THESIS BOOK

Application of Ultrasound in Classification and Production Technology of Meat Products

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The applicant met the requirement of the PhD regulations of the Corvinus University of Budapest and the thesis is accepted for the defence process.

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1. Introduction

In Denmark and other countries with well developed meat industry, research and innovative activity in the field of meat science, new technologies, and measurement technique gain significant financial and moral support. Most of the technologies and measurement systems used in the Hungarian meat industry are traditional, innovative developments are rarely represented in it. In the meat industry, progress presents itself through companies distributing additives and equipment. These companies, however, don't provide sufficient information for further development in the meat industry. Thus, innovation, regarding technology and measurement technique, is necessary to open new perspectives for the Hungarian meat industry.

Application of ultrasound has a potential for development and research both in the fields of measurement technique and technology. Regarding the use of ultrasound, measurement technique and technology are considered to be two separate ranges. Depending on the intensity of ultrasonic waves, passive and active ultrasounds are distinguished. Above 1 Wcm^{-2} it is considered as active ultrasound, below this value it is considered as passive ultrasound. Passive ultrasound is used in the measurement technique, active ultrasound is used in mechanical effects.

Determination of quality, and monitoring technological processes are essential in food procesing and trade. Generally, chemicals used in qualification are in direct contact with food, in case of destructive analytical methods samples become unfit for further processing, that hinders their use as foodstuffs. Thus, use of non-destructive, rapid and simple physical measurement methods should be chosen whenever it is possible, that enables further processing of samples and provides continuous information about the sample to be measured. Time-consuming sample preparation can be eliminated, so called „clear" measurement technique can be accomplished. Passive ultrasound belongs to the non-destructive methods. It doesn't change the characteristics of materails to be measured. Some examples of the application of passive ultrasound: orientation of submarines; measurement of velocity; examination of foetus and inner organs in medicine; determination of meat-fat ratio in pork grading etc..

Consumption of bacon is of important in Hungary and other European and Far-Eastern countries. Quality of bacon, either as raw material or as final product, is very important for the meat industry and trade. Nowadays its quality is determined by the meat-fat ratio. Determination of actual meat content is still an unsolved problem at reception and marketing of bacon. Experts and consumers decide on meat content by inspecting the meat-fat ratio in the total thickness of bacon. Unfortunately, as there are no appropriate measurement systems and evaluation methods available, quality defects, misunderstandings and disputes often arise between producers, merchants and consumers, that brings about economical and moral disadvantages. Consequently, we face a real problem in the production and marketing of bacon, that has to be solved.

Production of dry sausage, namely Hungarian winter salami in Szeged and Budapest, has a 120-130-year tradition in Hungary. In the last more than 100 years, salami masters accomplished the proper and controlled ripening technology. Nowadays, number of salami masters decreased, there are hardly any experts on this field, as the masters kept the trick of the trade as a secret. Hereby no new generation was trained, control of ripening technologies is incomplete. The meat industry has no index-numbers and monitoring systems to follow the ripening process, since the salami masters have determined the state of ripening by touching, and changed the parameters of ripening, temperature, relative humidity and air velocity. Practically, there is no way to learn the „profession", and this knowledge can not be attained only from books. Therefore, monitoring of the ripening process, prevention of rind-formation by building a non-destructive measurement system, and data registration is of great importance. Meat scientists in the traditionally dry sausage producing countries have investigated from several aspects texture and ultrasound characteristics of salami-types as a function of ripening, but no measurements have been carried out regarding rind-formation.

An other field of the application of ultrasound is active ultrasound, that has significant mechanical power. Its use is manifold: drilling of metal and rock, cutting of concrete, formation of aerosols, solution processes, crystallization, preparation of stable emulsions, meat tenderization etc.

Rapid technology has gained importance in meat curing because of economical and plant organizational reasons. Rapid technology means introduction of curing solution as fast and uniformly as possible. Technologies used up to now are injection of curing solution and tumbling, where the distribution of curing salt is not uniform. However, injection of curing solution ensures uniform salt distribution, but this method can be used only for big meat pieces, but in case of small meat particles filled in casing, or cooked hams, this method is inapplicable. Diffusion of the curing solution and development of texture determine the speed of curing. Several researchers have dealt with the application of active ultrasound in curing of meat. Main stress was put on the increase of diffusion. High intensity of active ultrasound and the phenomenon of cavitation are in the background of its use. Cavitation can beneficially influence membrane permeability, thus accelerating diffusion of the curing solution. Applied intensity values and treatment times found in literature are extreme, and the results are heterogeneous.

In the present study application of active and passive ultrasound is investigated in the field of measurement technique and technology in the meat industry.

2. Objectives

On account of the technological reasons mentioned in the introduction, my aim was to detect the meat-fat ratio in bacon, and rind formation in a dry sausage, namely Hungarian winter salami, by using the non-destructive nature of high frequency passive ultrasound.

