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The effect of vibration massage on the salting process of ostrich meat

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ABSTRACT

Existing massagers are characterized by relatively high energy consumption during operation, the structure's metal consumption, and the drive mechanism's complexity. Therefore, the search for effective implementation schemes of mixing operations and uniform structure formation of viscous and elastic-plastic raw materials, particularly minced meat, subject to increased contact interaction while minimizing the force on the products, is relevant to the conducted research. The purpose of this work is to substantiate the technological preparation modes of the given minced meat with the use of a developed vibrating massager, as well as to determine the kinematic parameters of the oscillation system and graphic-analytical analysis of their change. The experimental model of the vibrating massager with an eccentric drive mechanism, a measuring evaluation base of rheological characteristics of the minced ostrich meat, and kinematic parameters of the vibrating drive of the massager amplitude-frequency and speed characteristics were developed to carry out the specified tasks. High technological results were obtained using the forced eccentric drive of the massager, characterized by a minimum mass of the oscillation masses of the parts compared to traditional unbalanced vibrators, which reduce 2 – 2.5 times the energy consumption to drive the vibrating massager under study. The practical value of the conducted work includes the use of the eccentric forced vibrating exciter for obtaining the force control over the minced meat to be formed, which reduces the oscillation masses of the drive and minimizes the energy consumption for the process, accordingly; it has the simplest structure among the mechanical vibrators, significantly reduces the dynamic loads on the supporting units of the vibrator as well as provides a sufficiently high contact interaction for both the vibration impact and the processing intensity in general.

Keywords: meat massage, vibrating massagers, mixing, oscillating system, oscillation amplitude

INTRODUCTION

The meat processing industry remains a high-priority and strategic one for Ukraine. The globalization strengthening and Ukraine's integration into the world community make new demands on the meat processing industry to be developed: compliance with the international standards of quality, environmental friendliness, and safety; transition to an innovative industry development model, and active implementation of modern resource-saving production technologies based on the integrated use of raw materials, etc. **[1]**, **[2]**. The tendency to search for and develop innovative technological solutions to produce products characterized by a high level of quality, environmental friendliness, and biosafety, as well as their functional orientation, has been prevailing in the modern food industry. Today, ensuring the completeness and balance of nutrition is one of the urgent nutrition problems of the population **[3]**, **[4]**.

The production of high-quality non-traditional raw materials, which can be used in combination with beef and veal to produce meat products and expansion of this kind of products is an important task. The African ostrich meat represents an example of non-traditional meat which can be imported or produced domestically. This kind of meat can be accepted or not accepted by consumers **[5]**.

One of the priority tasks facing the meat processing industry is to implement resource-saving technologies and produce quality products with high consumer properties. These requirements are most fully satisfied by the group of ham products.

Meat delicacies, which traditionally occupy a significant share in the diet of the Ukrainian population majority, are a technological form for ham products to be created **[6]**. The use of enzyme technologies largely determines the development success of many modern economy industries, including the food industry. The application scope of enzyme preparations has been significantly expanded due to the creation and implementation of innovative technologies. Today, the enzymes help improve product quality and safety, increase the efficiency of the technological processes, and reduce production costs and the anthropogenic impact on the environment **[44]**.

In meat production technology, the quality of the final product primarily depends on the used technology, raw materials, and technical equipment.

At present, salty meat products have a high demand among the population. The meat salting process includes the meat processing with table salt or its solution and subsequent maintaining for a period sufficient for uniform salt distribution and internal physicochemical processes of the meat maturation, which provide the finished product with the intended taste qualities. There are three classic methods of meat salting: dry, wet, and combined. The dry method involves the application of salting mixtures on the meat surface; preferably, it is widely used when salting shredded raw materials. The wet salting method consists of the meat immersion in the solution of salting substances - brine or its distribution inside the product by injection. The combined approach combines the dry and wet methods of salting. According to classical technology, the meat salting process is divided into long-term and short-term: the long-term process consists of several days to several weeks, and it is preferably used when producing salted and smoked products, dried sausages of some varieties; the short-term process consists of a few hours, it is mainly used when making the boiled sausages.

To obtain high-quality meat products, it is essential to provide the maximum uniform filtration saturation of the meat piece throughout its weight, exposure for further diffusion distribution of salting ingredients, and biochemical transformations. The efficiency of the filtration saturation depends on the pore and capillary sizes as well as the driving force of the process - the pressure difference in the brine accumulation area **[7]**. Salting raw meat materials is one of the most complex and technologically significant processes in producing meat products. Properly selected methods, equipment, and parameters of technological processes guarantee the receipt of the products characterized by high organoleptic indicators, output, and stability during storage **[8]**.

The modern production technologies of meat products involve various acceleration methods of meat salting, including meat massage, the temperature increase of the brines, and injection of the meat pieces. One of the universal salting methods of the meat raw materials is the intramuscular injection of the brine solution and subsequent massage or tumbling to ensure the uniform distribution of the brine in the muscle tissue. To intensify these processes when producing the meat products after the technological operation of the meat injection, the use of vacuum and vibration impact during the massage of the meat raw materials is becoming more common, which justifies the research's relevance.

Domestic and foreign researchers, particularly, have shown that the proteolytic enzyme preparations of animal, vegetable, and microbial origin and own enzymes of the meat can affect the proteins and simultaneously increase the functional and technological properties of the raw materials as well as improve the organoleptic and structural-mechanical performance of the finished products **[9]**. An outstanding contribution to the development of the vibration technologies for implementing the mixing processes and uniform distribution of the components of the meat raw materials in the working volume, which is relevant to the technology under study, was made by well-known domestic and foreign scientists **[10]**. To increase the energy potential of the executive bodies of mixing devices, it is advisable to use the auger and blade mixing elements **[11]**. The Leningrad Institute of Technology has developed the vibrating mixer with combined blade executive bodies **[12]**, providing the counter-movement of materials in the working area for "plastic" products; it allows to create the continuous mode of the product processing, to delay the mass of the meat raw materials at the beginning of the mixer operation to improve the homogenization process or vice versa - to accelerate the environment movement, which indicates the technological flexibility of the equipment. Such design execution is inherent in the blade vibrating mixers of DVS – N type, which is characterized by the processing efficiency and quite complex design execution. The vibrating tray mixer for the elastic-plastic meat raw materials **[11]** is characterized by high productivity at small power consumption and structure simplicity. Improving the mixing efficiency is achieved due to the intense oscillations of the blades relative to the hinges with a frequency proportional to the stiffness of the latter ones and the own weight of the mixing elements. Displacement of the tray center of gravity towards its free-oscillation end provides the largest oscillation amplitude at minimal external energy consumption. However, the processing efficiency of the complex structured systems, particularly the minced meat, is insufficient. When mixing such product masses, the high efficiency is inherent to the drum-type devices, which are also equipped with additional mixture activators for increasing the device productivity, improving the quality of the finished mixture, and preventing it from sticking to the executive bodies of the equipment **[11]**. However, in such devices, a circulating material flow movement in one direction increases the processing duration. To create the multi-directional flows of the technological loading in the modified vibrating mixer **[11]**, the inserts are freely placed in the container and made in the form of a spring, one half of which has the left winding direction, and the other half has the right winding direction, are provided instead of a cylindrical roller. These problems can be ignored when using the vibration impact on the mixing process of the meat raw materials; it can significantly increase the device productivity, reduce energy consumption, and improve the product quality. At the same time, in some cases, the vibration can only intensify the main process. In other cases the vibration can cause specific vibration effects, namely, increasing the contact interaction, ignoring the "dead zones" when processing, as well as uniform energy saturation of the technological masses in the working area **[12]**.

