmic space (relatively freely mobile water);
— retention of extracellular water in capillary spaces ("drip losses").

Change of water-holding capacity during autolysis

The processing of animal tissues after slaughter and their transforming into a food product is accompanied with a row of physical-chemical and biochemical changes in muscle fibers, which result to WHC decrease. The reasons of this phenomenon, generally, are related with loosely reversible changes in the state of the protein complex of muscle tissue.

Before the onset of postmortem stiffening, the meat has a high water-holding capacity [16,19], which is explained by the low concentration of hydrogen ions and lack of bonds between actin and myosin due to the high level of ATP. As a result of the enzymatic splitting of ATP and build-up of lactic acid over the next 12–24 hours of autolysis, myosin and actin threads interact among each other and form of cross bridges. This interaction forms actomyosin, and water-holding capacity of meat drops down [2].

Bertram et.al. [20] showed in his researches that more water is contained inside the myofibrils of the I-strip than in A-strip, which is denser in terms of protein. As the myofibrils get shorter during autolysis and postmortem stiffening occurs, the volume of the I-strip area is reduced. According to the research [21], a decrease of myofibrils volume in this area together with their shrinkage leads to the displacement of water from the myofibrillar structure into the interfibrillar intracellular space and, ultimately, away from the muscles. Decrease of the medium pH brings the charge of proteins to the isoelectric state, which also helps to reduce water-holding capacity.

It is necessary to keep in mind that post-slaughet processes in muscle tissue are accompanied by the oxidation of myofibrillar proteins along with the transformation of some amino acids, including histidine, to carbonyl derivatives [22,23]. While that the intra- and/or inter-proteins disulfide transverse bonds [24] are formed. Since tissue proteolytic enzymes of calpain contain in their active centers both histidine and SH-groups of the residues of cysteine, Lametsch et.al. [25], Rowe et.al. [26] believe that these enzymes can be inacted in result of oxidation. Thus, oxidative changes inhibit proteins proteolysis and reduce the functional properties of meat, including its water-holding capacity.

After a certain time, the postmortem stiffening gradually resolves. It contributes to increase of water-holding capacity of proteins due to relaxation of muscle fibers, but not dissociation of actomyosin, and also as result of proteolytic changes in protein macromolecules, which helps increase the amount of available protein groups capable to bind water [12]. While the subsequent development of proteolysis, the number of active groups of proteins capable of binding water increases, however, according to Ke [11], this does not cause any significant increase of water-holding capacity.

So, summarizing the above material, it can be stated that the water in the composition of meat is more or less closely related to the muscle proteins. The water can be localized inside the cell, and in the intercellular space, as well as in micro- and macrocapillaries. The strength of water binding in the structure of the muscle cell according to [5] is determined by the method of its binding. Most of the researchers share the same opinion that the quantity and

condition of electrostatically bound water are not subject to changes during technological processing, including autolysis.

The water, localized around the polar groups of proteins, is quite tightly bound to them. However, as it removes from the centers of binding, the strength of interaction weakens. It can be assumed that part of the adsorptionally bound water is loosely susceptible to technological influences and is more involved in stabilization of protein macromolecules. Part of the adsorptionally bound water removed from hydrophilic areas of proteins is more subject to change due to the formation of actomyosin and subsequent contractions of myofibril sarcomeres. In this sense, this water can be considered rather immobilized than bound. However, being subjected to certain technological processes, like brine treatment, water displaced into the interfibrillar space will turn to bound state.

The water held by myofibrils significantly depends on the conditions within the cell environment and, above all, on the pH level. The state of the water significantly depends on the conformation of protein macromolecules and the number of available hydrophilic centers. Taking into account the high lability of muscle proteins in response to environment conditions changes, water immobilized in protein structures should be considered more likely bound than held. However, with certain technological influences, for example, with the addition of sodium chloride, this part of the water will easily go into a held state.

The water of the sarcoplasm and capillaries can be considered as mobile water, held by the structural elements of muscle tissue, i.e.: sarcolemma or the walls of the capillaries. This water is easily lost in the form of drip losses, dripping fluid, or evaporation from the meat surface. Nevertheless, as well as water associated into the structural elements of muscle tissue, this freely movable water can be transformed into a bound state.

Based on the above, the water should be considered as **held** water, when it is retained by electrical bonds and adsorption interactions. The term **bound (immobilized)** water should be applied to a part of the water in the adsorptionally formed diffuse layer, which is **loosely bound** within the myofibrils structure in proportion to its distance from the polar groups of these proteins and other binding centers, for example, from hydrophobic ones. The water of the sarcoplasmic space and water, bound by osmotic pressure within the capillaries system, should also be considered as bound water (immobilized water). This suggestion is proven by studies [21], which confirm that water loss in the form of droplets of meat juice during the cooling of carcasses occur as the water is released from myofibrils, its movement from the intracellular space to the extracellular space, and, as a result, the release of liquid on the surface of meat (so, it means that water losses occur due to immobilized water).