Accordingly, propagation velocity of ultrasound and its attenuation were measured in meat and fat layers of bacon, and in normal and rind layers of winter salami, and the thickness of these layers was determined.

Our objective was to monitor the state of rind formation and changes in solids content in salami bars during a 15-week ripening period by measuring propagation velocity, attenuation, attenuation coefficient and solids content of salami bars.

To develop curing technology, we intended to evolve a process that increases the rate of salt diffusion, shortens curing time by uniform salt diffusion and better texture development, results in a better texture and increases yield.

3. Materials and Methods

In this chapter, samples, measurement methods and treatments, used in the application of active and passive ultrasound, are presented. Details of active and passive ultrasonic treatments are discussed separately.

Passive ultrasound

In the investigations performed by passive ultrasound, bacon Kolozsvár type, smoked lard, and winter salami samples were included. A computer-aided measurement system was assembled, where the ultrasound-frequency instrument was controlled by a computer. The transducer was a dry coupled sensor with 1 MHz nominal resonance frequency. The receiver signal was detected by an oscilloscope, and an oscilloscope emulating interface card built in the computer, and a software, respectively.

Transmission mode was used in the investigations. Ultrasound impulses with different widths were transmitted through the samples with a given frequency, and the signals were measured by an oscilloscope, and by the computer-aided measurement system. The receiver-transmitter unit was fixed on a frame put on a vibration damper layer. During pre-investigations, temperature dependence of propagation velocity and of attenuation was studied in the range of 5 to 25°C. Direction dependence of the above mentioned characteristics was studied in case of transmission parallel or perpendicular to the layers in the sample, too. Characteristics of ultrasound and instrument constant were determined. In the course of data evaluation, the magnitude and delay of output signal were determined. Propagation velocity, attenuation and attenuation coefficient of ultrasonic waves in the different sample layers were calculated from these data. Attenuation is the gradual decrease in the energy of vibratory motion and its amplitude. Amplitude of the vibratory motion exponentially decreases with distance due to friction or other losses. Rate of decrease is determined by the α attenuation coefficient in the exponent. The process is described by the following relation:

$$U_{ki} = a \cdot e^{-b \cdot \alpha}$$

Apparent output signals were plotted as a function of thickness. The exponent of the equations describing the curves of the resulting exponential graphs, that is the invert of the attenuation coefficient, shows the sample width causing 1:2.71 reduction of the output signal.

On the basis of pre-investigations and mathematical relations, additivity of attenuation coefficients was raised as hypothesis, that was proven after the examination of the layers.

Active ultrasound

Deboned pork loin (longissimus dorsi) was used in the investigations in the form of

- smaller (5 x 5x 2 cm) and bigger (7 cm diameter, 450-470 g weight) pieces,
- raw ham paste (ham paste=meat exudate with small meat pieces in it) (90% curing solution/meat ratio)
- ham paste and cooked ham (finished product) with different curing solution contents (100, 110, 120 and 130 %)

Nitrite curing salt mixture was used in the pork loin pieces, and a mixture of curing solutions was used for the ham paste, and cooked ham (2,2% nitrite curing salt mixture, 0,4% tetrasodium-pyrophosphate, 32,5% tari-100, 64,9 meat protein).

In the present investigations a tumbler, and an equipment generating high intensity ultrasound were used.

Treatments and examinations

Tumbling, treatment by ultrasound at different intensities, and traditional curing (soaking in curing solution) were used for different holding times. Effect of the different treatment methods on quality parameters of meat samples, ham paste and cooked ham were determined. The parameters were as follows: diffusion coefficient, texture, salt diffusion, water binding and water holding capacity, protein denaturation, myofibrillar structure, texture of ham paste and cooked ham, mosaic character of cooked ham.

Determination of diffusion constant (D)

On determining the diffusion coefficient, we studied the speed of salt diffusion by tumbling, and curing by ultrasound compared to the traditional long time curing technology. According to the literature, ultrasound accelerates salt diffusion, but it is not yet cleared, to what extent. Accordingly, it is not yet known, whether tumbling or curing by ultrasound is more efficient in this respect.

Effect of treatments on texture of pork loin samples

Effect of different treatments on texture of pork loin samples was examined. The TPA (Texture Profile Analysis) method was used, when the load cell presses the sample twice, thus more information can be obtained about the texture characteristics, like firmness, chewing work, elasticity, cohesivity and chewiness.

Investigation of water binding and water holding capacity

Water binding capacity (WBC) indicates, that how much water or curing solution was bound by meat. The amount of bound water was calculated from the water content of the individual samples.

Water holding capacity (WHC) means the amount of water retained in meat after a certain mechanical treatment, e.g. loading by weight, centrifugation etc. It indicates, that to what extent was water or the curing solution bound to the proteins, and following standing for a certain time, how much water was released from meat. Water holding capacity was determined in the pork loin pieces and in cooked ham with increased curing solution content.