The purpose of this work is to substantiate the technological preparation modes of the given minced meat with the use of a developed vibrating massager, as well as to determine the kinematic parameters of the oscillation system and graphic-analytical analysis of their change. The following tasks must be solved to achieve this purpose:

- to substantiate the required technological parameters of the meat raw materials of the ostrich according to the developed technology;
- to obtain the dependences of movement trajectory, angular and linear speeds of the executive bodies of the developed oscillation system;
- to make the graphic-analytical substantiation of the studied process modes of the vibration mixing of the minced meat according to determined kinematic parameters.

Scientific hypothesis

The conceptual hypothesis of this work consists of the creation of the separate processing stages of the local compression and stretching areas of the meat raw materials at micromechanical impact with required structure formation within the technological environment when implementation, which is followed by the creation of the fluidized layer of the technological mass, increase of the contact surface planes of its particles, prevention of the segregation of the product layers under the action of these power factors, which operate separately or in combination, ensuring the implementation of the above technological effects.

MATERIAL AND METHODOLOGY

Samples

The meat products of the control and studied samples were researched with the use of the following meat raw materials: African ostrich meat, according to TU U 15.1-2497315254-001:2006 **[3]**, functional supplement "Poltermyshung Rot Superior" LLC "TD Lagos", made in Germany – according to the product specification, enzyme preparation of plant origin – papain, LLC "Alex", made in China – according to the product specification, table salt according to DSTU 3583 **[4]**, white sugar according to DSTU 4623 **[5]**, sodium nitrite according to GOST 32781 (2014) **[6]**.

Chemicals

Sodium hydroxide, NaOH (grade A, analytical grade, (Khimlaborreaktyv) Limited Liability Company, Ukraine).

Methyl red, $C_{15}H_{15}N_3O_2$ (grade A, analytical grade, (Khimlaborreaktyv) Limited Liability Company, Ukraine).

Sulfuric acid, H2SO4 (grade A, chemically pure, (Khimlaborreaktyv) Limited Liability Company, Ukraine).

Petroleum ether, H_3C-O-CH_3 (excise, analytical grade, (Khimlaborreaktyv) Limited Liability Company, Ukraine).

Animals and Biological Material

For studies, used ostrich thigh and leg meat were obtained after slaughtering the bird at 12 months (supplier farm "Agro-Soyuz" of Dnipropetrovsk region, Ukraine).

Instruments

Drying cabinet (SNOL, producer (Khimlaborreaktyv) Limited Liability Company, Ukraine).

Muffle furnace (SNOL, producer (Khimlaborreaktyv) Limited Liability Company, Ukraine).

Fat analyzer (SOX 406, producer (Khimlaborreaktyv) Limited Liability Company, China).

Mineralizer (Velp Scientifica, producer (Khimlaborreaktyv) Limited Liability Company, Italy).

Distiller for steam distillation (Velp Scientifica UDK 129 producer (Khimlaborreaktyv) Limited Liability Company, Italy).

Automatic penetrometer (K95500, producer (Khimlaborreaktyv) Limited Liability Company, USA).

pH meter (HI8314 HANNA, producer (Spectro lab) Limited Liability Company, Ukraine).

Thermometer (digital laboratory thermometer TH310 Milwaukee, producer (Spectro lab) Limited Liability Company, Ukraine).

Laboratory scales (AXIS BDM 3, (Spectro lab) Limited Liability Company, Ukraine).

Laboratory Methods

Determination of parameters characterizing the chemical composition of ham was carried out according to established appropriate standard methods: the mass fraction of moisture by drying the product sample down to a fixed weight at a temperature of 100 – 105 °C according to DSTU ISO 1442:2005 **[13]**; the mass fraction of the total fat content was determined by the Soxhlet method, which consists in the extraction of fat from the dry mass of the sample with a solvent, based on determining the change in the sample's weight after fat extraction with a solvent by DSTU 8380:2015 **[14]**; the mass fraction of protein by determining the total nitrogen by the Kjeldahl method. Cinefaction of samples was performed on the Velp Scientifica DK6 series (Italy) with a vacuum pump (JP). Distillation was made on a steam distillation device Velp Scientifica UDK 129 (Italy), GOST 25011-2017 **[15]**; the mass fraction of ash by weight method, after mineralization of the product's sample weight in a muffle furnace at a temperature of 500 – 600 °C according to DSTU ISO 936:2008 **[16]**. Determination of ultimate shear stress was carried out by measuring shear characteristics at small deformations, which are subsequently used to evaluate the product's strength, tenderness, and consistency **[17]**. Study of active acidity by determination of pH - by the potentiometric method according to DSTU ISO 2917 – 2001 **[18]**.

The temperature of the studied samples was measured using a digital needle thermometer TH310 Milwaukee.

Laboratory technical scales AXIS BDM 3. were used to weigh the samples.

Description of the Experiment

Sample preparation: Ham samples were used for research, made according to three different formulations of injection brines. The study was conducted in the laboratory conditions of the department of technology of meat, fish, and marine products, National University of Life and Environmental Sciences of Ukraine.

Number of samples analyzed: Three types of ham were used in the study: control – ham with the classical introduction of brine for pickling, and two samples of ham based on a functional additive and the addition of papain.

Number of repeated analyses: The study was repeated 5 times, with the experimental data processed using mathematical statistics.

Number of experiment replication: Each study was carried out five times, and the number of samples was three, resulting in fifteen repeated analyzes.

Design of the experiment:

Ostrich meat was portioned into pieces, which were injected with brine (30, 40, and 50% by weight of raw material) at a temperature of 0 – 4 °C for 12 hours.

Recipes of brines were presented in the following sequence:

- classic brine for pickling;
- brine based on a functional additive;
- brine based on a functional additive with the introduction of papain.

Then the ham was massaged at 8 rpm for 20 minutes and subjected to heat treatment - cooking at t = 80 °C ±2 °C until the temperature in the center of the product was 72 – 75 °C. The ham samples were cooled to a temperature in the product layer of 8 °C and stored at a temperature ranging from 0 to +4 °C.

Statistical Analysis

The statistical evaluation of the results was carried out by standard methods using statistical software Statgraphics Centurion XVII (StatPoint, USA) – multifactor analysis of variance (MANOVA), LSD test. Statistical processing was performed in Microsoft Excel 2016 in combination with XLSTAT. Values were estimated using mean and standard deviations.

RESULTS AND DISCUSSION

Products with different nutritional characteristics are produced from the same type of meat raw material by changing the regimes and conditions of raw material preparation, influencing the tissue structure, and changing thermal processes. The peculiarity of the ham products production technology is that at the stage of ham formation, it is salted, injected with 30, 40, and 50% brine at t = 0 – 4 °C. The results of the organoleptic evaluation showed that the ham with the addition of the enzyme papain, after the proposed process of vibration massage, had better taste indicators: the appearance of the ham was rounded, with a dry, clean surface without damage, dense and elastic consistency and was noticeably different from the control sample of ham without the use of vibration massage, with greater juiciness and tenderness, without extraneous smells and tastes. The results of studies on the chemical composition of ham made from ostrich meat are shown in Table 1.

Table 1 Characteristics of the chemical composition of ham.

Sample of ham	Mass fraction, %			
	moisture content	protein	fat	mineral substances
Control sample	67.34 ±2.21	26.17 ±0.42	1.63 ±0.28	1.05 ±0.04
Ham after salting	69.85 ±2.37	27.64 ±0.66	1.55 ±0.88	1.02 ±0.06

Note: (n = 5, $p \leq 0.05$).

