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Use of ultrasound and acerola (*Malpighia emarginata*) residue extract in meat pork

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Abstract

Consumers are more demanding in relation to meat quality, developing new demands, such as increased shelf life and good sensory quality. The tenderness of the meat is one of the most important elements in the choice of the product, the modification in the intrinsic structure of the meat, for example, increase of the proteolysis and fragmentation of the myofibrils contribute to the improvement of the tenderness. However, it is necessary to develop technological strategies so that this ultrasound technology can be added to improve meat tenderness. Thus, the objective of this review was to know the main aspects of the use of ultrasound and acerola residue in meat tenderness. Overall, existing research demonstrates excellent prospects for this new redesign approach.

Keywords: ultrasound; meat quality; natural antioxidant; *malpighia emarginata*; oxidation; texture.

Practical Application: Marination and ultrasound cause the muscle fibers to break and thus provide better penetration of added liquids.

1 Introduction

Consumers are more demanding in relation to meat quality, developing new demands, such as increased shelf life and good sensory quality (Lima et al., 2022). The tenderness of the meat is one of the most important elements in the choice of the product, the modification in the intrinsic structure of the meat, for example, increased proteolysis and fragmentation of the myofibrils contribute to the improvement of tenderness (Alarcon-Rojo et al., 2019; Xiong et al., 2020; Arruda et al., 2021; Araújo et al., 2022).

There are techniques that cause changes in the physical structure of the meat, providing tenderization (chemical, mechanical and enzymatic) (Araújo et al., 2022). Among the techniques highlighted in the literature are marination by immersion, injection and use of equipment such as tambler. However, innovative techniques that are considered emerging are being investigated by researchers, such as the use of ultrasonic waves and their combination with marination technology (Alarcon-Rojo et al., 2019).

The application of ultrasonic waves in meat generates the formation of cavitations caused by a vibrational sound energy within the system, where small collapses in the intrinsic structure occur, contributing to the degradation of proteins and removal of fibers (Amiri et al., 2018).

Research shows that depending on the time and intensity of ultrasound in the meat, myofibrils in the Z line, datroponin and myosin denaturation can occur, contributing to the tenderization and improving the penetration of liquids in the marination process (Yeung & Huang, 2017; Amiri et al., 2018; Wang et al., 2018; Alarcon-Rojo et al., 2019; Xiong et al., 2020).

In combination with marination, ultrasound causes the muscle fibers to break and thus provides better penetration of added liquids. In this context, the penetration between the fibers occurs more efficiently, leading to an improvement in the dispersion of the liquid in the meat (Alarcon-Rojo et al., 2019). The liquids used for marination commonly contain substances that lead to the proteolytic action of the meat, however, in sum, this liquid can be a source of compounds that provide other benefits to the quality of the product, such as antioxidant action. (Rezende et al., 2018).

Antioxidants can be both synthetic and natural. However, studies have been developed in search of the application of natural antioxidants, since the use of synthetic antioxidants may be associated with the triggering of chronic diseases in the consumer (Silva et al., 2009). In this sense, several studies have been engaged in the search for natural antioxidants from plants and fruit residues (Barbosa-Pereira et al., 2014; Guerra-Rivas et al., 2016; Chauhan et al., 2019; Domínguez et al., 2020).

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Acerola (Malpighia emarginata) is a fruit widely consumed in the world and with great economic value in Brazil, recognized for being a good source of vitamin C, phenolic compounds, flavonoids and anthocyanins, where they have antioxidant potential (Silva et al., 2019). Rezende et al. (2018) indicate that residues from fruits have antioxidant potential, being an alternative in the reuse of residues and in the replacement of synthetic antioxidants (Araújo et al., 2022). Thus, the objective of this review was to know the main aspects of the use of ultrasound and acerola residue in meat tenderness.