Electronmicroscopic examination of muscle fibres

Changes in distances between muscle fibres, swelling of fibres, and structural changes in myofibrilla were investigated by electronmicroscope. Changes in muscle fibres were determined by scanning electronmicroscopy, and changes in myofibrilla were detected by transmission electronmicroscopy.

DSC examinations

DSC (differential scanning calorimetry) examinations gave information about the temperature maximum of protein denaturation influenced by curing solution uptake and the physico-chemical effect of the given treatment.

Determination of salt distribution and texture in pork loin

Salt diffusion and distribution in the bigger pork loin pieces was determined. Firmness of the samples was measured in penetration mode. Mesurement of penetration indicates changes in the cohesive force between muscle fibres as a result of tumbling or ultrasonic treatment. It shows, whether loosening of muscle fibres in the inner layers takes place, and whether distances between myofibrilla increase or not.

Texture analysis of ham paste, determination of treatment time

When preparing ham paste, pork loin was minced by a grinder plate with perforations of 12 mm in diameter, then curing solution was added and treated by tumbler, by 2,5 Wcm^{-2} intensity ultrasound, and by traditional curing, respectively. Treatment times were 3, 4, and 5 hours, respectively.

With the help of texture measurement by Back-extrusion cell we got information about the cohesion, adhesion, and stickiness of the exudates of raw ham paste and meat particles, about the stability of the colloid system as a function of treatments and treatment times. Knowing the extrusion data, treatment time, necessary to the development of proper texture, could be determined.

Effect of increasing the ratio of curing solution/meat on quality of meat paste and finished product

In the series of investigations with cokked ham, the amount of added curing solution was increased (curing solution/meat ratio: 100, 110, 120 and 130%). The different ham pastes were filled into casings then cooked at 78°C, and cooled. We wanted to determine, whether changes in texture, water holding capacity and mosaic character of ham pastes and finished products occurred as a result of different curing methods and increased curing solution content. Back extrusion cell was used for the texture analysis.

Generally, in the evaluation of a series of samples, several methods are used in texture analysis. Texture analyses of finished ham were performed by TPA, Warner-Bratzler cell, and Kramer cell. If the given texture characteristics are the same, independent of the type of cell used in the test, then the effect of certain treatments on texture is proved. Measurement of water holding capacity was done in the same way as in the case of pork loin pieces. Photos illustrate the mosaic character of the different finished ham products.

4. Results and Discussion

Based on the investigations by passive ultrasound, the propagation velocity of ultrasound is higher in dryer and denser layers, like meat layers in bacon or rind of salami. Accordingly, propagation velocity is lower in layers with loose structure and high water content.

Rind of salami and meat layers of bacon attenuate ultrasound more intensively, that is, their attenuation coefficient is higher.

To sum up, ultrasound travels faster in dry and dense layers, but their intensity decreases significantly, that is, they are attenuated to a higher degree than in materials with looser and more elastic structure that contain liquid phase.

Knowing the propagation velocity, meat-fat ratio of bacon can be estimated. In the grading of salami, rind formation and the thickness of rind can be controlled.

Additivity of attenuation was proven in the case of the examined samples. By using the additivity, thickness of two layers with different tissue structure and composition can be calculated with high certainty, and thus quality (e. g. presence of rind) and meat-fat ratio of samples (winter salami, bacon from Kolozsvár) can be determined in a non-destructive way.

Propagation velocity and attenuation of ultrasound passing through the salami bar can be measured in a given time of ripening. Comparing the obtained data with the calibration graph, state of ripening process can be determined from the propagation velocity and attenuation in a given time. That is, solids content of a salami bar can be estimated, which is a determinant of the degree of drying at ripening. Thus, technological parameters can be changed, which are important from quality assurance and economical point of view.

Based on the results of curing by ultrasound we could state, that application of ultrasound in the investigated intensity range accelerates diffusion and salt uptake. Rate of diffusion increases exponentially by increasing intensity in the applied intensity range. Salt distribution within the sample is uniform, so to achieve the same salt concentration, curing solution with lower salt concentration is sufficient. Big difference in concentration between meat and the curing solution is not needed as driving force of diffusion.

As a result of cavitation caused by ultrasound, texture of meat becomes looser. Texture of meat is uniformly tender in the whole volume of meat, that promotes salt diffusion and increases palatability.

In the present investigations, we found 2,5 Wcm^{-2} intensity ultrasound to be optimal regarding to texture, water binding and water holding capacity. In the case of higher intensity (3-4 Wcm^{-2}) salt diffusion is faster and the distances between myofibrilla are higher, and fibres are thicker as shown on the electrinmicroscopic photos. However, denaturation caused by the treatment damages texture, water binding and water holding capacity are decreased. Samples treated by ultrasound hold water well. Tumbled meat pieces take up a high amount of water, but the water is slightly bound or is not bound at all.