It should be noted that the protein content in the control sample is 26.17%, in the experimental sample 27.64% - due to the introduction of a functional additive and papain enzyme, which positively affects the taste properties of the developed ham products and makes them juicier with using an improved massaging process.

During the maturation of the meat raw materials enriched with functional ingredients, one of the main problems is accelerating the diffusion of brine components and their uniform distribution by mass of the meat raw materials. The vibration massage has been used in the developed drum-type device to solve this problem. A series of similar experiments on processing raw materials of plant and animal origin without vibration massage is described in the works of I. Palamarchuk **[19]**, **[20]**, M. Mushtruk **[21]**, **[22]**, V. Palamarchuk **[23]**, **[24],** and others **[25]**, **[26]**, which will negatively affect the quality and organoleptic indicators of the final product.

The studied vibrating device is an oscillation system with two freedom degrees (Figure 1), which is actuated by the drive that provides the shaft, equipped with the eccentric axis of rotation, with the constant rotation torque. Similar technological schemes of equipment without vibration effects are used in the production of various products in the food industry **[27]**, **[28]**, **[29]**. Still, the use of such equipment without conditions determines its performance, which can lead to an increase in material costs during production.

The executive body absorbs the energy from the vibrating drive of the device and acts directly on the products being processed. This mechanism in the vibrating massager is the actual working container. The object being processed consists of the meat products in the form of the individual pieces, salt solution, and other ingredients provided by the technology. The main disadvantages of this model are the increase of dynamic loads on the bearing assemblies and the need to disassemble the mechanism to perform adjustment operations, which are not significant enough compared to the disadvantages of the pronated system **[30]**, **[31]**, **[32]**. When operating the device, the engine torque is converted into the vibrating motion of the working container, which transmits the oscillations to the environment being processed; and the inertial, elastic, and dissipative properties of the technological load influence the movement of the working body and indirectly on the elements of the vibrating drive, in particular, on the rotation of the drive shaft of the vibrating exciter.

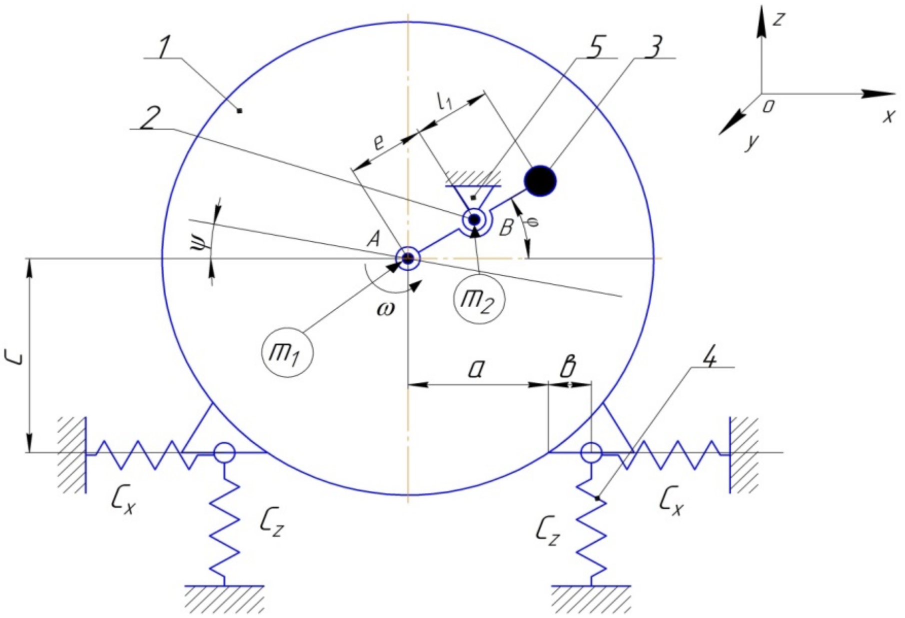

Figure 1 Calculation scheme of the developed vibrating massager. Note: 1 – drum-type working container; 2 – eccentric drive shaft; 3 – counterweight; 4 – elastic elements of the container; 5 – support bearing assembly; e – eccentricity of the drive shaft; l1 – counterweight ordinates; m_1, m_2 – main mass of vibrating device; φ, ψ – freedom degrees of the device; C_x, C_z – stiffness components of elastic elements relative to axes O_x, O_z; ω – angular rotation speed of drive shaft.

It is assumed that the moment of resistance forces between the eccentric and container 1 is proportional to the angular rotation speed of the eccentric. For the generalized coordinates, we take the rotation angle of the eccentric φ and the rotation angle of the container ψ. To make the motion equations of the vibrating device, we will use the Lagrange equation of the second kind:

$$\begin{aligned} A\ddot{\varphi} + B\ddot{\varphi} &= M - \beta\dot{\varphi} + f(\varphi,\psi) \\ B\ddot{\varphi} + D\ddot{\varphi} &= \beta\dot{\varphi} + g(\varphi,\psi) \end{aligned} \tag{1}$$

Where: $A = m_1 l_1^2 + m_2 e^2 + M_K e^2 + J_1 + J_2 \; B = M_K e h_C; \; D = J_K + M_K h_C^2$

Where:
Mк – the mass of the working container; M – drive moment; J_K – container moment of inertia; h_C – vertical component of container center of mass; $f(\varphi,\psi) = Q_\varphi^K$, $g(\varphi,\psi) = Q_\psi^K$ – conservative components of generalized forces of the system under study.

The above conservative components of the generalized forces of this oscillation system have the form:

$$\begin{aligned} Q_\varphi^K &= \frac{\partial \Pi}{\partial \phi} = \left(m_1 g l_1 + m_{ct} g \frac{l_1}{l_2} - m_e g e + M_K g h_C \right) \sin\varphi - \\ &- 2c_x (e\sin\varphi + a\cos\psi - c\sin\psi + b\cos\psi) e\cos\varphi - \\ &- 2c_y (a\sin\psi - a\cos\varphi + c\cos\psi) e\sin\varphi \end{aligned} \tag{2}$$

$$\begin{aligned} Q_\psi^K &= -\frac{\partial \Pi}{\partial \phi} = -M_K g h_C \sin\psi + 2c_x (e\sin\varphi + a\cos\psi - c\sin\psi + b\cos\psi) \cdot \\ &\cdot (a\sin\psi - a\cos\psi + b\sin\psi) + 2c_y (a\sin\psi - e\cos\varphi + c\cos\psi) \cdot (a\sin\psi - a\cos\psi) \end{aligned}$$

As a result of the mathematical transformations when using the Lagrange formula of the motion equation of t.

The vibrating platform (Figure 1) takes the form:

$$\begin{aligned} x &= \frac{\mathrm{Pg}\cos\omega t}{2G_2(\omega^2 - \omega_0^2)} (2\cos\omega t - e^{\omega_0 t} - e^{-\omega_0 t}) + \frac{1}{2\omega_0^2} (2 - e^{\omega_0 t} - e^{-\omega_0 t}) \\ z &= \frac{\mathrm{Pg}\cos\omega_0 t}{\omega_0 G_2(\omega^2 - \omega_0^2)} + \left(\frac{G_2}{C_z} - \frac{G_1}{\omega_0^2}\right)\cos\omega_0 t + \frac{G_1}{\omega_0^2} + \frac{\mathrm{Pg}\sin\omega t}{G_2(\omega^2 - \omega_0^2)} \end{aligned} \tag{3}$$

Where: *P = (m₁ +m₂) g – the* mass of moving parts of vibrating drive;

Where:
$G_2 = m_2 g$; *$G_1 = m_1 g$*; *ω* and *ω_0* – respectively forced and free speed; *t* – processing time; *C_z* – stiffness of elastic elements in the direction of the z-axis.

