ТЕХНІЧНІ НАУКИ

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EFFECT OF TECHNOLOGICAL PARAMETERS OF THE NEEDLE INJECTING UPON THE QUALITY OF THE PROCESSING OF RAW MEATS

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Subject of research. *Hydromechanical treatment of various types of raw meats by needle injection using a multi-needle brine injector.* ***Purpose of the study.*** *Establishment of rational scientifically substantiated, technically and technologically acceptable modes of processing various types of raw meats by needle injection on a multi-needle brine injector.* ***Methods.*** *Injection of whole muscle raw meats was performed using a pneumatic brine injector Ya5-FSh1L with 50 needles. Carbonade (pork round), beef and pork neck were injected. The treated pieces of raw material were weighed before the start of the injection and after 5 minutes after the operation. The same piece of meat was injected on an NK-27 injector using low pressure technology. The shear stress of the sample and the specific cutting work were determined. The degree of penetration of meat products was found as the ratio of the mass of absorbed brine to the mass of the original meat (in percent).* ***Research results.*** *When injecting meat tissues with a strictly oriented fiber structure, the choice of the optimal number of injection sites and, consequently, the speed of transport of the product through the injector is essential. Processing of pieces of meat with a thickness of 100 mm and more entails the need to re-inject them with inversion for more complete and uniform saturation throughout the volume. To achieve the tenderness of meat of the sufficient hardness the most effective diameter of needles is 2,5-3,5 mm. The smallest tendering effect is observed when processing raw meat with needles with adiameter of 2 mm. When tendered with needles with a diameter of 2 mm, the nature of themechanical impact is essentially closer to the traditional piercing process. The rational degree of penetration is 15 – 20%, the hardness of whole muscle meat products decreases most intensively in the initial stages of tendering and reaches a maximum at a penetration rate of20%, and then stabilizes. The accuracy of the injection (uniformity of the degree of injection) isaffected by the spray pressure only at a value of 6 kg / cm^2, until a sufficient spray effect isachieved.* ***Scope of research results.*** *The results of the experiments will be used to improve thetechnology and specialized equipment for injection of whole muscle meat raw materials toincrease the profitability of meat processing, food safety of meat products, enhance their quality.*

Keywords: *hydromechanical treatment, whole muscle meat products, meat raw material injection, brine injectors, multi-needle injectors, penetration, meat raw material tendering*

ВПЛИВ ТЕХНОЛОГІЧНИХ ПАРАМЕТРІВ ГОЛКОВОГО ІН'ЄКТУВАННЯНА ЯКІСТЬ ОБРОБКИ М'ЯСНОЇ СИРОВИНИ

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Предмет дослідження. *Гідромеханічна обробка різних видів м'ясної сировини шляхом голкового ін'єктування із застосуванням багатоголкового ін'єктора розсолу.* ***Мета дослідження.*** *Встановлення раціональних науково обґрунтованих та прийнятних у техніко-технологічному сенсі режимів обробки різних видів м'ясної сировини шляхом голкового ін'єктування на багатоголковому ін'єкторі розсолу.* ***Методи.*** *Ін'єктування цільном'язової м'ясної сировини виконували за допомогою пневматичного ін'єктора розсолу, марка Я5-ФШ1Л з 50 голками. Шприцювали карбонад, яловичину та шийку. Оброблювані шматки сировини зважували до початку ін'єкції та через 5 хв. після закінчення операції. Такий самий шматок м'яса ін'єктували на ін'єкторі NK-27 із застосуванням технології низького тиску. Визначали напруження зрізу зразка та питому роботу різання. Ступінь пенетрації м'ясних виробів знаходили як відношення маси поглиненого розсолу до маси вихідного м'яса (у відсотках).* ***Результати дослідження.*** *При шприцюванні тканин м'яса, що мають строго орієнтовану волоконну структуру, вибір оптимального числа місць ін'єкції і, отже, швидкість транспортування продукту через ін'єктор, має істотне значення. Обробка шматків м'яса товщиною 100 мм і більше тягне за собою необхідність їх повторного шприцювання з перевертанням для більш повного та рівномірного насичення по всьому об'єму. Для тендеризації м'яса підвищеної жорсткості найбільш ефективним діаметром голок є 2,5-3,5 мм. Найменший тендеризувальний ефект спостерігається під час оброблення м'ясної сировини голками діаметром 2 мм. При тендеризації голками діаметром 2 мм характер механічного впливу ближче до звичайного проколювання. Раціональний ступінь пенетрації становить 15-20%, жорсткість цільном'язових м'ясних виробів найбільш інтенсивно знижується на початкових стадіях тендеризації і досягає максимуму при ступені пенетрації 20%, а потім стабілізується. На точність ін'єктування (рівномірність ступеня ін'єктування) тиск розпилення впливає тільки при значенні 6 кг/см^2, доки не досягається достатній ефект розпилення.* ***Сфера застосування результатів дослідження.*** *Результати проведених дослідів використовуватимуться з метою вдосконалення технологій і спеціалізованого обладнання для ін'єктування цільном'язової м'ясної сировини для підвищення рентабельності м'ясопереробного виробництва, забезпечення харчової безпеки м'ясних виробів, підвищення їх якості.*