On preparing cooked ham, 4 hour treatment time seemed to be optimal. To avoid denaturation, 20 mins treatment periods and 20 mins breaks should alternate with each other both during tumbling and curing by ultrasound.

Regarding texture characteristics, chewing force of meat pieces treated by ultrasound was significantly smaller than in case of other treatments. Optimal intensity was again 2,5 Wcm^{-2}, but similar values were obtained by using 2 or 3 Wcm^{-2} intensity. Chewing characteristics were better at 2 and 3 Wcm^{-2} by increasing treatment time, and at 3,5 and 4 Wcm^{-2} intensity, the effect was variable. Texture of hams treated by ultrasound was more loose, its cohesivity was better and the water holding capacity was satisfactory. The product retained its mosaic character, thus ultrasound didn't damage the small meat pieces in the ham in contrast to tumbling. On introduction of higher amounts of curing solution, texture characteristics and dripp loss of hams were changing only in a small extent.

5. Summary

In this study, application potential of ultrasound in the meat industry was investigated. Methods of generating ultrasound and its potential use was described. Effect of ultrasound on the structure of meat samples, and factors affecting curing and technological steps were presented. Non-destructive passive ultrasound was used to monitor the meat-fat ratio in bacon, rind formation in salami bars, and to control the ripening process of salami. Mechanical effect of active ultrasound on meat structure was used in the curing technology to develop this kind of technology.

Propagation velocity of ultrasound and its attenuation were measured and determined in the fat and meat layers of bacon samples, in the normal consistency salami layers and in the rind. Attenuation coefficients of individual layers in the samples were calculated. Changes in intensity of output signals were examined at different temperatures, with the measuring head parallel or perpendicular to the samples.

Attenuation of the individual layers of samples was measured, then additivity of attenuation was proved, that is, when attenuations of different layers is added up, the result is the attenuation of the whole sample. Knowing the propagation velocity, attenuation and attenuation coefficient, meat-fat ratio of samples was determined in two ways. This method, developed for the measurement of propagation velocity and attenuation of ultrasound, provides information for the trade, industry and consumers about the quality of the given product.

Based on the measurement of propagation velocity and attenuation of ultrasound, formation and thickness of a dry rind, as a result of improper ripening technology and storage, can be determined.

Furthermore, ripening process of salami can be monitored through the measurement of ultrasound characteristics. Propagation velocity, as well as attenuation are characteristic of the certain stages of ripening and solids content of the samples. Thus, by the application of ultrasound, ripening process can be monitored in a non-destructive way, and possible rind formation can be detected. Most critical stage of salami processing, namely ripening, can be practically automated with the help of this method.

During the application of ultrasound in curing technology, effects of ultrasound intensity and treatment time on texture and tenderness of meat were investigated. Changes in the diffusion coefficient were determined and compared to those of traditional curing and curing by tumbling. Curing by ultrasound increased the diffusion coefficient in the intensity range studied, however, diffusion coefficient, obtained by 4 Wcm^{-2} intensity ultrasound, only approximated the diffusion coefficient of tumbling, but couldn't reach it.

Effects of tumbling and curing by ultrasound were determined on textural changes and salt diffusion within the samples. Curing by ultrasound resulted more homogeneous salt diffusion and more uniformly tender texture in the samples. Of course, the two parameters are correlated with each other. Owing to the loose structure, distribution of curing solution is more uniform than in case of tumbling. Increase in treatment time and intensity promotes uniform salt diffusion and texture.

Effect of the different curing methods on fibre structure, distances between myofibrilla and their swelling was studied by electonmicroscope. Electronmicroscopic photos showed, that ultrasound loosened fibres significantly, water uptake of myofibrilla increased, thus they became swollen. Increase in the thickness of myofibrilla proved this phenomenon. In the intensity range from 2 to 4 Wcm^{-2}, thickness of myofibrilla and distances between them increased with increasing intensity.

Effects of treatments on denaturation temperature of actin and on water binding of proteins were measured by differential scanning calorimetry. Furthermore, effects of the different curing methods (traditional, tumbling and ultrasound) on water uptake and water holding of meat were investigated. Latter was determined by measuring drip loss. Based on the maximum value of actin denaturation temperature and results of water holding capacity, water holding capacity of meat pieces treated by ultrasound was somewhat smaller than that of the tumbled ones, but according to the values of water holding capacity, samples treated by ultrasound bound water better.

Effect of the different treatments on texture of ham paste was also examined. Optimal curing time was determined based on texture measurements, and 4-hour curing seemed to be optimal.