The first three terms of this equation describe the own system oscillations, the fourth term describes the forced oscillations.

The working oscillation amplitude of the executive bodies of the vibrating massager is:

$$A_P = \frac{\mathrm{Pg}}{G_2(\omega^2 - \omega_0^2)} \tag{4}$$

The equation of motion for the working drum at the steady operation mode of the vibrating massager is:

$$x = \frac{2Pg\cos 2\omega t}{G^2(\omega^2 + \omega_0^2)} \tag{5}$$

$$x = \frac{2Pg\sin\omega t}{G^2(\omega^2 - \omega_0^2)} \tag{6}$$

Then the speed components of the working container take the form:

$$\vartheta_x = \dot{x} = \frac{2Pg\omega\sin 2\omega t}{G^2(\omega^2 - \omega_0^2)} \tag{7}$$

$$\vartheta_z = \dot{z} = \frac{2Pg\omega\cos 2\omega t}{G^2(\omega^2 - \omega_0^2)} \tag{8}$$

The absolute speed value of the working container is:

$$\vartheta_B = \sqrt{\vartheta_x^2 + \vartheta_x^2} = \frac{Pg\omega}{G^2\left(\omega^2 + \omega_0^2\right)}\sqrt{\cos^2 \omega t - 4\sin^2 2\omega t} \tag{9}$$

The oscillation amplitude of the working container is:

$$A_p = \frac{Pg}{G^2\left(\omega^2 - \omega_0^2\right)} = \frac{m^1 e\omega^2}{m^2\left(\omega^2 - \omega_0^2\right)} \tag{10}$$

Using the formula (10), we construct the amplitude-frequency characteristics of the oscillation system under study. In this case, we vary the ratio of m_1/m_2 (Figure 2) for a fixed value of the eccentricity *e* of the drive shaft; as well as the amplitude-frequency characteristics of the container of the vibrating massager when changing the eccentricity e at a fixed ratio m_1/m_2 (Figure 3). In the scientific works **[33]**, **[34]**, **[35]** by the authors, only calculations of the amplitude-frequency characteristics of similar systems were carried out without constructing graphical dependencies, which does not provide an opportunity. In the works of the following authors **[36]**, **[37]**, **[38]**, the variation of the mass ratio at a fixed value of the eccentricity of the drive shaft was not taken into account. The amplitude-frequency characteristics of the container were determined only at one fixed mass ratio, which can lead to the equipment entering unregulated modes of operation.

The value of the angular speed ω=28 rad/s can be noted in the resonant processing mode, which is characterized by the difficulty of maintaining the operating amplitude and frequency under conditions of low-frequency oscillations of the container with the mass of the meat raw materials being processed. In scientific manuscripts **[39]**, **[40]**, **[41]**, various ranges of angular velocities in the range from 10 to 20 rad/s were studied, where the resonant mode of processing is also noted. In my opinion, this is true in the fast-operating modes, the equipment will simply fail, and the technological production process will be disrupted. Further to the value of ω = 45 – 50 rad/s, there is a transient mode, after which there is a resonant mode. The latter is characterized by the constancy of the operating amplitude, which contributes to the reduction of dynamic loads on the support nodes, due to which it is possible to increase the service life of the equipment and reduce the costs of electron carriers, which will lead to a decrease in the cost of the final product. In scientific works **[42]**, **[43]**, the authors investigated speed ranges from 55 to 60 rad/s during salting of pork and chicken, where transient processing modes are indicated without specifying constant amplitudes. Still, such characteristics of the work process will contribute to a significant increase in the workload on workers' organs of the machine, which can lead to a violation of the technological process — for example, abnormal salting of raw materials or mechanical damage to the finished product.

For statistical optimization of the received dependences of the kinematic characteristics of the Vibro massage, we note the following parameters: the amplitude of oscillations A of the working container, which affects the penetration of mechanical vibrations deep into the stuffing mass; frequency of oscillations ω, which determines the intensity of vibrations; the eccentricity of the drive shaft e, which determines the amount of dynamic impact due to contact interaction within the technological mass of the product; the ratio of rotating and oscillating m_1/m_2, which determines the metal capacity and, accordingly, the energy capacity of the machine's vibration exciter. Variations of these parameters are accepted within the following limits: e = 1 – 5 mm, ω = 0 – 120 rad/s, angle of rotation of the drive shaft φ = 0 – 3600, m_1/m_2 = 4 – 13 .

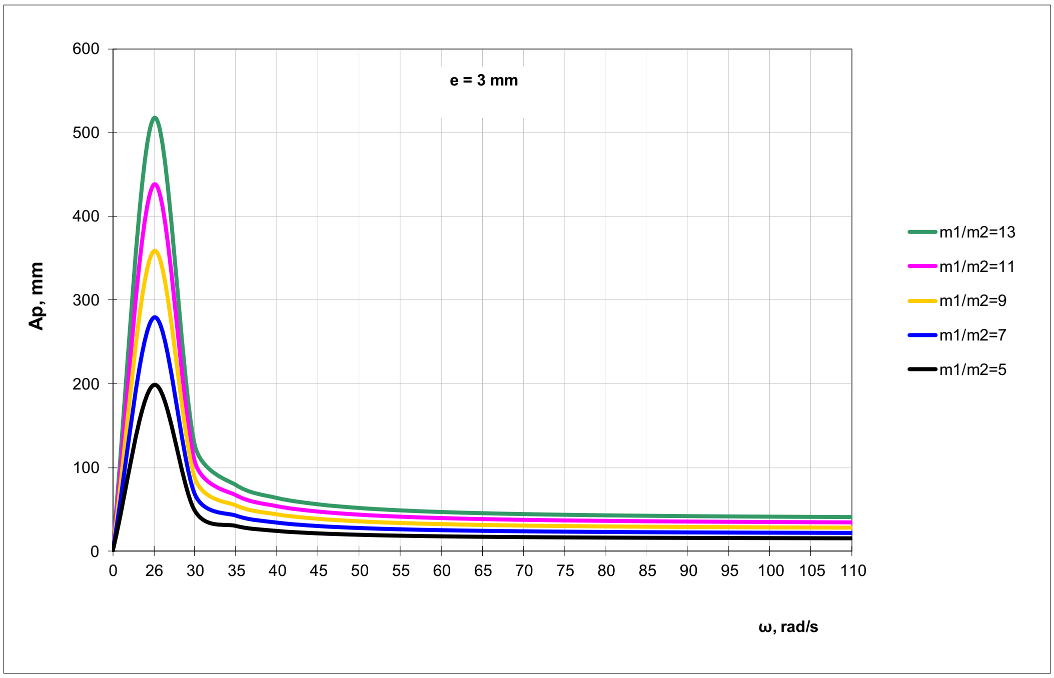

Figure 2 Amplitude-frequency characteristics of oscillation system under study when changing ratio m_1/m_2 and constant value of eccentricity e.

Using the formulas (5) and (6), we construct the trajectories of horizontal (Figure 4) and vertical (Figure 5) motions of the center of mass of the working container of the oscillation system under study. In this case, we vary the ratio of m_1/m_2 at a constant value of eccentricity e = 2 mm.