2 Pork meat

The swine production chain is one of the most widespread activities and of great socioeconomic importance in the world. In 2021, the total volume of pork produced in the world was 112.200 million tons, of which about 4,701 million tons represented Brazilian production. Between 2020 and 2021, there was an 11.03% increase in Brazilian pork production, remaining fourth in the world ranking of production and exports. Per capita consumption exceeded 15.30 kilos per inhabitant/year (Associação Brasileira de Proteina Animal, 2021).

In 2019, Brazil had the highest rates of pork exports so far (750 thousand tons), of this amount, 85.71% was exported in the form of cuts, 9.72% of offal, 1.53% of preparations, 1.41% of sausages, 0.84% of carcasses, 0.51% of fat, 0.26% of tripe, 0.02% of salted and 0.001% of hides and skins (Associação Brasileira de Proteina Animal, 2021). When compared with the results presented in the previous year, only salted products, hides and skins had a drop in values exported while the others had an increase in exports. Even with high export values, this only represented 19% of annual production, so the domestic market absorbed the largest amount of production with 81% (Associação Brasileira de Proteina Animal, 2021).

Pork is recognized for being a food with an optimal distribution of essential compounds that perform important functions for the body, such as the construction and maintenance of tissues. Proving to be an excellent source of essential amino acids, vitamins, minerals and lipids (Silva et al., 2015). Among these nutrients, fat is a determining factor in meat quality and consumer choice. On the other hand, fat is a limiting factor in triggering lipid oxidation (Shah et al., 2014).

3 Lipid oxidation in meat

Lipid oxidation in meat is one of the factors that most influence the quality of the product, changing characteristics such as aroma, flavor, texture, color and chemical composition (Amaral et al., 2018; Domínguez et al., 2019). In addition to the sensory and chemical changes in meat, oxidative rancidity contributes to the production of toxic compounds to the body, such as malonaldehyde and cholesterol oxides (Estévez, 2021).

The main targets of lipid oxidation in meat are the polyunsaturated fatty acids present in the phospholipids of cell membranes. However, there are factors that accelerate the oxidation process, such as the type of fatty acid, temperature, exposure to light, oxygen and metals, considered pro-oxidant agents (Leal-Castañeda et al., 2017).

The oxidation process is divided into initiation, propagation and termination phases. Initially (initiation), the integration of triplet oxygen and light forms singlet oxygen. Singlet oxygen is highly oxidative when compared to molecular oxygen (triplet), after its activation, it removes a hydrogen molecule from the methyl group of an unsaturated fatty acid, promoting the formation of the first extremely unstable free radical (Masuda et al., 2010).

Propagation occurs through the reaction of free radicals with fatty acids and oxygen, forming peroxides and hydroperoxides. After the free radicals cease, the products of the second phase begin to decompose (termination) into secondary products: alcohols, ketones, aldehydes, hydrocarbons and esters. These compounds are responsible for altering the characteristic rancid odor, taste, and texture (Li et al., 2015).

Pork is more susceptible to lipid oxidation because it has a greater amount of unsaturated fatty acids in its chemical constitution when compared to beef, goat and sheep. It is important to emphasize that unsaturated fatty acids are more unstable and vulnerable to lipid oxidation because they have an odd amount of electrons in their structure, making them susceptible to being captured by another molecule (Amaral et al., 2018).

In this sense, antioxidants act in the neutralization of free radicals, donating hydrogen molecules and stabilizing them. On the other hand, some antioxidants act by inhibiting pro-oxidant agents, delaying lipid oxidation (Kodali et al., 2020).

However, synthetic antioxidants, the most used in the food industry, have been reported as a possible precursor of cancerous diseases, in exacerbated use (Silva et al., 2009). Studies indicate that plants, fruits and agro-industrial residues may contain bioactive substances capable of presenting antioxidant activity and replacing synthetic additives (Amaral et al., 2018).