Huff-Lonergan et.al. [12], Pulanne et al. [27] in technological practice distinguish the following forms of water-to-meat bonds: tightly bound, loosely bound, available (immobilized) and loosely bound excessive (free) water in the composition of meat, while their shares account for 5%, 15% and 85% of them from the total value.

Using this approach, it can be assumed that the capacity of muscle fabric to interact with water is formed due to its capacity to hold water (WHC) and capacity to bind or immobilize it (WBC). To determine the aggregate capacity of muscle tissue to bind (WBC) and hold (WHC) water, probably it's necessary to introduce an additional term, for example: "Water-binding potential" or "capacity of muscle tissue for water interaction". To resolve the conflict of terms, it is also possible to use the term "water-binding capacity" of muscle tissue as a more general one, including the assessment of both held and bound water in the analyzed objects. In foreign literature, the term "WBC" is also used more often as a more general one, and it applies, more often, to assess the general capacity of meat to bind and hold water than in reference to some specific methods and forms of water binding within the meat.

Methods of water-holding and water-binding capacity determination

Currently, to determine water-holding (WHC) and water-binding (WBC) capacity of meat and meat products, many methods are used — from the simple ones, like mere pressing, to the original methods — with the help of nuclear magnetic resonance. All known methods are based on determination of the loss of water in conditions of gravity, under applied pressure, including determination of drip loss of meat exposed to centrifugation. In some methods WHC is indirectly assessed through the reverse parameter, when the amount of meat juice loss (drip losses) is measured. Drip loss includes exudate or water released on the surface of meat during its exposure.

All methods can be divided into gravimetric methods, methods with external pressure, and adsorption methods according to Honikel at al. [28]. It should be kept in mind that it is not possible to determine the WHC in absolute units of measurement, because each of the methods is used within the framework of specific tasks, and the results obtained by different methods are loosely comparable.

Gravimetric methods

This group includes methods for measuring the meat weight loss due to separation of free water from the meat (dripping) at temperatures from 1 to 5 °C for 48–72 hours, sometimes for 18–92 hours [29]. These methods are very conditions-sensitive, but require a lot of time (from one to several days). These methods include the measurement of water losses by the bag (bag-BM) "DL", proposed by Honikel [4], the method using filter paper (FPW) described by Kauffman et al. [30], Rassmussen et al. [31], including the storing of meat samples in a container for collecting of released water, which method is called the EZ-Driploss

method ("EZ"). This method is recommended by the Danish Meat Research Institute (DMRI) for routine lab researches [32].

For WHC determination by the gravimetric method with the bag ("DL"), a sample of muscle tissue weighing 40–100 g after fat trimming is weighed, hung on the thread and is placed in a hermetic plastic bag to prevent loss of water caused by evaporation so that the meat does not contact with any of the walls of the bag. After exposure for 48–72 hours at a temperature of 0 to 4 °C, it is weighed for the second time and the loss of the tissue liquid is determined by the difference of the sample weight before and after exposure [29].

Honkel [19], Abdalhai et al. [33] offer to determine water-binding capacity of meat on the samples of 40–50 g and a size of 30 × 60 × 25 mm, placed in a hermetic container and exposed for 48 hours at 4 °C. Water losses are calculated as the difference in the mass of the sample before and after hanging as a percentage from the initial mass. WHC is expressed as a percentage of water content in meat.

In addition to this method, several gravimetric methods are proposed [30] also, such as "EZ-DRip Loss", "method of the tray" and the Danish "dripping pipe method".

The EZ-Drip Loss method is similar to the "DL" method, but it uses cylindrical samples of muscle tissue weighing 5–10 g. The result is measured, as a rule, after 24 hours of exposure. According to the EZ-Drip Loss method, a 25-mm cork drill is used along the muscle fibers to cut out a sample weighing about 10 g of a cylindrical shape with a diameter of 25 mm and 25 mm long. The sample is weighed and placed in a suspended state in a special container "EZ" to collect tissue fluid. The container is closed with a lid to avoid loss of water due to evaporation. According to the method procedure the samples are exposed for 24 hours at 4–6 °C, after that the sample is re-weighed. Before each weighing, the surface of the samples is carefully wiped with a paper towel. Water losses are expressed as a percentage in relation to the initial mass of the sample.

$$DripLoss = \frac{W_1 - W_2}{W_3 - W_2} \times 100, \%$$

where

W_1 — is weight of container with liquid,
W_2 — is weight of empty container,
W_3 — is weight of container with meat.