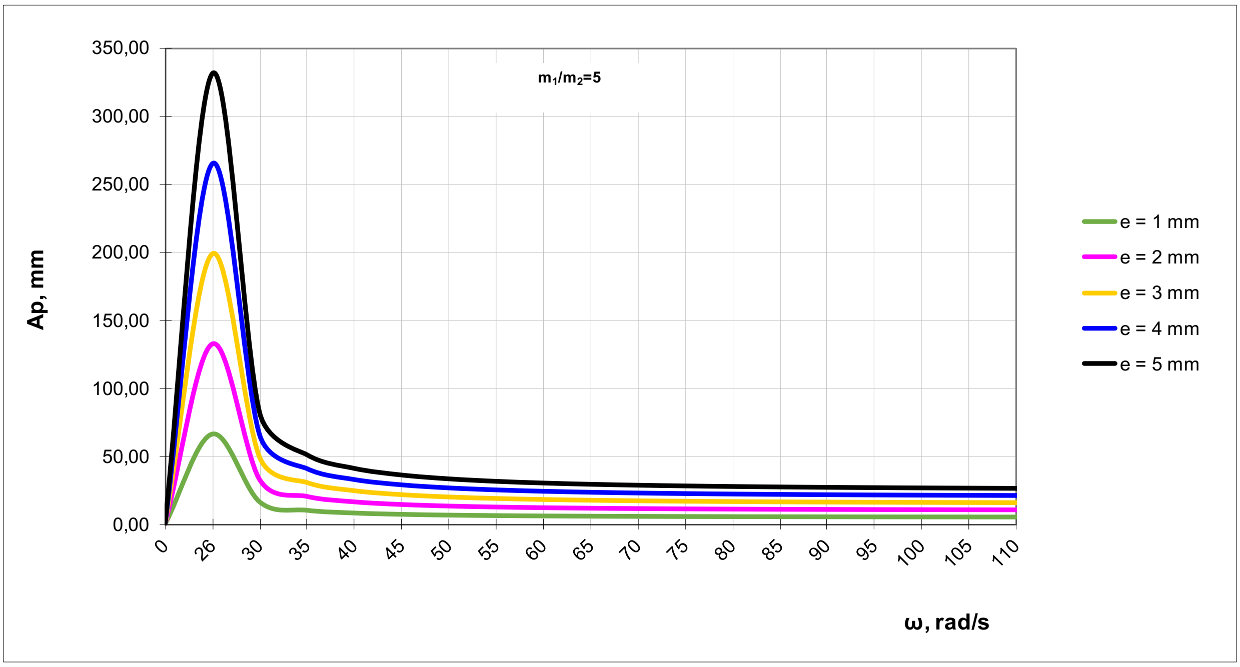

Figure 3 Amplitude-frequency characteristics of oscillation system under study when changing the value of eccentricity e and constant ratio m_1/m_2.

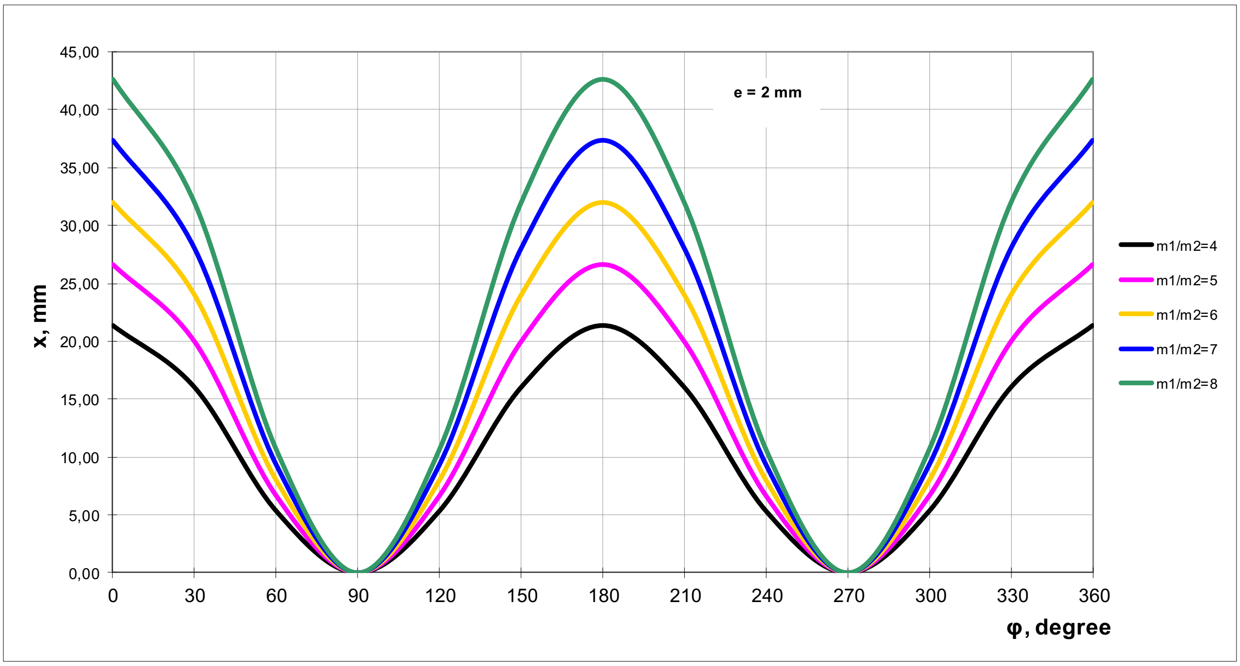

Figure 4 Trajectories of horizontal motion of the center of mass of working container of oscillation system under study when changing ratio of m_1/m_2 and constant value of eccentricity e = 2 mm.

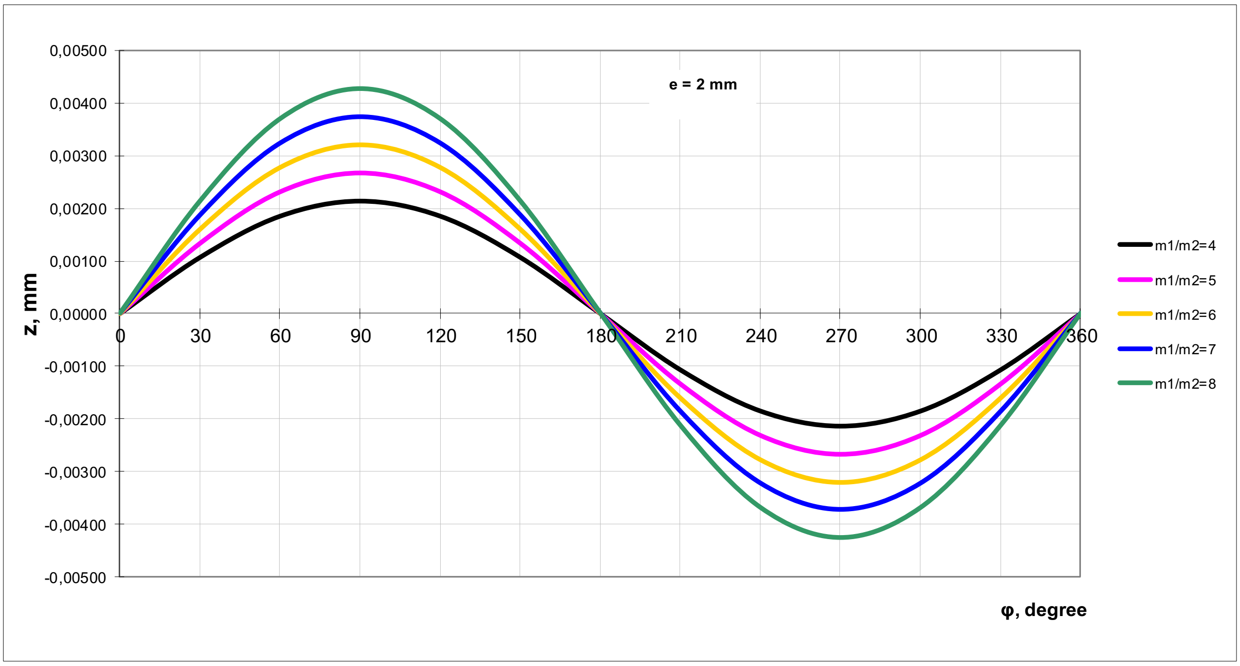

Figure 5 Trajectories of vertical motion of the center of mass of working container of oscillation system under study when changing ratio of m_1/m_2 and constant value of eccentricity e = 2 mm.