Ключові слова: *гідромеханічна обробка, цільном'язові м'ясні вироби, ін'єкція м'ясної сировини, ін'єктори розсолу, багатоголкові ін'єктори, пенетрація, тендеризація м'ясної сировини*

Formulation of the problem. Meat delicacies, in addition to a number of sausages, include boneless salted, boiled-smoked, smoked and cured whole-muscle products. Like a number of meat products on the bone (brisket, chicken legs, etc.), the meat products listed above is in demand among domestic consumers. Although whole-muscle products are not cheap, consumers are willing to pay for their naturalness and unique taste – provided the high performance of these products.Meat brining, i.e. the introduction of salt and other salting substances, is carried out to prevent microbial spoilage of meat products, as well as give them a characteristic taste, aroma, color, texture and other sensorial properties by rubbing salting

substances into raw meats or by immersing meat in containers filled with salting brine. Today, these proven but extensive methods of salting [1,2] have been replaced by new intensive methods: needle injection of salting brine [3,4], tendering of meat by its vacuum gravity-shock machining, the use of complex multicomponent brines. On the one hand, the intensification of salting is possible only with the use of modern high-performance salting brines containing structure-forming, moisture-binding, flavoring and other necessary components. On the other hand, to increase the yield of finished products, reduce the duration of the production cycle, the even distribution of components of salting brines in muscle tissue requires the use of brine injectors and meat massagers. Depending on the properties of the processed raw materials and the composition of the applied brine, a single treatment of raw meat with a multi-needle brine injector provides an increase in raw material weight by 15-20% due to the introduction of salting substances into the muscular tissues of meat. Subsequent softening of the raw meats in the massager is accompanied by additional saturation of the meat tissues with brine, due to which the pieces increase in weight by10% to the weight of the raw material.

When salting meat, its significant changes occur at the submolecular and macromolecular levels: swelling, destruction of muscle fibers, changes in the ionic composition of myofibrillar proteins, including the ratio of active groups, moisture-binding capacity, physical, chemical, biochemical and rhological characteristics. From the point of view of technological effects on raw meats, proteins are of the greatest interest these being of different type, structure and function performed in a living organism. The ratio of protein and water in meat is approximately 1:3 – 1:4. The presence of water is not a decisive factor: not the percentage, but the state of proteins and the type of water binding determine the moisture-binding capacity of meat. Meat processors know that the meat of young animals is characterized by a higher moisture-binding capacity than the meat of old ones; cow meat, on average, binds moisture slightly better than bull meat; meat of higher categories differs in the increased moisture-binding ability. The marbling of the muscles as well as the increased content of connective tissue in them determine the good moisture-binding ability of such raw materials. There are three forms of binding of water to protein. Hydration water (approximately 10% of all water in meat) is adsorbed by protein, its molecule due to the bipolar nature joins ions and other polar groups. Hydration water is strongly bound, is characterized by altered physical properties, is not susceptible to physiological effects and does not affect the dynamics of the moisture-binding capacity of meat. Immobilized (bound) water is firmly held by a network of membranes and muscle protein fibers. This part of the water is very difficult to squeeze out of the meat, so it is held firmly without load. In the space between the cells is free water – weakly bound and easily flowing [5].

The to-day intensive method of salting, providing the formation of the necessary taste and aroma characteristics, tenderness, juiciness, reduces the duration of salting and prevents microbiological spoilage, is widely used in the production of delicatessen and natural semi-finished products method of injection deep into muscle tissue. In modern technologies of whole muscle products, the amount of brine introduced into the raw material can exceed 100% by weight. Needle injection allows to intensify the distribution of brine and maturation of meat, increases its tenderness and moisture-binding ability, while increasing the yield and reducing its cost [6,7].

Researchers and practitioners in the meat industry note that injection improves the consumer properties of meats by improving its softness, juiciness and yield. Injecting brine promotes maceration of meats by acting on it in two ways: (1) mechanically, causing the destruction of muscle fibers, and (2) chemically, introducing into the meat ingredients that increase water retention or promote proteolysis of muscle fibers. Relatively simpler brine and lower injection rates are used in beef processing compared to pork ham production, as in the firstcase the purpose of the pickling is to improve the consistency, not to increase the yields. The simplest brine consists of water, salt (2-3%), phosphates (1%) and other essential ingredients such as antioxidants. For beef, the recommended injection levels are 8% to 10%. At the specified percentage of salt and phosphates and in this range of injection levels, the finished product will

contain approximately 0.2-0.3% salt and 0.1% phosphate [8].