To keep accuracy of the method Filho et al. [34] recommend to expose pork samples for 48 hours. Kilgannon et al. [35] offer to expose beef samples for 72 hours, and lamb samples — for 96 hours, according to Holman [36]. Measurement of water losses in the form of drip losses enables to assess water-binding capacity of meat quite accurately, but in practice it is still a difficult and time-consuming task.

Methods using external pressure

The first method for determination of water-binding capacity of meat was published by Child et al. in 1934 [37]. This is the pressing method (FP PM), which was subsequently improved by Grau and Hamm [38]. Currently several modifications of this method have been proposed. In Russia, the method was modified by Vovininskaya V. P. et al. [40]. The method is based on determination of the amount of separated water, determined by the area of the wet spot on filter paper left after pressing the meat sample of 0.3 g with a load of 1 kg for 10 minutes.

Joo [40] recommends this method for determination of meat water-holding capacity. According to this method a sample of meat is placed between two pre-weighed plexiglass plates with a size of 60x60 mm and filter paper with a certain absorbent capacity. Then a load of 2.5 kg is applied and the sample is exposed to pressure for 5 minutes. After the separation of water, the compressed meat sample is taken out, wet filter paper with two plastic films is quickly weighed and the amount of water is recorded. The obtained value serves as determination of water-holding capacity.

This group of methods includes also centrifugation method [41]. This method is based on determination of the amount of water, pressed out of minced meat or meat samples under the influence of centrifugal force. The method is recommended for determination of the WHC of intact (not crushed) muscle tissue, provided that the samples are not destroyed and deformed [42,43]. A sample of 10 g is centrifuged at a rotation speed of 3000 rpm for 15 minutes, using graduated centrifugal test tubes with a mesh. Samples are weighed before and after centrifugation. The mass of dry substances contained in the liquid separated by the centrifugation is added to the mass of the sample after centrifugation. To calculate the amount of bound water, it is necessary to have data on the total content of water in the examined sample.

The method of high-speed centrifugation proposed by Hermanson et al. [42], is used to determine the share of loosely bound water in meat. Samples from 1 to 20 g are centrifuged at centrifugal force rate 5000 × G and 40,000 × g. The amount of water released is determined by weighing the separated water or by weighing the sample before and after centrifugation.

Methods of adsorbtion

Adsorption methods are based on application of adsorbing materials, like filter paper, cotton-viscose material, gypsum, clay. The method is based on the effect of absorption of unbound water from muscle tissue by the adsorbing material. According to the Chan et al. [44] pre-dried and weighed adsorbing material (for example, filter paper) is pressed to the surface of the meat sample and in 3 seconds is weighed again. The amount of absorbed water is calculated as the difference between these two weighings. However, the filter paper method is not

suitable for determination of the WBC in meat samples with high content of fat.

The method of filter paper weighing [30] (FPW) is that pre-weighed filter paper with a diameter of 45 mm is pressed to the surface of the sample, held for 10–20 minutes, and water losses are determined by the difference in weight of filter paper before and after the exposure.

The method proposed by Walukonis et.al. [45] for pork, uses a cotton-gauze material (tampon) weighing about 3 g. This tampon is inserted into the PC muscle through the subcutaneous fat layer. This material is inserted through an incision cut in shape of "+" to a depth of about 2.4 inches in a strictly defined place (for example, in the area of the 12th or 9th rib) and held there for 15 minutes. According to the authors, the exposure for 45 minutes shows the best correlation between adsorption and the loss of meat juice. The value of the adsorption (WHC) is calculated as the difference between the final mass of a cotton-gauze material with absorbed exudate and the initial mass of a dry tampon. This method involves a fairly accurate and quick assessment of the WHC in the early post-slaughter period.

Hofmann [46] proposed a method of capillary volumeter based on application of capillary forces to muscle tissue. The method consists in placing a plaster plate on the surface of intact muscle tissue for 30–120 seconds, while loosely bound water is absorbed into the porous material, and the air displaced from the capillaries under the action of meat juice enters a V-shaped calibrated capillary glass tube with a dyed liquid. The volume of displaced air, determined by fluid displacement, equals to the volume of released water and inversely proportional to WHC of muscle tissue.

Non-traditional methods of WHC determination

The development of technological progress and computerization of scientific research has made it possible to improve the methods of WHC determination.

Method of electrical conductivity

Lee et.al. [47] conducted studies of the electrical conductivity of meat with the help of conductivity analyzer to predict the water-binding capacity of pork. The authors found that PSE meat features higher electrical conductivity than normal meat and DFD meat. According to the authors the higher electrical conductivity of PSE meat is caused by the low water-binding capacity, which leads to losses of liquid and substances dissolved there. The results of this study have shown that electrical conductivity can be used as a possible parameter for assessing the water-binding capacity of meat. Measuring the electrical conductivity in 24 hours after slaughter allows assessing the water-holding capacity of meat.