Using the formulas (7) and (8), we construct the speed characteristics of the oscillation system under study. In this case, we vary the ratio of m_1/m_2 (Figure 6) and assume a constant value of eccentricity e = 2 mm.

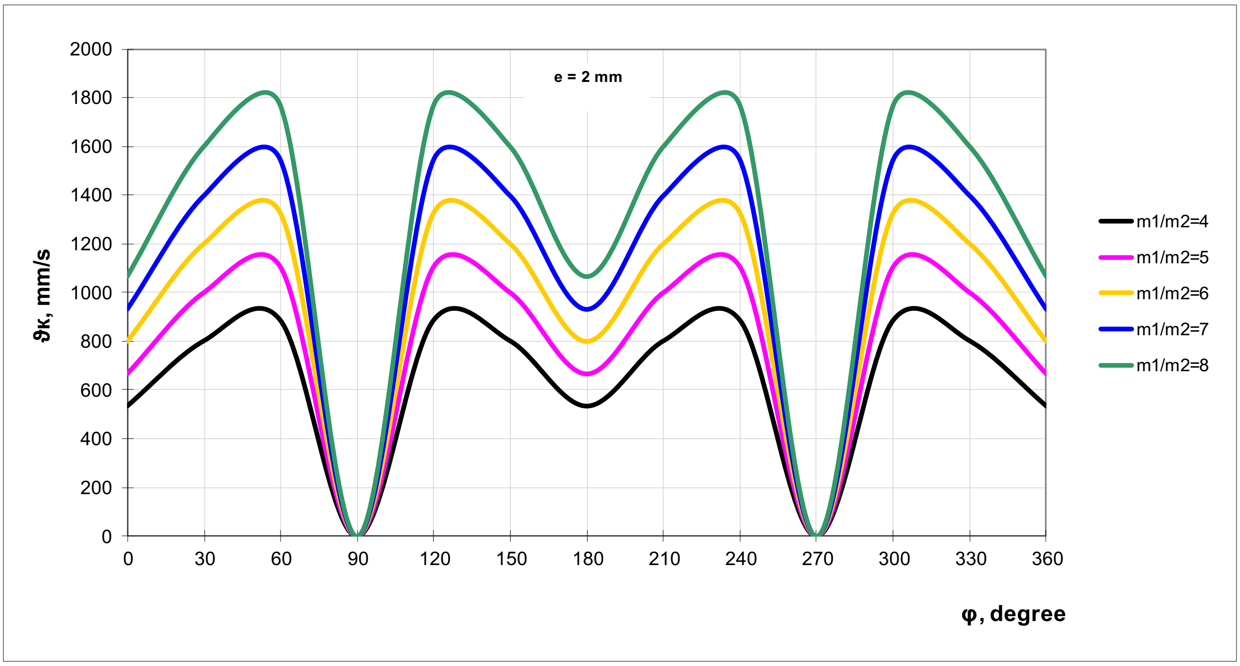

Figure 6 Speed characteristics of the center of mass of working container of oscillation system under study when changing ratio of m_1/m_2 and constant value of eccentricity e = 2 mm.

The dependences of the kinematic characteristics of the oscillation system under study (Figures 2 – 6) indicate that at angular speed $\omega = 50$ rad/s, there is a stabilization of the processing operation mode of the meat products at the value of the oscillation amplitude $A = 6.5$ mm. Therefore, in a further graphic-analytical study, we believe that the operating parameters of the vibrating massager are $\omega = \omega_p = 50$ rad/s and $A = A_p = 6.5$ mm.

Based on the research results during the development of technology, a brine containing papain enzyme was used for whole-muscle products from ostrich meat. As the main raw material, ostrich thigh meat, obtained after slaughtering the bird at 12 months, was chosen. The enzyme papain was added to the composition of the multicomponent brine in the amount of 0.07% of the mass of the brine, which corresponded to 0.015% of the mass of unsalted raw materials at 30% injection. The composition of syringe brine is shown in Table 2.

Table 2 Composition of injection brine, kg.

Name component	Content of salting ingredients (per 100 kg of brine)			
	control	Brine No 1	Brine No 2	brine No 3
Water, kg	91.2	90.9	92	91.93
Salt, kg	7.5	7.5	4.7	4.5
Sodium nitrite (in the form of 2.5% solution), kg	0.3	0.3	-	-
Sugar, kg	1	1.	-	-
Phosphates, kg	-	0.3	-	-
Papain enzyme	-	-	-	0.07
Functional supplement, kg	-	-	3,5	3,5
Total:	100	100	100	100

Thus, the penetration of saline active substances in the physical and chemical composition of meat tissues and their interaction with proteins changes the product, determining the main properties of salted meat (swelling, consistency, viscosity, etc.). Changes in meat proteins during salting are accompanied by an increase in bound moisture in the product, the product at further heat-treated retains moisture better and rises product output.

As a result of the research, the salt content in the finished product in the control sample of ham is 3.45% due to the loss of moisture during traditional mixing. The experimental sample is 3.3% due to the improved massaging process. Similar series of experimental studies are described in scientific papers **[45]**, **[46]**, **[47]**, where cattle and pig meat were used as raw materials. Still, the scientific teams carried out the salting process without using the massaging process, therefore, in our opinion, the salt content in such samples may be overestimated, which in turn can negatively affect the organoleptic indicators of finished products.

CONCLUSION

1. The value of the angular speed of the drive shaft in the range of $\omega_p = 10 – 28$ rad/s corresponds to the resonant operation mode of the container with the technological masses, which creates difficulties in controlling the operating mode sustainability and increases the load on the executive bodies of the device.
2. If the value of the drive shaft's angular speed exceeds $\omega_p = 45 – 50$ rad/s, there is a stabilization of the oscillation amplitude for almost all ratios m_1/m_2, which increases the durability of the support units of the drive.
3. The effective parameters for the operating mode of the container of the vibrating massager include the following: the vibration amplitude $A_p = 6.5$ mm, the eccentricity of the drive shaft $e = 2$ mm, and the mass ratio of the container and the kinematic vibrator $m_1/m_2 = 5$.
4. Under the selected regime parameters of the Vibro massage process, introducing the functional additive and enzyme papain with a content of 27.64% in the experimental sample improves the taste properties of the developed ham products, particularly, juiciness.

REFERENCES

1. Berher A. D. (2017). Current trends in the development of the meat processing industry of Ukraine. In Intellekt XXI (Vol. 1, pp. 41–51). Helvetica.