Effect of traditinal curing, tumbling and ultasound on finished and cut ham was examined as well. Amount of curing solution was increased, then changes in texture as a result of the different treatments were measured. According to the results, hams treated by ultrasound were less sensitive to the increase in the ratio of curing solution, that is, because of the more homogeneous distribution of curing solution, they bound the curing solution better. Hams cured by ultrasound were easier to chew.

Water holding capacity and and the mosaic character of the finished product was investigated as a function of incresing ratio of curing solution. As a result of ultrasonic treatment, water holding capacity of ham was slightly weaker than that of the tumbled product, but it was not so sensitive to the increase of the amount of curing solution.

Important advantage of ultrasonic treatment compared to tumbling was, that cut up and cooked ham cured by ultrasound retained its mosaic character.

It was proven by the investigations, that curing technology itself and product quality can be improved by the application of ultrasound. Further investigations are needed to clear up, whether ultrasound combined with tumbling would be a rapid curing technology, ensuring high introduction of curing solution into the product.

6. Thesis

1. I collected a data base about the propagation velocity of ultrasonic waves in meat and fat layers of bacon, and in the layers of salami with normal consistency and in rind. I proved, that knowing the propagation velocity, meat-fat ratio in bacon and thickness of rind in winter salami can be calculated.
2. Based on the examinations in the different layers, I proved that logarithmic attenuation of ultrasonic waves is additive, that is, by summarizing the attenuations of individual layers the attenuation of the whole sample is obtained. On the basis of this finding, I developed a method for the estimation of thickness of layers in bacon and winter salami with unknown inner layer thickness by measuring the ultrasonic attenuation and sample thickness with the help of the data base containing the attenuation characteristics of the possible components in the sample.
3. Based on the investigations, I developed a method for the estimation of solids content in winter salami, and for the control of rind formation during ripening, by the measurement of both propagation velocity and attenuation of ultrasound. Measurement of propagation velocity or attenuation on its own is sufficient to monitor ripening, but accuracy of estimation can be increased by their combined use.
4. In the course of the application of ultrasound in curing technology I proved, that ultrasound increases the velocity of salt diffusion. By increasing the intensity of ultrasound, diffusion can be exponentially increased in the intensity range of 2-4 Wcm^{-2}. In the investigated intensity range of ultrasonic irradiation, diffusion coefficient (d, [m^2/s]) changes with intensity (I, [Wcm^{-2}]) according to the $d=2,7\cdot10^{-10}\cdot e^{0,477\cdot I}$ formula.
5. In meat pieced treated by ultrasound, texture is more uniform in the whole cross-section of meat, there is almost no difference between the firmness of outer and central layers. Analysing the effect of active ultrasound on the structure of meat, I proved that ultrasonic treatment loosens the structure of meat significantly, increases the space between myofibrilla by 2-3 times. Decided increase in the distances between fibres can be achieved already within 1,5 hours at 3-4 Wcm^{-2} intensity. As a result of more loose structure caused by ultrasound, salt diffusion and water uptake is more uniform within the sample.
6. I proved that after only 3-hour curing by 3 Wcm^{-2} intensity ultrasound, a salt concentration of 1,2% can be achived, that is close to the salt concentration in the central layer of tumbled meat. In meat pieces treated by ultrasound, layer by layer differences in salt concentration are more

equalized. Differences in salt concentration can be almost totally equalized within the meat samples by the application of 3 Wcm^{-2} intensity ultrasound during a 3-hour treatment, thus this method can be combined either with tumbling or curing by injection of curing solution, and in this way time of curing can be decreased.

7. Ultrasonic treatment increased the thickness of myofibrilla by 100 % because of the swelling effect of bound water. Maximal increase in fibre thickness can be achieved by 3-4 Wcm^{-2} intensity treatment in 1,5 hours. The loosening effect of ultrasound significantly increases water binding capacity of meat, but doesn't reach the value obtained by tumbling. Meat treated by ultrasound retains water in a higher extent, thus ultrasonic treatment decidedly increases water holding capacity.
8. In case of cooked ham, texture of hams became more tender as an effect of ultrasound, their chewiness was improved, which confirmed the loosening, technologically positive effect of ultrasound on muscle fibres. At the same time, mosaic character of the products was retained. Increase in the curing solution/meat ratio caused less changes in texture and water holding capacity of hams cured by ultrasound than in the ones cured by tumbling. Hams cured by ultrasound were less sensitive to the increase of added curing solution, thus ultrasonic curing technology improves yield.