Method of nuclear magnetic resonance

The method of nuclear magnetic resonance is widely used in various studies and can be used to determine the WHC. Determination by NMR method of relaxation time for water, immobilized in the pores and capillaries of different sizes, allows measuring the relative "freedom" of water molecules movement in the magnetic field, which, in its turn, indirectly allows assessing the level of the WHC.

NMR method proposed by Abdullah et.al. [48] is that the meat sample weighing from 1 to 5 g is evenly distributed in the test tube, brought to setpoint temperature, and then scanned in a NMR-spectrometer several hundred times to obtain the average value of the relaxation time of water molecules in the sample. The measured relaxation time is the time necessary for the nuclei of the water molecules (protons, deutrons or oxygen atom) to return to their first energy level after excitement. According to Bertram et.al. [49] this method correlates quite well with known gravimetric and adsorption methods for the WHC determination.

Method of microwave spectroscopy

The authors [48] used a new method of microwave spectroscopy for assessment of meat juice losses (WHC) and compared the obtained results with the widely used EZ-Driploss method [31]. The principle of using microwave sensors is based on the interaction of electromagnetic waves with the examined sample. When the sample is subjected to electromagnetic irradiation, it changes the speed of signal, weakens or reflects it back. According to this method, the tested sample is placed in the center of the microwave resonator of polyethylene material, and exposed to microwave energy. Depending on the frequency, size and properties of the material inside the waveguide, electric and magnetic fields may take various forms, like transverse electric field and transverse magnetic field. Depending on the resonance mode and frequency, the distribution of electric and magnetic fields will change, thus affecting the interaction between the tested sample and the electromagnetic field inside the cavity. The microwave cavity is connected to the vector network analyzer and a special interface to collect spectral data. The spectra difference will determine the amount of the released water.

Video image method

A modern method is proposed [50] that simplifies the measurement of water-holding capacity of meat by pressing via filter paper. It includes new parameters and a new measuring instrument. In the proposed device "WHC-trend instrument", a video camera is installed above the meat sample compression system, which analyzes the video image by measuring the area formed by 250 mg of homogenized meat. The measurement starts from the beginning of the process, and then the images are taken every 15 seconds for 10 minutes after pressing the sample with a force of 500 N. A dynamic measurement of fluid release over time was obtained, which was called "WHCtrend".

The method has been tested on various types of meat and can be available for fast determination of the water-binding capacity of meat.

Infrared spectroscopy method

The method is based on determination of the reflective coefficient of the meat surface depending on water content. The method measures the difference between the composition of light beam from the light source in the device and the light beam reflected from the tested sample after its exposure to electromagnetic radiation in the near infrared region from 700 to 3000 nm. The light reflected from the sample is converted into units of absorbed light, which quantifies the chemical composition of the meat sample [49].

The method of color differences

According to some researchers, the correlation between the color of meat and water-binding capacity is quite complex. However, Bendall J. R. et.al. [21] believe that to detect PSE meat, it is possible to use the lightness index L, and to determine WHC it is possible to use the reflective coefficient of the sample. According to Swatland et.al. [51], reflective coefficient of the sample correlates with the violet and red spectrum. This correlation can be applied to determine WHC. Joo et.al. [52] make claim that lightness (L) is the best indicator for predicting water-binding capacity.

Conclusion

As the scientific research to determine the WHC, the methods of sample pressing on filter paper and centrifugation are most widely used. However, it must be taken into account that not all methods for the WHC determining are suitable for some particular case and application, as inappropriate method can lead to erroneous conclusions. This means that for assessment of meat capacity to bind and hold water, a special consideration should be given to the selection of a method for each specific case. For instance, it's necessary to have regard to the spatial structure of the sample — whether it is minced meat or undestroyed muscle tissue, it's also necessary to consider the depth of technological processing — whether it is raw meat or cooked meat. The strength properties of the tested sample, the magnitude and duration of the applied load will also affect the obtained results. Nevertheless, the use of any method makes it possible to trace changes in WHC and WBC in the dynamics of some process, for example, autolysis of meat or during its exposure to brine treatment, during mechanical or enzymatic processing.

It should be borne in mind that the presented methods determine different forms of water retention and therefore the results obtained by different methods are not comparable with each other. For example: gravimetric methods make it possible to estimate WBC rather than WHC, while methods of pressing and centrifugation determine the summarized WBC and WHC. To determine the WHC only, apparently, it's necessary to subtract the WBC value obtained by one of the gravimetric methods from the value obtained by one of the methods that use external pressure.

Therefore, for each scientific research it is necessary to choose an appropriate method for determining the capacity of meat to bind or hold water, which is most suitable for the specific goals, objectives and the object under research.

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