2. Shtonda, O., & Israelian, V. (2021). Changes in functional and technological indicators of African ostrich meat under the action of vegetable enzymes in the composition of salting brine. In Naukovì dopovìdì Nacìonalʹnogo unìversitetu bìoresursiv ì prirodokoristuvannâ Ukraïni (Issue 1(89)). National University of Life and Environmental Sciences of Ukraine. https://doi.org/10.31548/dopovidi2021.01.004

3. TU U 15.1-2497315254-001:2006 Ostrich meat and offal. Specifications.

4. DSTU 3583. 2015. Table salt. General technical conditions. Quality management systems – Requirements.

5. DSTU 4623, 2006 White sugar. General technical conditions. Quality management systems – Requirements.

6. GOST 32781, 2014. Food additives. sodium nitrite. General specifications. Quality management systems – Requirements.

7. Holembovska, N., Tyshchenko, L., Slobodyanyuk, N., Israelian, V., Kryzhova, Y., Ivaniuta, A., Pylypchuk, O., Menchynska, A., Shtonda, O., & Nosevych, D. (2021). Use of aromatic root vegetables in the technology of freshwater fish preserves. In Potravinarstvo Slovak Journal of Food Sciences (Vol. 15, pp. 296–305). HACCP Consulting. https://doi.org/10.5219/1581

8. Koval, O. A. (2013). Intense pickling. Achievements, problems, and prospects for the development of hotel and restaurant and tourism business: materials of the II All-Ukrainian scientific-practical conference (pp. 168–170). http://dspace.nuft.edu.ua/jspui/handle/123456789/24310

9. Bal-Prylypko, L., Yancheva, M., Paska, M., Ryabovol, M., Nikolaenko, M., Israelian, V., Pylypchuk, O., Tverezovska, N., Kushnir, Y., & Nazarenko, M. (2022). The study of the intensification of technological parameters of the sausage production process. In Potravinarstvo Slovak Journal of Food Sciences (Vol. 16, pp. 27–41). HACCP Consulting. https://doi.org/10.5219/1712

10. Ivaniuta, A., Menchynska, A., Nesterenko, N., Holembovska, N., Yemtcev, V., Marchyshyna, Y., Kryzhova, Y., Ochkolyas, E., Pylypchuk, O., & Israelian, V. (2021). The use of secondary fish raw materials from silver carp in the technology of structuring agents. In Potravinarstvo Slovak Journal of Food Sciences (Vol. 15, pp. 546–554). HACCP Consulting. https://doi.org/10.5219/1626

11. Palamarchuk, I., Tsurkan, O., & Kostenko, O. (2016) Vibratsiini protsesy ta obladnannia upererobnomu silskohospodarskomu vyrobnytstvi (Vibration processes and equipment in processing agricultural production). Vinnytsia: Higher School of Higher Education. 266 p.

12. Palamarchuk, I., Mushtruk, M., Sukhenko, V., Dudchenko, V., Korets, L., Litvinenko, A., Deviatko, O., Ulianko, S., & Slobodyanyuk, N. (2020). Modelling of the process of vybromechanical activation of plant raw material hydrolysis for pectin extraction. In Potravinarstvo Slovak Journal of Food Sciences (Vol. 14, pp. 239–246). HACCP Consulting. https://doi.org/10.5219/1305

13. DSTU ISO 1442:2005 Meat and meat products. Moisture determination method (control method) – Requirements.

14. DSTU 8380:2015 Meat and meat products. The method of measuring the mass fraction of fat – Requirements.

15. GOST 25011-2017 Meat and meat products. Protein determination methods – Requirements.

16. DSTU ISO 936:2008 Meat and meat products. Methodology for determining the mass fraction of total ash – Requirements.

17. Antypova, L. V., Hlotova, Y. A., & Rohov, Y. A. (2001). Research methods of meat and meat products. Kolos, 376 p.

18. DSTU ISO 2917-2001. Meat and meat products. Determination of pH (control method) – Requirements.

19. Bober, A., Liashenko, M., Protsenko, L., Slobodyanyuk, N., Matseiko, L., Yashchuk, N., Gunko, S., & Mushtruk, M. (2020). Biochemical composition of the hops and quality of the finished beer. In Potravinarstvo Slovak Journal of Food Sciences (Vol. 14, pp. 307–317). HACCP Consulting. https://doi.org/10.5219/1311

20. Burger, M., Capasso, V., & Morale, D. (2007). On an aggregation model with long and short-range interactions. In Nonlinear Analysis: Real World Applications (Vol. 8, Issue 3, pp. 939–958). Elsevier BV. https://doi.org/10.1016/j.nonrwa.2006.04.002

21. Palamarchuk, I., Vasyliv, V., Sarana, V., Mushtruk, M., Zheplinska, M., Burova, Z., Gudzenko, M., Filin, S., & Omelyanov, O. (2021). Substantiation of amplitude-frequency characteristics and design parameters of vibration exciter in volume oscillation separator. In Animal Science and Food Technology (Vol. 12, Issue 2). National University of Life and Environmental Sciences of Ukraine. https://doi.org/10.31548/animal2021.02.006

22. Ivanova, I., Serdiuk, M., Malkina, V., Bandura, I., Kovalenko, I., Tymoshchuk, T., Tonkha, O., Tsyz, O., Mushtruk, M., & Omelian, A. (2021). The study of soluble solids content accumulation dynamics under the influence of weather factors in the fruits of cherries. In Potravinarstvo Slovak Journal of Food Sciences (Vol. 15, pp. 350–359). HACCP Consulting. https://doi.org/10.5219/1554

23. Chuang, Y.-L., Huang, Y. R., D'Orsogna, M. R., & Bertozzi, A. L. (2007). Multi-Vehicle Flocking: Scalability of Cooperative Control Algorithms Using Pairwise Potentials. In Proceedings 2007 IEEE International Conference on Robotics and Automation. 2007 IEEE International Conference on Robotics and Automation. IEEE. https://doi.org/10.1109/robot.2007.363661

24. Couzin, I. D., Krause, J., Franks, N. R., & Levin, S. A. (2005). Effective leadership and decision-making in animal groups on the move. In Nature (Vol. 433, Issue 7025, pp. 513–516). Springer Science and Business Media LLC. https://doi.org/10.1038/nature03236

25. Zajác, P., Czako, P., Čapla, J., Vietoris, V., Maršálková, L., Čurlej, J., Belej, Ľ., Golian, J., Benešová, L., & Martišová, P. (2018). The effect of UV-C irradiation on grape juice turbidity, sensoric properties and microbial count. In Potravinarstvo (Vol. 12, Issue 1). HACCP Consulting. https://doi.org/10.5219/856

26. Degond, P., & Motsch, S. (2008). Large Scale Dynamics of the Persistent Turning Walker Model of Fish Behavior. In Journal of Statistical Physics (Vol. 131, Issue 6, pp. 989–1021). Springer Science and Business Media LLC. https://doi.org/10.1007/s10955-008-9529-8

27. Ha, S.-Y., & Liu, J.-G. (2009). A simple proof of the Cucker-Smale flocking dynamics and mean-field limit. In Communications in Mathematical Sciences (Vol. 7, Issue 2, pp. 297–325). International Press of Boston. https://doi.org/10.4310/cms.2009.v7.n2.a2

28. Kolyanovska, L., Palamarchuk, I., Sukhenko, Y., Mussabekova, A., Bissarinov, B., Popiel, P., Mushtruk, M., Sukhenko, V., Vasuliev, V., Semko, T., & Tyshchenko, L. (2019). Mathematical modeling of the extraction process of oil-containing raw materials with pulsed intensification of the heat of mass transfer. In R. S. Romaniuk, A. Smolarz, & W. Wójcik (Eds.), Optical Fibers and Their Applications 2018. SPIE. https://doi.org/10.1117/12.2522354