List of Publications

Articles with impact factor

1. Friedrich L, Felföldi J, (2006) Ultrasonic Method for Monitoring of Meat Freezing Process, - Acta Alimentaria (2006) (elfogadva, megjelenés alatt)

2. L. Friedrich, I. Siró, Cs. Balla, I. Dalmadi, K. Horváth, R. Ágoston, (2007) Influence of various preservatives on the quality of minced beef under modified atmosphere at chilled storage, - Meat Science (2008) (elfogadva, megjelenés alatt)

3. L. Friedrich, E. Tuboly, K. Pásztor-Huszár, Cs. Balla, Cs. Vén (2008) Non-destructive measurement of rind thickness of dry sausage using ultrasound technique, - Acta Alimentaria 37. kötet 3. szám (2008) (elfogadva, megjelenés alatt)

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1. Friedrich László, Siró István, Balla Csaba (2006) Védőgázos csomagolású friss húsok optimális gázösszetételének meghatározása – a HÚS 2006/2, pp. 71-79.

2. Friedrich László, Vén Csilla, Balla Csaba (2007) Aktív ultrahang alkalmazása a pácolási technológiában – a HÚS 2007/1, pp. 71-79.

3. Vén Csilla, Friedrich László, Balla Csaba, Ittes Eliza, Tóth Krisztina (2007) A húsérés befolyásolása nagy intenzitású ultrahang alkalmazásával– a HÚS 2007/2, pp. 85-89.

Full conference publications (English)

1. Friedrich L, Felföldi J, (2004) Non-destructive quality control by ultrasonic method – Proc. of AgEng 2004 International Conference on Agricultural Engineering, Leuven, Paper number: pp. 7-15.

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Conference publications with summary (English)

1. László Friedrich and József Felföldi (2004) Monitoring of the Mechanical Structure of Meat Samples During Freezing – 6th International Conference on Food Physics and Dairy Sciences, Pécs, 2004, pp. 32-33.

2. Friedrich L, Siró I, Balla Cs, (2005) Influence of Modified Atmosphere Packaging (MAP) and Storage Temperature on Microbial Quality of Fresh Meat – Chemical Engineering Mathematics, Budapest, pp. 29.

3. Kinga Horváth, Éva Andrássy, Margit Korbász, Judit Beczner, József Farkas, László Friedrich, (2006) The Use of automatic impedimetry for monitoring spoilage bacteria on chilled pork cutlets – FoodMicro 2006, Bologna, pp. 540.

4. József Farkas, Zsolt Seregély, István Dalmadi, Kinga Horváth, Éva Andrássy, László Friedrich (2006) Chemometric evaluation of elektronic nose measurements for bacterological spoilage assessment of refrigerated pork meat – FoodMicro 2006, Bologna, pp. 563.

5. L. Friedrich, E. Tuboly, I. Siró, I. Dalmadi and Cs. Balla, (2006) Changes in Physico-chemical characteristic of fish-meat under different storage temperatures and packaging conditions – 3rd Central European Congress on Food, Sofia 2006, pp.122.

6. L. Friedrich, Cs. Vén, E. Tuboly and Cs. Balla, (2006) Effect of ultrasound on the diffusion process rate during curing of longissimus dorsi - 3rd Central European Congress on Food, Sofia 2006, pp.123.

7. L. Friedrich, E. Tuboly, K. Huszár and Cs. Balla, (2006) Non-destructíve measurement of the callus sausage by using an ultrasound technique - 3rd Central European Congress on Food, Sofia 2006, pp.124.

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1. Friedrich L. és Felföldi J. (1999) Szalonnák hús - zsír arányának meghatározása ultrahangos módszerrel – XXIV. Országos Tudományos Diákköri Konferencia Agrártudományi Szekció, Gyöngyös, I. Kötet, pp. 196-197.

2. Friedrich L. és Felföldi J. (2002) Ultrahangos állománymérési módszer húsok fagyasztásának követésére – MTA Agrár Műszaki Bizottsága, Kutatási és Fejlesztési Tanácskozás, Gödöllő, pp. 37.

3. Friedrich L. és Felföldi J. (2003) Fagyasztás közbeni állományváltozás követése ultrahangos módszerrel – "Lippay János – Ormos Imre – Vas Károly" Tudományos Ülésszak, Budapest, pp. 220-221.

4. Friedrich L., Siró I. és Balla Cs. (2005) Friss húsok színváltozásának dinamikája a tárolási hőmérséklet és a védőgáz összetétel függvényében - "Lippay János – Ormos Imre – Vas Károly" Tudományos Ülésszak, Budapest, pp. 66-67.

5. Horváth Kinga, Andrássy Éva, Korbász Margit, Beczner Judit, Farkas József, Friedrich László, (2006) Baktériumok sertéshúson szaporodásának nyomon követése automatikus impedimetriával – KÉKI - MTA Élelmiszertudomány – MÉTE 324. Tudományos Kollokvium, pp. 296.

6. Horváth Kinga, Seregély Zsolt, Dalmadi István, Andrássy Éva, Farkas József, Friedrich László, (2007) Baktériumos romlás becslése szeletelt sertés húson gyors módszerekkel – "Lippay János – Ormos Imre – Vas Károly" Tudományos Ülésszak, Budapest, pp. 58-59.