For intensive salting of muscle raw materials (meat of slaughter animals, poultry and fish) appliances equipped with hollow (hypodermic) needles, called brine injectors are used. The principle of their operation is that the raw material, manually or mechanically, is pierced with needles (from one to several dozen), and salting brine is pumped through their central channels to small diameter holes in the tip and / or periphery of the needle. In modern injectors, brine is usually injected at a pressure of 2 to 4 kg / cm^2 through needles inserted directly into the meat, on the side surface of which there are holes with a diameter of 1 mm, so that the brine evenly fills the space between meat fibers and delivers salts and other substances to all internal zones of the processed piece. At the same time, the high rate of diffusion of these substances in the raw meats provides an acceptable intensification of the salting process. Slight run-off of brine after injection, even distribution of salting ingredients, absence of unsalted or too salted pieces in each batch, as well as no differences in their organoleptic characteristics, are practical criteria that the injection of raw meat is carried out qualitatively. To calculate the intensity of the flow of brine after injection, the ratio of the amount of brine, leakage from the meat, to the time during which the specified leakage occurred is calculated [7].

The simplest devices for injecting raw meats have long been known – injectors designed for small businesses with one or more hollow needles, which are inserted into the meat by hand, and the salting brine is supplied by a pump. The use of devices of the described design is also advisable in the case of salting hams and other large cuts. About 50 years ago, highly productive multi-needle brine injectors were developed with a continuous supply of raw materials to the working area of injection using push or plate conveyors, the drives of which are synchronized with the drives of the needle blocks. The specified synchronization provides such interaction of mechanisms when at introduction into meats of injection needles and injection of brine the conveyor of giving in the standby mode, and pieces of the raw materials which are directly under the needle block are injected. Depending on the type of brine used, the pump performs a continuous or metered supply of brine to the needles. Injectors designed for the processing of boneless raw materials are equipped with lowering blocks fixed with needles. Injectors, which provide the possibility of pieces of raw materials with bones in their thickness, have a more complex design. In machines for this purpose, each needle is equipped with a mechanical (spring) or pneumatic damper that prevents deformation or breakage of each of the needles in case of contact with bone tissue [9].

Spray injection is a method of needle injection by feeding salting brine is fed under high pressure through needles with holes of small diameter, which is about 0.3 to 0.6 mm. Some spray injectors provide brine at a pressure of 2 to 8 kg/cm^2, others – from 6 to 12 kg/cm^2. Theoretical bases and practical features of spray-injection of raw meat are reflected in the works of Spanish [10-12], Russian [13], Peruvian [14] and Chinese [15] specialists. Spray injection provides intensive and uniform distribution of brine and salting substances in the muscle, at the same time the complexity of manufacturing and maintenance of injection needles with holes of very small diameter, the need to create and maintain high operating pressure, special requirements for cleanliness and physical characteristics the constrain the ubiquity of such machines [10].

As a rule, electromechanical drives are used to implement the processes of raw material supply, brine injection and reciprocating movement of the injection needle unit during needle injection, so the decision of scientists and designers of IFR of NAAS to develop a series of pneumatic multi-needle brine injectors can be considered innovative. For research purposes, a Ya5-FShR manual injector equipped with 29 needles was developed and manufactured. Thesame number of needles is provided by the design of the Ya5-FShM injector (Fig. 1) intended foruse in small enterprises. In this device, a pneumatic actuator is used in this design to drive the needle block and inject the brine, but the supply of raw meat to the working injection zone remains manual. Pneumatic injector Ya5-FSh1L (Fig. 2) is equipped with 50 needles and is designed for injection of boneless raw meat in automatic mode. One pneumatic actuator of this machine drives the needle unit and supplies brine to the holes of the injection needles, and the

other provides the supply of raw materials using a push conveyor [2, 7, 16].

Fig.1. Ya5-FShM brine injector with manual feed of raw materials and pneumatic drive of brine supply and needle block lowering

Fig. 2. Automatic brine injector Ya5-FSh1L of two pneumatic drives

In addition to the actual design of multi-needle devices for injecting raw meat, IFR of NAAS specialists also participated in the development of regulations governing safety and hygiene in the development, maintenance and operation of multi-needle injectors set out in the current standard of CEN (European Committee for Standardization) – EN 13534 : 2006 + A1: 2010 "Food processing machinery – Curing injection machines – Safety and hygiene requirements" [17]. The Ukrainian Research Institute of Food Industry with the participation of the specialists of IFR of NAAS performed work on harmonization of this standard in Ukraine with the development of the national standard DSTU EN 13534: 2016 "Food processing machinery – Curing injection machines – Safety and hygiene requirements" (EN 13534: 2006 + A1: 2010, IDT) [18], which is fully in line with the Directive 2006/42 / EC Machinery [19]. The Scope of application of DSTU EN 13534: 2016 embraces injection pickling machines with devices for feeding material into the processing area and removing material from this area, which can also be equipped with loading devices. The Standard contains requirements for risks, hazardous situations and events that may occur both during normal operation of the injectors according to the manufacturer's instructions and for erroneous actions, typical cases of which must also be specified in the manufacturer's accompanying documentation. Small portable and manual injectors are not covered by this regulation [20].

The meat processing industry is characterized by a variety of technological processes and specialized equipment used for their implementation [21-24], including a number of innovative physical and biotechnological methods used in practice of the meat industry [23-25], which are selected for application on the basis of various technical and technological criteria, the main of which is energy efficiency, and without the involvement of innovative technologies and appropriate means of production, it is impossible to achieve progress in the meat and meat

processing industry [26] .