4 Acerola agro-industrial waste

Acerola (Malpighia emarginata) is a fruit native to North and Central America, belonging to the Malpighiaceae family. Brazil is the main producer in the world, the fruit has a pleasant flavor and a high content of vitamin C (Xu et al., 2020). Due to its perishability, the process of harvesting and processing the fruit is very fast, the acerola can be consumed in natura, in jellies, juices, juices, etc (Malegori et al., 2017). According to Silva et al. (2019) acerola contains bioactive compounds such as phenolics, vitamin C and anthocyanins, substances that have antioxidant properties and can replace synthetic antioxidants.

The population increase and the demand for food in the world is a major challenge, the United Nations Food and Agriculture Organization (FAO) indicates that by 2050 the world will have to increase its production by 60% to meet the population, consequently, greater production of agro-industrial waste (Saath & Fachinello, 2018). Rezende et al. (2018) suggests that some agro-industrial residues from fruit pulping are rich sources of phenolic compounds and possibly antioxidants. Arabine-rich polysaccharides found in the acerola pulping residue showed antioxidant activity (Malegori et al., 2017).

Considering that a lipidic oxidação is um dos principais fatores na redução da vida de prateleira das carnes and o reaproveitazione de resíduos agroindustriais é uma matéria-first alternative na produção de extratos com atividade antioxidante. A application of extratos antioxidantes naturais auxiliados por ondas ultrassônicas em superfícies de flesh can increase a preservative oxidative and interact with micro-extruture from meat. Araújo et al. (2022) concluiram que a aplicação de ultra-som à carne (170 W, 35 kHz) in time of 5 and 10 minutes combined with marinating with a natural antioxidant extracted from acerola residue improves the quality characteristics, decreasing to hardness and to chewability.

5 Ultrasound principles

The technology of application of ultrasonic waves is widely studied and discussed in several areas (Demirci, et al., 2022; Liao et al., 2022; Monteiro et al., 2022) , in recent years ultrasound has become an alternative for improvement in food technology in the processes of marination, freezing, drying, emulsification, inactivation of microorganisms, softening of meats and improved pasta switching (Araújo et al., 2022; Demirci et al., 2022; Liao et al., 2022; Monteiro et al., 2022).

Precisely ultrasound is energy generated by sound waves, where its frequency strength is given in kHz, within an ultrasound system mechanical energy is transformed into vibrational energy, part of this energy is lost in heat exchange and the other fraction contributes in the formation of cavitations. Cavitations within the matrix generate small collapses causing chemical, physical and biological changes (Alarcon-Rojo et al., 2015).

Ultrasound is divided into frequency and intensity categories: high frequency (2-20 MHz) and low intensity (<1 W cm-2) waves do not have enough energy to cause changes, normally used in non-invasive image analysis and composition (Alves et al., 2013) and waves of low frequency (20-100 kHz) and high power (10-1000 W cm-2) can form cavitations that allow modifications in the contact matrix (Piyasena et al., 2003).

There are three ways to apply ultrasound in products: direct application, coupled to the device and immersion in an ultrasound bath (Chemat et al., 2011). The form of ultrasound application directly influences the cavitations, the ultrasonic bath is considered an indirect application, where the ultrasonic wave first crosses the liquid contained inside the equipment to later cross the sample wall. A disadvantage is the loss of energy by the liquid, however, the direct application generates a greater cavitational intensity being a positive point depending on the food, a negative point is the greater exposure to microbiological contamination and losses of volatile compounds (Chemat et al., 2011; Singla & Sit, 2021).

5.1 Effect of ultrasound on meat

The use of ultrasound in meat began in the 1950s, with the objective of evaluating the percentage of fat in the live animal. However, in the last decades the application of ultrasonic waves has been growing in order to improve the quality of the meat in attributes such as flavor, tenderness and improvement in the penetration of pasta. Table 1 shows studies from the last few years that demonstrate the potential for using ultrasound in meat.