7. Friedrich L., Vén Cs., Balla Cs., Hanula- Kövér Gabriella, Jónás Gábor, (2007) Aktív ultrahang alkalmazása a pácolási technológiában - "Lippay János – Ormos Imre – Vas Károly" Tudományos Ülésszak, Budapest, pp. 122-123.

8. Balla Cs., Friedrich L., Vén Cs., Hanula- Kövér Gabriella, (2007) Áruházi hűtőpultok új módszerekkel történő hőmérséklet-monitorozása térben és időben - "Lippay János – Ormos Imre – Vas Károly" Tudományos Ülésszak, Budapest, pp. 124-125.

9. Vén Cs., Friedrich L., Balla Cs., Ittes Eliza, Tóth Krisztina, (2007) A marhahús érlelése aktív ultrahang alkalmazásával - "Lippay János – Ormos Imre – Vas Károly" Tudományos Ülésszak, Budapest, pp. 134-135.

Book

1. Friedrich László (2006) MAP (Módosított atmoszférás csomagolású) hús- és baromfiipari termékek eltarthatósági idejének növelése; in: Pásztorné Huszár Klára és Kiss István Minőségkímélő élelmiszertechnológiák és élelmiszer-biztonság, Budapesti Corvinus Egyetem Élelmiszertudományi Kara és a Mezőgazda Kiadó kiadása. p. 43-49.

2. Friedrich László (2006) Húsok színváltozásának alakulása a gázösszetétel függvényében; in: Pásztorné Huszár Klára és Kiss István Minőségkímélő élelmiszertechnológiák és élelmiszer-biztonság, Budapesti Corvinus Egyetem Élelmiszertudományi Kara és a Mezőgazda Kiadó kiadása. p. 80-82.

3. Friedrich László (2007) Módosított atmoszférás csomagolású hús- és baromfiipari termékek eltarthatósági idejének növelése; in: Balla Csaba és Siró István Élelmiszer-biztonság és minőség II., Élelmiszertechnológiák, Mezőgazda Kiadó kiadása. p. 117-123.

4. Friedrich László (2007) Húsok színváltozásának alakulása a gázösszetétel függvényében; in: Balla Csaba és Siró István Élelmiszer-biztonság és minőség II. , Élelmiszertechnológiák, Mezőgazda Kiadó kiadása. p. 150-152.

Manager of scientific innovation project

1. Friedrich L., Balla Cs., Vén Cs., (2006) Új pácolási technológia fejlesztése és alkalmazása a páclé diffúziója növelésére a termék állományának és anyagkihozatalának javítására
2. Friedrich L., Balla Cs., Horváth K., (2006) Előhűtött nyers darált marhahús eltarthatóságának növelése kombinált tartósítási módszerekkel
3. Friedrich L., Balla Cs., Vén Cs., (2006) Marhahús érlelésének innovatív fejlesztése új érlelési technológia kidolgozása

Member of scientific innovation project

1. Nyers pulyka (alsó, felső comb, felső comb filé és szárny) termékek csomagolásának vizsgálata az elszíneződés és a romlási folyamatok csökkentése érdekében
2. Nyers pulyka (alsó, felső comb, felső comb filé és szárny) termékek csomagolásának vizsgálata az elszíneződés és a romlási folyamatok csökkentése érdekében
3. Darált marhahúsok csomagolástechnológiájának és eltarthatóságának vizsgálata (Gazdaságos, Standard, Fitt) tárolási próbával egybekötve 0-2 és 5°C-on
4. Előhűtött ponty és busa védőgázos és vákuumos technológiával összehasonlítva csomagolásának vizsgálata a jegeléses tárolási
5. Védőgázos csomagolású feldolgozott húskészítmények optimális gázösszetételének meghatározása
6. Vákuumos csomagolású friss húsok esetén a csontos részek okozta vákuumhiba minimalizálása
7. Friss húsok vákuumcsomagolása esetén a lékiválást minimalizáló anyag/technológia kidolgozása
8. Védőgázos csomagolású friss húsok optimális gázösszetételének meghatározása
9. Különböző zsírtartalmú darált marhahúsok eltarthatóságának növelése védőgáz és adalékanyagok felhasználásával
10. Friss nagydarabos húsok vákuumcsomagolása esetén a lékiválást minimalizáló anyag/technológia kidolgozása
11. Fluoreszcencia módszerének alkalmazástechnikai kutatása és fejlesztése friss húsok és sajtok minőségi jellemzőinek és minőségváltozásának meghatározására
12. Védőgázos csomagolású darált pulyka felsőcomb avasodási mértékének csökkentése adalékanyagok és csomagolóanyagok felhasználásával
13. Jégpelyhen tárolt ponty és busa szelet vizsgálata különböző tárolási körülmények között
14. Hűtő- és fagyasztó pultok, ill. szigetek hőkamerás feltérképezése