The subject of research. The hydromechanical treatment of various types of raw meat by needle injection using a multi-needle brine injector.

The purpose of the study. Establishment of rational scientifically substantiated and technically and technologically acceptable modes of processing various types of raw meat by needle injection on a multi-needle brine injector.

Materials and methods. The experimental injection of whole muscle meat raw materials was performed using a pneumatic brine injector brand Ya5-FSh1L with 50 injection needles (Fig. 6) produced by the State Experimental Enterprise of IPR of NAAS. The specified design allows setting the following values of the supply stroke of raw materials: 15, 20, 25 and 30 mm. Carbonade (pork round), beef and pork neck were injected during the experiments. The treated pieces of raw material were weighed on laboratory scales before injection and after 5 min. after the specified operation. The same piece of meat was injected on the Karpowicz NK-27 injector using low pressure technology [27].

The shear stress of the sample Q_{ss} and the specific cutting work A_{cw} were used as a criteria for evaluating the efficiency of the modes of the process under study. The rheological properties of meat products were studied with the use of the universal testing machine CMT2503 (Shenzhen SANS Testing Machine Co., PRC) and its Kramer Shear Press, which is a fixed rectangular chamber with ten slots b = 3 mm wide and a movable knife with ten blades. The speed of the knife V_n was equal to 50 mm / min.

The degree of penetration of meat products was found as the ratio of the mass of absorbed brine to the mass of the original meat (in percent). Semi-finished products with a penetration rate of 5, 10, 15, 20 and 25% were used in the experiments.

Results and discussion. Experiments were carried out on the multi-needle injector Ya5-FSh1L, the design of which allows to change the speed of the transporting rack. Carbonade, beef and neck were injected [2]. The yield of the product was determined depending on the average speed of its transportation during injection molding [2]. The highest yield of carbonade was obtained at a transport speed of 0.012-0.0125 m/s (Fig. 3).

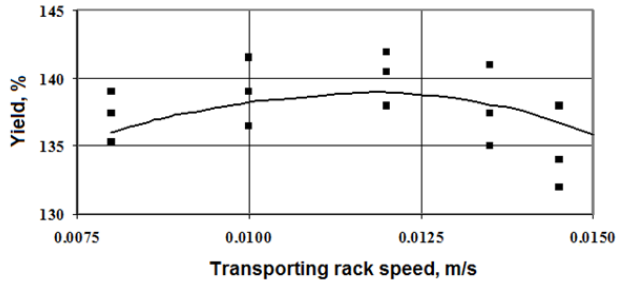

Fig. 3. Effect of rack speed upon the yield of carbonade

When processing beef, the yield has a maximum value in the range of speed of movement of the comb 0.01-0.0115 m\s (Fig. 4), and at higher values of speed the yield of the finished product is reduced by reducing the volume of muscle tissue having channels for brine penetration. This decrease in yield at low speeds can be explained by the significant flow of brine at the stage of heat treatment.

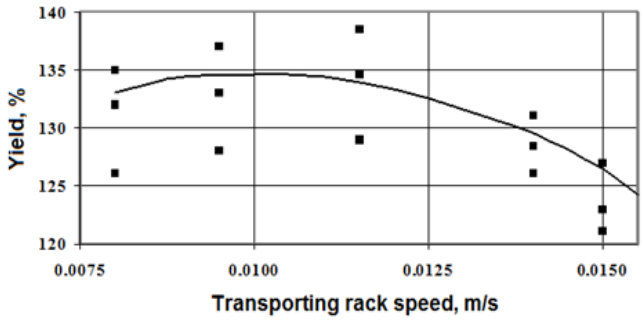

Fig. 4. Effect of rack speed upon the yield of beef

The fact that the pork neck is characterized by numerous inclusions of adipose tissue, significantly affects the nature of the dependence of the product yield on changes in the speed of its transportation (Fig. 5). The yield of the neck decreases with increasing speed of its movement, that is, when injecting the product, it is advisable to pass it with a minimum speed of transportation, achieving an average increase in yield of 2 – 4% compared to twice the speed of transportation.

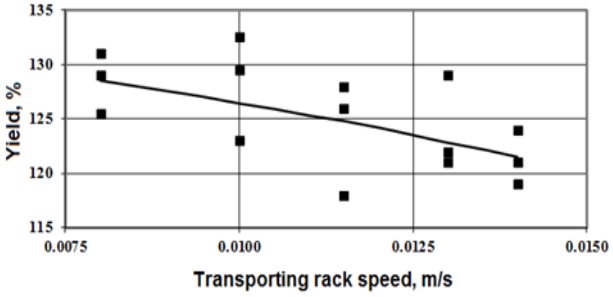

Fig. 5. Effect of rack speed upon the yield of neck

It was found that in the injection of meat tissues having a strictly oriented fiber structure, the choice of the optimal number of injection sites and, therefore, the rate of transport of the product through the injector is essential. It is established that when injecting products with low transport speed, there is increased wear of the equipment due to the greater number of movements of the needle head, the number of actuations of the piston pump and other mechanical components per unit of processed product.