Most of these studies focus on the application of ultrasound to improve tenderness, water and salt dynamics in meat and assist in marinating. However the form of application, frequency, intensity and time of application are highly variable, studies indicate promising ultrasound technology in the meat industry (Stadnik et al., 2008; Li et al., 2015; Araújo et al., 2022) with positive effects up to a certain time (Ojha et al., 2016) but emphasize the need for further studies, especially when the ultrasound effect interacts with other variables in the meat.

5.2 Modifications caused by the application of ultrasound

Several studies using ultrasound on meats agree that within time (33 seconds to 90 minutes), frequency (15 to 130 kHz) and

Table 1. Studies with the application of ultrasound in meat.

Meat	Intensity/frequency/time	Ultrasound effect on meat	Reference
Pork	1MHz, 150w and 25kHz, 500w for 40 minutes	The application of ultrasound and actinidia decreased the shear force.	Jørgensen et al. (2008)
Bovine	2 W cm^{-2}, 5 kHz, 120 seconds	Reduced shear force and decreased rigor mortis time	Stadnik et al. (2008)
Pork	40 kHz; 37.5 W/dm^3	Increased penetration of salt into meat	Ozuna et al. (2013)
Pork	0.2 Wcm^{-2} and 0.4 W cm^{-2}, 25 kHz	Decreased freezing time without physicochemical changes	Gambuteanu & Petru (2013)
Pork	0, 40, 56, 72 W/cm^{-2}, 34–40 kHz, (2, 4, 6 hours)	Better dough exchange in salting without modifying sensory atributes	McDonnell et al. (2014)
Chicken	300 W, 40 kHz on time (10, 20, 30 and 40 minutes)	After 10 minutes of ultrasound, the hardness decreased, improving the texture.	Li et al. (2015)
Pork	54.9 W cm2, 20 kHz in time (90 and 120 minutes)	In 90 minutes of ultrasound there was a better mass exchange with the brine, after 120 minutes the water holding capacity decreased.	Ojha et al. (2016)
Pork	2200 W, 15 kHz on time (0, 0.5, 1, 2, 3, 4 and 6 minutes)	After 6 minutes of treatment there was a decrease in hardness	Yeung & Huang (2017)
Bovine	11 W cm2 40 kHz in time (0, 40, 60 and 80 minutes)	The application of ultrasound (from 40 minutes) on the seventh day of storage improved the tenderness of both muscles	Gonzalez-Gonzalez et al. (2020)

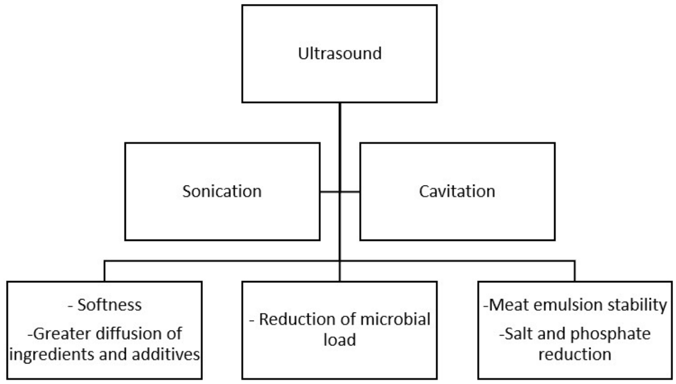

Figure 1. Schematic illustration of the main effects of ultrasound on meat and meat products. Adapted (Câmara, 2021).

intensity (1.89 to 64 W cm2) there is an improvement in meat tenderness (37, 39, 60, 61).

The application of ultrasound in meats triggers positive intrinsic effects, combined with other technologies or applied alone. Depending on the intensity, it promotes the rupture of the myofibril in the z line, degraded to troponin and denatured to myosin. On the other hand, the application of ultrasound favors an increase in the activity of enzymes, such as calpains, which modify the internal structures of the meat and contribute to tenderization (Yeung & Huang, 2017; Amiri et al., 2018; Wang et al., 2018; Alarcon Rojo et al., 2019).