15. Hűtőlánc élelmiszerbiztonsági feltételeinek innovatív fejlesztése a hűtött élelmiszerek idő- és térbeli hőmérsékletprofiljának monitorozása
16. Előhűtött csomagolt és csomagolatlan sertés húsok hőmérséklet változásának vizsgálata különböző tartózkodási hőmérsékleteken (12 és 20°C)
17. Sütőkemence hőmérséklet-eloszlásának feltérképezése termoelem és hőkamera alkalmazásával
18. Közeli infravörös spektroszkópia (NIR) módszerének alkalmazástechnikai kutatása és fejlesztése friss húsok minőségi jellemzőinek és minőségváltozásának meghatározására
19. Savanyított tejszínkészítmény (tejföl) termékpoziciónálása
20. Hűtött és fagyasztott termékek élelmiszerbiztonsági feltételeinek fejlesztése élelmiszerek infravörös hőmérsékleti a kereskedelmi hűtőbútorokban lévő Monitorozásával
21. Édesvízi halak szállíthatósági és forgalmazási paramétereinek kidolgozása
22. Közeli infravörös spektroszkópia (NIR) módszerének alkalmazástechnikai kutatása és fejlesztése friss húsok minőségi jellemzőinek és minőségváltozásának meghatározására
23. Savanyított tejszínkészítmény (tejföl) termék- pozícionálása
24. Hűtött és fagyasztott élelmiszerek élelmiszerbiztonsági feltételeinek innovatív fejlesztése a kereskedelmi hűtőbútorokban lévő élelmiszerek térbeli hőmérsékletprofiljának termokamerás monitorozásával
25. Nagy nedvességtartalmú növényi termékek nyitott polcon történő gyors fonnyadását gátló technológia és technika kutatása, alkalmazás-technológiai fejlesztése
26. Védőgázos csomagolású nyers baromfi húsok eltarthatósági idő- gázösszetétel-hőmérséklet kapcsolat meghatározása az eltarthatósági idő és az élelmiszerbiztonság növelése céljából
27. Hűtött és fagyasztott élelmiszerek élelmiszerbiztonsági feltételeinek innovatív fejlesztése a kereskedelmi hűtőbútorokban lévő élelmiszerek térbeli hőmérsékletprofiljának termokamerás monitorozásával
28. Hűtőlánc élelmiszerbiztonsági feltételeinek innovatív fejlesztése a hűtött élelmiszerek idő- és térbeli hőmérsékletprofiljának monitorozásával
29. Hűtőlánc élelmiszerbiztonsági feltételeinek innovatív fejlesztése a hűtött élelmiszerek idő- és térbeli hőmérsékletprofiljának monitorozásával
30. Csomagolás nélküli előhűtött húsok, húskészítmények és saláták hűtőpulti tárolási módjának innovatív fejlesztése a fizikai és mikrobiológiai állapotjellemzők javítására
31. Mono- és polipropilén tálcák összehasonlítása sertés és marhahúsok fizikai, kémiai és mikrobiológiai állapotának, valamint a tálcák gázzáró képességének tekintetében
32. Világítótestek hősugárzásának hatása a termékek felületi hőmérsékletére
33. Védőgázos darált marhahúsminták védőgáz összetételének és mikrobiológiai állapotának vizsgálata
34. Hűtött élelmiszerek melegedésének vizsgálata a környezeti hőmérséklet függvényében II.
35. Hűtött élelmiszerek melegedésének vizsgálata a környezeti hőmérséklet függvényében III.
36. Hűtött élelmiszerek melegedésének vizsgálata a környezeti hőmérséklet függvényében IV.
37. Pulyka kábításának innovatív fejlesztése, paramétereinek optimálása a kábultság és a húsminőség tekintetében

38. Hűtött és fagyasztott élelmiszerek élelmiszerbiztonsági feltételeinek innovatív fejlesztése a háttérhűtőkben tárolt élelmiszerek térbeli hőmérsékletprofiljának termokamerás monitorozásával
39. Hűtött termékek élelmiszerbiztonsági feltételeinek innovatív fejlesztése a kereskedelmi hűtőlánc elemei idő- hőmérsékletprofiljának rádiófrekvenciás monitorozásával
40. Hűtött és fagyasztott élelmiszerek élelmiszerbiztonsági feltételeinek innovatív fejlesztése a háttérhűtőkben tárolt élelmiszerek térbeli hőmérsékletprofiljának termokamerás monitorozásával
41. Hűtött és fagyasztott élelmiszerek élelmiszerbiztonsági feltételeinek innovatív fejlesztése a kereskedelmi hűtőláncban lévő élelmiszerek idő- és térbeli hőmérsékletprofiljának hőmérsékletregisztráló rádiófrekvenciás mérőkártyás monitorozásával