It has been established that the processing of pieces of meat with a thickness of 100 mm and more entails the need to re-inject them with inversion for more complete and uniform saturation throughout the volume. To avoid reinjecting the turned the pieces of meat, it is advisable to increase the number of holes along the length of the needles, which will lead to a more even distribution of brine throughout the volume of the processed piece of meat in one cycle. It was also found that the use of brine dosing cylinder allows increasing the injection pressure and more even distribution of brine in the muscles of raw meats, preventing its leakage from the channels formed by needles, eliminate overheating of brine and reduce its losses compared to injectors in which the supply of brine is organized continuously.

Experiments were also performed to determine the rational diameter of the needles and the degree of penetration of semi-finished products, which was recorded by the amount of brine absorbed. To do this, we used a round of beef in the cooled state. The experiments allowed determining the dependence of the shear stress and cutting work on the degree of penetration of meat products using injectors with different needle diameters (Figs. 6, 7).

Salts, organic acids and phosphates can be introduced into meat by dipping, injecting or marinating, and their effect on the tenderness of meat products is well known [27,28]. These ingredients improve meat tenderness by acting on muscle structure, altering protein solubility, or mediating it through the action of proteases. A process such as infusion of curing brine into the circulatory system is also widely used in practice and gives good results. Marinating improves the tenderness, taste, and value of meat [28-30]. Marinating in acidic solutions is an effective and proven process for improving the tenderness of meat, however, due to the slow penetration of exogenous acids and other compounds, the process must be sufficiently long to achieve the full effect. Injection and infusion provide faster diffusion of the compounds into the muscles and speeds up the acquisition of proper tenderness by the meat. The obtained dependences indicate that for tenderization of meat with increased hardness, the most effective needle diameter is 2.5 – 3.5 mm. At the same time, the hardness of the experimental products is reduced by 208% compared to the control ones, and the shear stress reaches 350-380 Pa. The smallest tenderizing effect is observed when raw meats are processed with needles with a diameter of 2 mm. Curve 1 has a flatter character, and the shear stress decreases only to 500 Pa. This is due to the fact that when tenderizing with needles with a diameter of 2 mm, the nature of the mechanical action is essentially closer to the traditional process – the separation of muscle and connective fibers without significant incisions. As a result of such an impact, semi-finished products are saturated with brine with virtually no change in the structure of tissues, which reduces the tenderizing effect of penetration.

The analysis of graphic dependences shows that the hardnessy of meat raw materials with the same degree of penetration when processed with needles with a diameter of 2 mm is 50% higher than when processed with needles with a diameter of 3 mm. The hardness of the raw material also increases when processed with needles with a diameter of 4 mm. In this case, a significant role is played by the number of cycles of mechanical action during penetration.

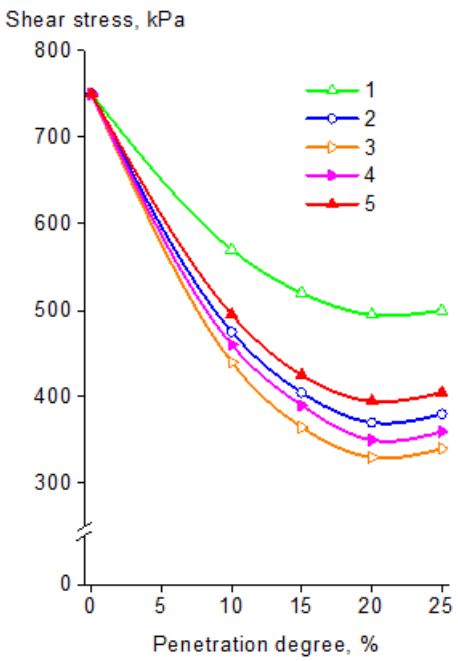

Fig. 6. Effect of penetration degree upon the shear stress for needles their diameter being (mm): 1 – 2.0; 2 – 2.5; 3 – 3.0; 4 – 3.5; 5 – 4.0

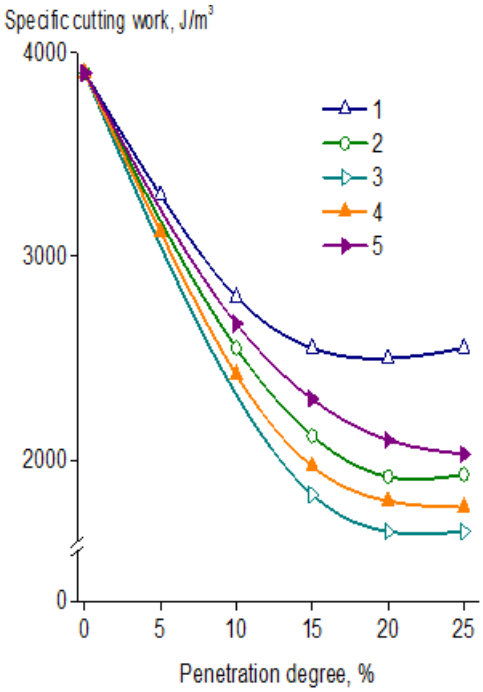

Fig. 7. Effect of penetration degree upon the specific cutting work for needles their diameter being (mm): 1 – 2.0; 2 – 2.5; 3 – 3.0; 4 – 3.5; 5 – 4.0.