The water holding capacity, leakage and cooking loss are quite variable, (Kang et al., 2017; Wang et al., 2018) in a study with high-intensity ultrasound applied during the meat brine process observed an increase in ability to retain water and a decrease in leakage and cooking loss, however (Gómez-Salazar et al., 2018) in a study with rabbit meat 2.25 W/cm^2 for 20 minutes observed a decrease in water holding capacity and increased exudation loss. This variability can be attributed to the type of ultrasound application, frequency, intensity, different application times, type of muscles and animal.

Color is an attribute of great importance when choosing meat, meat consumers make a direct link between bright red color and quality. Sikes et al. (2014) in research observed that the temperature generated by the application of ultrasound was not sufficient to denature proteins and pigments. On the other hand, at the intensity (22 W/cm^2) there was a decrease in the red color when compared to the control treatment (Stadnik & Dolatowski, 2011).

The applications of ultrasound are numerous and, especially in the last decade, they have been reviewed by researchers and professionals in the field, both alone and in combination with other methods, for uses ranging from improving quality attributes such as softness, modifying functional properties of proteins, restructuring of meat products, increase in shelf life and yield and reduction of sodium chloride (Figure 1).

6 Conclusion

The application of ultrasound favors the modification of important parameters in meat, however, its use as a facilitator in the penetration of antioxidant extracts is little studied. Therefore, it is a viable strategy to help the application of natural antioxidant extract of acerola in pork, improving its penetration and consequently the shelf life of the product.

References

Alarcon-Rojo, A. D., Carrillo-Lopez, L. M., Reyes-Villagrana, R., Huerta-Jiménez, M., & Garcia-Galicia, I. A.. (2019). Ultrasound and meat quality: a review. *Ultrasonics Sonochemistry*, 55, 369-382. http://dx.doi.org/10.1016/j.ultsonch.2018.09.016. PMid:31027999.

Alarcon-Rojo, A. D., Janacua, H., Rodriguez, J. C., Paniwnyk, L., & Mason, T. J. (2015). Power ultrasound in meat processing. *Meat Science*, 107, 86-93. http://dx.doi.org/10.1016/j.meatsci.2015.04.015. PMid:25974043.

Alves, L. L., Cichoski, A. J., Barin, J. S., Rampelotto, C., & Durante, E. C. (2013). O ultrassom no amaciamento de carne. *Ciência Rural*, 43(8), 1522-1528. http://dx.doi.org/10.1590/S0103-84782013000800029.

Amaral, A. B., Silva, M. V., & Lannes, S. C. S. (2018). Lipid oxidation in meat: mechanisms and protective factors – a review. *Food Science and Technology (Campinas)*, 38(suppl 1), 1-15. http://dx.doi.org/10.1590/fst.32518.

Amiri, A., Sharifian, P., & Soltanizadeh, N. (2018). Application of ultrasound treatment for improving the physicochemical, functional and rheological properties of myofibrillar proteins. *International Journal of Biological Macromolecules*, 111, 139-147. http://dx.doi.org/10.1016/j.ijbiomac.2017.12.167. PMid:29307807.

Araújo, C. D. L., Silva, G. F. G., Almeida, J. L. S., Ribeiro, N. L., Pascoal, L. A. F., Silva, F. A. P., Ferreira, V. C. S., & Martins, T. D. D. (2022). Use of ultrasound and acerola (*Malphigia emarginata)* residue extrac tenderness and lipid oxidation of pork meat. *Food Science and Technology (Campinas)*, 42, e66321. http://dx.doi.org/10.1590/fst.66321.

Arruda, T. R., Vieira, P., Silva, B. M., Freitas, T. D., Amaral, A. J. B., Vieira, E. N. R., & Leite Júnior, B. R. C. (2021). What are the prospects for ultrasound technology in food processing? An update on the main effects on different food matrices, drawbacks, and applications. *Journal of Food Process Engineering*, 44(11), e13872. http://dx.doi.org/10.1111/jfpe.13872.