29. Mushtruk, M., Deviatko, O., Ulianko, S., Kanivets, N., & Mushtruk, N. (2021). An Agro-Industrial Complex Fat-Containing Wastes Synthesis Technology in Ecological Biofuel. In Lecture Notes in Mechanical Engineering (pp. 361–370). Springer International Publishing. https://doi.org/10.1007/978-3-030-77823-1_36

30. Mushtruk, M., Gudzenko, M., Palamarchuk, I., Vasyliv, V., Slobodyanyuk, N., Kuts, A., Nychyk, O., Salavor, O., & Bober, A. (2020). Mathematical modeling of the oil extrusion process with pre-grinding of raw materials in a twin-screw extruder. In Potravinarstvo Slovak Journal of Food Sciences (Vol. 14, pp. 937–944). HACCP Consulting. https://doi.org/10.5219/1436

31. Cherednichenko, O., Bal-Prylypko, L., Paska, M., & Nikolaenko, M. (2021). The expediency of creation of technology for the production of meat products of long term of storage of the combined structure. In IOP Conference Series: Earth and Environmental Science (Vol. 723, Issue 3, p. 032086). IOP Publishing. https://doi.org/10.1088/1755-1315/723/3/032086

32. Mushtruk, M., Vasyliv, V., Slobodaniuk, N., Mukoid, R., & Deviatko, O. (2020). Improvement of the Production Technology of Liquid Biofuel from Technical Fats and Oils. In Advances in Design, Simulation and Manufacturing III (pp. 377–386). Springer International Publishing. https://doi.org/10.1007/978-3-030-50491-5_36

33. Nowak, D., & Lewicki, P. P. (2004). Infrared drying of apple slices. In Innovative Food Science & Emerging Technologies (Vol. 5, Issue 3, pp. 353–360). Elsevier BV. https://doi.org/10.1016/j.ifset.2004.03.003

34. Zheplinska, M., Mushtruk, M., Kos, T., Vasyliv, V., Kryzhova, Y., Mukoid, R., Bilko, M., Kuts, A., Kambulova, Y., & Gunko, S. (2020). The influence of cavitation effects on the purification processes of beet sugar production juices. In Potravinarstvo Slovak Journal of Food Sciences (Vol. 14, pp. 451–457). HACCP Consulting. https://doi.org/10.5219/1284

35. Palamarchuk, I., Mushtruk, M., Vasyliv, V., & Zheplinska, M. (2019). Substantiation of regime parameters of vibrating conveyor infrared dryers. In Potravinarstvo Slovak Journal of Food Sciences (Vol. 13, Issue 1, pp. 751–758). HACCP Consulting. https://doi.org/10.5219/1184

36. Palamarchuk, I., Tsurkan, O., Palamarchuk, V., & Kharchenko, S. (2016). Research of competitiveness vibrovolnovoy conveyor infrared dryer for postharvest processing of grain. In Eastern-European Journal of Enterprise Technologies (Vol. 2, Issue 7(80), p. 79). Private Company Technology Center. https://doi.org/10.15587/1729-4061.2016.65887

37. Shanina, O., Galyasnyj, I., Gavrysh, T., Dugina, K., Sukhenko, Y., Sukhenko, V., Miedviedieva, N., Mushtruk, M., Rozbytska, T., & Slobodyanyuk, N. (2019). Development of gluten-free non-yeasted dough structure as factor of bread quality formation. In Potravinarstvo Slovak Journal of Food Sciences (Vol. 13, Issue 1, pp. 971–983). HACCP Consulting. https://doi.org/10.5219/1201

38. Smetanska, I., Tonkha, O., Patyka, T., Hunaefi, D., Mamdouh, D., Patyka, M., Bukin, A., Mushtruk, M., Slobodyanyuk, N., & Omelian, A. (2021). The influence of yeast extract and jasmonic acid on phenolic acids content of in vitro hairy root cultures of Orthosiphon aristatus. In Potravinarstvo Slovak Journal of Food Sciences (Vol. 15, pp. 1–8). HACCP Consulting. https://doi.org/10.5219/1508

39. Sukhenko, Y., Mushtruk, M., Vasyliv, V., Sukhenko, V., & Dudchenko, V. (2019). Production of Pumpkin Pectin Paste. In Lecture Notes in Mechanical Engineering (pp. 805–812). Springer International Publishing. https://doi.org/10.1007/978-3-030-22365-6_80

40. Sukhenko, Y., Sukhenko, V., Mushtruk, M., & Litvinenko, A. (2018). Mathematical Model of Corrosive-Mechanic Wear Materials in Technological Medium of Food Industry. In Lecture Notes in Mechanical Engineering (pp. 507–514). Springer International Publishing. https://doi.org/10.1007/978-3-319-93587-4_53

41. Zheplinska, M., Mushtruk, M., Vasyliv, V., Sarana, V., Gudzenko, M., Slobodyanyuk, N., Kuts, A., Tkachenko, S., & Mukoid, R. (2021). The influence of cavitation effects on the purification processes of beet sugar production juices. In Potravinarstvo Slovak Journal of Food Sciences (Vol. 15, pp. 18–25). HACCP Consulting. https://doi.org/10.5219/1494

42. Sesikashvili, O., & Zverev, S. (2018). Heating and dehydration of grain and cereals at a combined energy supply. In Potravinarstvo (Vol. 12, Issue 1). HACCP Consulting. https://doi.org/10.5219/840

43. Donchenko, L. V., Doroshenko, T. N., Krasnoselova, E. A., Konuhova, E. V., & Petrik, G. F. (2020). Impact of technological scheme of apple tree cultivation on fractional content of pectin substances. In IOP Conference Series: Earth and Environmental Science (Vol. 488, Issue 1, p. 012008). IOP Publishing. https://doi.org/10.1088/1755-1315/488/1/012008

44. Koksharov, S. A., Aleeva, S. V., & Lepilova, O. V. (2019). Description of adsorption interactions of lead ions with functional groups of pectin-containing substances. In Journal of Molecular Liquids (Vol. 283, pp. 606–616). Elsevier BV. https://doi.org/10.1016/j.molliq.2019.03.109

45. Salzano, A., Cotticelli, A., Marrone, R., D'Occhio, M. J., D'Onofrio, N., Neglia, G., Ambrosio, R. L., Balestrieri, M. L., & Campanile, G. (2021). Effect of Breeding Techniques and Prolonged Post Dry Aging Maturation Process on Biomolecule Levels in Raw Buffalo Meat. In Veterinary Sciences (Vol. 8, Issue 4, p. 66). MDPI AG. https://doi.org/10.3390/vetsci8040066

46. Ugnivenko, A., Kos, N., Nosevych, D., Mushtruk, M., Slobodyanyuk, N., Zasukha, Y., Otchenashko, V., Chumachenko, I., Gryshchenko, S., & Snizhko, O. (2022). The yield of adipose tissue and by-products in the course of the slaughter of inbred and outbred bulls of the Ukrainian beef breed. In Potravinarstvo Slovak Journal of Food Sciences (Vol. 16, pp. 307–319). HACCP Consulting. https://doi.org/10.5219/1758

47. Ramanathan, R., Mafi, G. G., Yoder, L., Perry, M., Pfeiffer, M., VanOverbeke, D. L., & Maheswarappa, N. B. (2020). Biochemical changes of postmortem meat during the aging process and strategies to improve the meat quality. In Meat Quality Analysis (pp. 67–80). Elsevier. https://doi.org/10.1016/b978-0-12-819233-7.00005-7

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