Thus, it has been established that in order to obtain semi-finished products with the same degree of penetration, it is necessary to perform a smaller amount of mechanical action with needles of a larger diameter. The raw material absorbs the brine more intensively, the larger the diameter of the needles, and hence the size of the cuts. Reducing the number of cycles of mechanical action reduces the uniformity and frequency of incisions throughout the entire volume of muscle tissue. At the same time, part of the muscle and connective fibers remains in the native state.

Estimating the hardness of meat raw materials in terms of shear stress and the specific cutting work, we can draw the following conclusion: when using needles with a diameter of 4 mm, the tenderizing effect (compared to processing with needles with a diameter of 2.5-3.5 mm) is reduced by an average of 10%. Thus, it is necessary to tenderize meat of increased rigidity with needles with a diameter of 2.5- 3.5 mm.

Studies have also made it possible to determine the rational degree of penetration, which corresponds to 15-20%. The analysis of graphic dependences shows that the rigidity of semi-finished products decreases most intensively at the initial stages of tenderization and reaches a maximum at a penetration degree of 20%, and then stabilizes.

A sensorial evaluation of samples with different degrees of penetration was carried out according to the most important indicators – tenderness and juiciness. Studies have shown that the sensory evaluation of the samples correlates with the data of structural and mechanical characteristics. Moreover, the dependence is directly proportional: the lower the shear stress and cutting work, the greater the degree of penetration of samples, the higher the juiciness and tenderness of the product.

Most multi-needle injectors use continuous pumps, with the help of which the brine is fed into the meat through 2-4 holes with a diameter of 1 mm or more. The brine flows out through the holes, forming continuous streams, and the nature of the outflow depends on the diameter of the holes. These machines operate freely at various pressures in the brine circuit, usually not

exceeding 4 kg/cm². The principle of operation of this type of injector is such that a higher pressure causes damage to the structure of the meat, since the brine settles down inside the meat in an unbound form, which causes poor separation and brine retention. Subsequently, these injection defects turn into salting anomalies, which take the form of colored spots and adversely affect the appearance of the product.

There are publications about the so-called spray injectors created by leading foreign companies, which allow introducing from 5 to 100% brine into the mass of unsalted raw materials, with a productivity of 500 to 2000 kg/hour or more [10-14]. A distinctive feature of these injectors is that the brine is injected using hollow needles, which, depending on the thickness of the pieces of meat, have up to 22 holes of small diameter (0.6 mm) located at different heights. Due to the small size of the holes and the use of higher pressures, the brine injection, according to the developers of such installations, sprays the jet into drops. Their size and high speed allows them to penetrate deeply between tissues without damaging the structure of the meat. The brine introduced in this way has minimal loss due to leakage, since the main reason for it is the free brine remaining in the channels formed by the needles after they exit the meat. The duration of the outflow of brine into the muscle tissue is up to several tenths of a second. Another important feature of the spray injectors is the volumetric dosing system used. The brine is always supplied by the piston at the same speed, so that the same spray pressure is always guaranteed, regardless of the degree of injection obtained.

A number of experiments were carried out to determine the influence of the working pressure of the brine on the uniformity of the degree of injection of pieces of meat. The object of the study was *longissimus dorsi*, taken from a chilled carcass of young cattle about 15 cm long, which was injected into a residual brine content of about 20% on a Y5-FSh1L multi-needle injector with a working pressure of 2, 4 and 6 kg/cm^2. The same piece of meat was injected with a Karpowicz NK-27 injector using low pressure technology. The injection pressure on this injector was 1.5 kg/cm^2, the brine was supplied by a continuous pump. Experimental workings were repeated three times, in each series there were 5 pieces of raw materials. Each piece was weighed before and after injection, and the percentage of brine was calculated. Each series of experiments was evaluated by statistical methods and standard deviations were calculated. The results of the experiments are given in Table. 1. It can be seen from it that the value of the standard deviation for samples injected on the Y5-FSh1L injector affects the spray pressure only by the operating pressure not exceeding 6 kg/cm^2, while at the same time, for a pressure exceeding 6 kg/cm^2, there are significant differences is not observed, while the values of the standard deviation are around 0.6. This is due to the weak effect of brine atomization at a pressure in the range of 2-4 kg/cm^2, when large droplets are formed with a low speed. Undersuch conditions, certain resistances due to natural differences in muscle structure affect the flow from the injection holes, causing local differences in pressure, which are the reason for the increase in deviations for these series of experiments. It has thus been found that the injection accuracy (uniformity of the injection degree) is only affected by the spray pressure at a value of 6 kg/cm^2 until a sufficient spray effect is achieved. The results of the experiments are presented in Table 1.

Table 1

Effect of the operating pressure upon the injection degree

Injector type	Brine pressure, bar	Average injection degree,%	Standard deviation
Ya5-FSh1L	2	20.21	1.21
Ya5-FSh1L	4	20.40	0.93
Ya5-FSh1L	6	20.18	0.61
Karpowicz NK-27	1.5	20.37	1.63

At the same time, there is an important difference in the provision of working pressure in injectors equipped with positive displacement pumps and injectors using continuous pumps, for which the standard deviation is much higher (1.63).

Based on this, it can be concluded that the injection accuracy with volumetric dosing of brine is much higher than the dosing accuracy provided by continuous pumping systems, which results in a product with much more uniform sensorial characteristics, without salting defects.

Conclusion. The performed analysis of scientific and technical information confirms the feasibility and technological prospects of intensive salting of whole muscle raw materials with the involvement of multi-needle brine injectors operating in the high (spray injection) and low pressure ranges.

When injecting meat tissues with a strictly oriented fiber structure, the choice of the optimal number of injection sites and, consequently, the speed of transporting the product through the injector is essential. It has been established that the processing of pieces of meat with a thickness of 100 mm or more entails the need to re-inject them with turning over for a more complete and uniform saturation throughout the volume. The use of a brine dosing cylinder makes it possible to increase the injection pressure and more even distribution of the brine in the thickness of the muscles of the raw meat, preventing its leakage from the channels formed by the needles, does not overheat the brine and reduces its losses compared to injectors with continuous brine supply.

It was revealed that for tenderization of meat of increased hardness, the most effective diameter of needles is 2.5-3.5 mm. At the same time, the rigidity of the experimental productsis reduced by 208% compared to the control ones, the shear stress reaches 350-380 Pa. The smallest tenderizing effect is observed when raw meat is processed with needles with a diameter of 2 mm. When tenderizing with needles with a diameter of 2 mm, the nature of the mechanical action is essentially closer to the traditional process – the separation of muscle and connective fibers without significant incisions.

The studies also made it possible to determine the rational degree of penetration, which corresponds to 15–20%, the rigidity of whole muscle meat products decreases most intensively at the initial stages of tenderization and reaches a maximum at a penetration degree of 20%, and then stabilizes.

As a result of experiments to determine the influence of the working pressure of the brine on the uniformity of the degree of injection of meat pieces, it was found that the accuracy of injection (uniformity of the degree of injection) is affected by the spray pressure only at the value of 6 kg/cm^2, until a sufficient spray effect is achieved.

References

1. Tumenova, G., Sadupova, T., Dauletkhankyzy, A., Abilda, A., Kudrenova, L. (2020). Biokhimicheskie aspekty protsessa posola tsel`nomyshechnykh miasnykh produktov (Biochemical aspects of salting process of whole muscle meat products). Prodovolstvennye resursy (Food Resources). 14. 175-188 http://doi.org/10.31073/foodresources2020-14-11 [in Russian].

2. Verbytskyi, S. B. (2022). Determination of technological parameters of the operation of a multi-needle injector for raw meats. Bulletin of the M. Kozybayev NKU. 1(53). 129-133 http://doi.org/10.54596/2309-6977-2022-1-129-133.

3. Jůzl, M., Nedomová, Š. Quality of animal products. Mendel University in Brno, 2015.

4. Planas i Solivera, S. Caracterització de salmorres i avaluació en un model de producte carni cuit. Universitat de Girona, Escola Politécnica Superior, 2018 [in Catalan].

5. Verbytskyi, S. B., Shevchenko, V. V. (2009). Intensivnyy posol myasnogo syr'ya: teoreticheskie osnovy protsessa, oborudovanie dlya podgotovki posolochnykh rassolov – Intensive pickling of raw meats: theoretical grounds of the process, equipment for preparation of pickling solutions. Myasnoy biznes – Meat Business. 8(83). 74-80. [in Russian].

6. Pryanishnikov, V. V., Starovoyt T. F. (2012). Innovatsionnye tekhnologii in"etsirovaniya myasnykh produktov – Innovative technologies of injecting meat products. Pishchevaya Industriya – Food Industry. 2(12). 63, 64 [in Russian].

7. Verbytskyi, S., Starchevoi, S., Usatenko, N., Kryzhska, T. (2019). Inyektuvannia miasnoi syrovyny rozsolamy z kolahenvmisnymy komponenetamy – Injection of raw meats with brines containing collagen components. Prodovolchi resursy – Food Resources. 12. 35-49 http://doi.org/10.31073/foodresources2019-12-04 [in Ukrainian].

8. Rocha McGuire, A. E. (2022). Mejorando la suavidad de la carne de bovino con tecnología de inyección. Carnetec: https://www.carnetec.com/Industry/TechnicalArticles/Details/104982 (Visitado 08 junio 2022) [in Spanish].

9. Verbytskyi, S., Shevchenko, V. (2011). Nuzhno by pointensivnee (Igol'nye in"ektory i massazhery myasa – You should do it in more intensive way (Needle injector and meat tumblers). Myasnoy biznes – Meat Business. 4(99). 49-52 [in Russian].

10. Xargayó Teixidor, M. (2007). Proceso de fabricación de productos cárnicos cocidos de músculo entero II: Inyección y tenderización. Documentos Tecnológicos de Metalquimia. Girona: Metalquimia. 20-28 [in Spanish].

11. Freixanet, L. (2005). Inyección de la carne con efecto atomizador. Influencia de la presión de inyección en la calidad de los productos inyectados. Documentos Tecnológicos de Metalquimia. Girona: Metalquimia. 68-77 [in Spanish].

12. Xargayó, M., Lagares, J., Fernández, E., Borrell, D., Juncà, G. (2017). Marinado por efecto "spray": una solución definitiva para mejorar la textura de la carne. Recuperado el, 24-07 [in Spanish].

13. Ryzhov, S. A., Golik V. I. (2002). Osobennosti tekhnologii sprey-in"etsirovaniya tsel'nomyshechykh myasnykh produktov – Peculiarities of the spray-injecting of the whole muscle meat products. Myasnaya indutria – Meat Industry. 7. 48-49. [in Russian].

14. Lavado Wong, M. D. Efecto del marinado, congelación y descongelación sobre las propiedades tecnológicas de la carne de alpaca (*Vicugna pacos*). Lima : Universidad Nacional Agraria La Molina, 2018. 39,40 [in Spanish].

15. 孟冉 – Ran, M. (2005). 高压盐水喷雾注射对注射产品质量的影响 – Spray-injecting of meat products amid high pressure. 肉类研究 – Meat Research. 11. [in Chinese].

16. Verbytskyi, S. (2015). Oborudovanie dlya igol'nogo in"etsirovaniya myasnogo syr'ya: konstruktsii – Equipment for needle injecting of raw meats: designs. Myasnoy biznes – Meat Business. 1(140). 42-45. [in Russian].

17. EN 13534:2006+A1:2010. Food processing machinery – Curing injection machines – Safety and hygiene requirements. [In force from 2010-12-01]. Brussels: CEN – European Committee for Standardization, 2010. 44 p.

18. DSTU EN 13534:2016 Ustatkovannia dlia kharchovoi promyslovsti. Mashyny dlia posolu shprytsiuvanniam. Vymohy shchodo bezpeky ta hihiieny – Food processing machinery – Curing injection machines – Safety and hygiene requirements (EN 13534:2006+A1:2010, IDT) [In force from 2018-01-01]. Kyiv : DP «UkrNDNTs», 2018. 66 p. [in Ukrainian].

19. Directive EC. Machinery. (2006). Directive 2006/42/EC of the European Parliament and the Council of 17 May 2006 on machinery, and amending Directive 95/16.EC *(recast)*.

20. Verbytskyi, S. (2015). Oborudovanie dlya igol'nogo in"etsirovaniya myasnogo syr'ya: trebovaniia bezopanosti i gigieny soglasno normam ES – Equipment for needle injecting of raw meats: safety and hygiene requirements according to EU norms. Myasnoy biznes – Meat Business. 2(141). 34-38. [in Russian].

21. Barbut, S. (2016). Meat Processing-Equipment. In: Poultry Products Processing, CRC Press, 239-264 https://doi.org/10.1201/9781420031744 .

22. Cummins, E., Lyng, J. (2016). Emerging technologies in meat processing, 1-5.

23. Bekhit, A. (2017). Advances in Meat Processing Technology. CRC Press.

24. Ojha, K., Kerry, J., Tiwari, B. (2017). Emerging technologies for the meat processing industry. In: Advanced technologies for meat processing. CRC Press, 297-318.

25. Smetana, S., Terjung, N., Aganovic, K., Alahakoon, A., Oey, I., Heinz, V. (2019). Emerging Technologies of Meat Processing. In: Sustainable Meat Production and Processing. Academic Press, 181-205 https://doi.org/10.1016/B978-0-12-814874-7.00010-9 .

26. Kovalenko, O., Verbytskyi, S., Yashchenko, L., Lysenko, H. (2020). Peculiarities of technical means of meat processing industry in Ukraine. The Scientific Journal of Cahul State University "Bogdan Petriceicu Hasdeu" Economic and Engineering Studies, 7(1), 66-72.

27. Berge, P., Ertbjerg, P., Larsen, L. M., Astruc, T., Vignon, X., Møller, A. J. (2001). Tenderization of beef by lactic acid injected at different times post mortem. Meat Science, 57, 347–357 https://doi.org/10.1016/S0309-1740(00)00110-8 .

28. Bhat, Z. F., Morton, J. D., Mason, S. L., Bekhit, A. E. D. A. (2018). Applied and emerging methods for meat tenderization: A comparative perspective. Comprehensive Reviews in Food Science and Food Safety, 17(4), 841-859 https://doi.org/10.1016/j.meatsci.2013.10.031.

29. Aktas, N., Aksu, M. I., Kaya, M. (2003). The effect of organic acid marination on tenderness, cooking loss and bound water content of beef. Journal of Muscle Foods, 14, 181–194 https://doi.org/10.1111/j.1745-4573.2003.tb00699.x.

30. Goli, T., Ricci, J., Bohuon, P., Marchesseau, S., Collignan, A. (2014). Influence of sodiumchloride and pH during acidic marination on water retention and mechanical properties of turkey breast meat. Meat Science, 96, 1133-1140 https://doi.org/10.1016/j.meatsci.2013.10.031.