Associação Brasileira de Proteina Animal – ABPA. (2021). *Central de inteligência de aves e suínos*. Retrieved from https://www.embrapa.br/suinos-e-aves/cias/estatisticas

Barbosa-Pereira, L., Aurrekoetxea, G. P., Angulo, I., Paseiro-Losada, P., & Cruz, J. M. (2014). Development of new active packaging films coated with natural phenolic compounds to improve the oxidative stability of beef. *Meat Science*, 97(2), 249-254. http://dx.doi.org/10.1016/j.meatsci.2014.02.006. PMid:24598072.

Câmara, A. K. F. I. (2021). *O uso do ultrassom como coadjuvante tecnológico na indústria cárnea*. Food Connection. Retrieved from https://www.foodconnection.com.br/especialistas/o-uso-do-ultrassom-como-coadjuvante-tecnologico-na-industria-carnea

Chauhan, P., Pradhan, S. R., Das, A., Nanda, P. K., Bandyopadhyay, S., & Das, A. K. (2019). Inhibition of lipid and protein oxidation in raw ground pork by Terminalia arjuna fruit extract during refrigerated storage. *Asian-Australasian Journal of Animal Sciences*, 32(2), 265-273. https://doi.org/10.5713/ajas.17.0882.

Chemat, F., Zill-e-Huma, & Khan, M. K. (2011). Application of ultrasound in food technology: Processing, preservation and extraction. *Ultrasonics Sonochemistry*, 18(4), 813-835. http://dx.doi.org/10.1016/j.ultsonch.2010.11.023. PMid:21216174.

Demirci, M., Tomas, M., Tekin-Çakmak, Z. H., & Karasu, S. (2022). *Berberis crataegina* DC as a novel natural food colorant source: ultrasound -assited extraction optimization using response surface methodology and thermal stability studies. *Food Science and Technology (Campinas)*, 42, e03421. http://dx.doi.org/10.1590/fst.13421.

Domínguez, R., Gullón, P., Pateiro, M., Munekata, P. E. S., Zhang, W., & Lorenzo, M. (2020). Tomato as potential source of natural additives for meat industry. A review. *Antioxidants*, 9(1), 73. http://dx.doi.org/10.3390/antiox9010073. PMid:31952111.

Domínguez, R., Pateiro, M., Gagaoua, M., Barba, F. J., Zhang, W., & Lorenzo, J. M. (2019). A comprehensive review on lipid oxidation in meat and meat products. *Antioxidants*, 8(10), 429. http://dx.doi.org/10.3390/antiox8100429. PMid:31557858.

Estévez, M. (2021). Critical overview of the use of plant antioxidants in the meat industry: opportunities, innovative applications and future perspectives. *Meat Science*, 181, 108610. http://dx.doi.org/10.1016/j.meatsci.2021.108610. PMid:34147961.

Gambuteanu, C., & Petru, A. (2013). Effects of ultrasound assisted thawing on microbiological, chemical and technological properties of unpackaged pork longissimus dorsi. *AUDJG Food Technology*, 37, 98-107.

Gómez-Salazar, J. A., Ochoa-Montes, D. A., Cerón-García, A., Ozuna, C., & Sosa-Morales, M. E. (2018). Effect of acid marination assisted by power ultrasound on the quality of rabbit meat. *Journal of Food Quality*, 2018, 1-6. http://dx.doi.org/10.1155/2018/5754930.

Gonzalez-Gonzalez, L., Alarcon-Rojo, A. D., Carrillo-Lopez, L. M., Garcia-Galicia, I. A., Huerta-Jimenez, M., & Paniwnyk, L. (2020). Does ultrasound equally improve the quality of beef? An insight into longissimus lumborum, infraspinatus and cleidooccipitalis. *Meat Science*, 160, 107963. http://dx.doi.org/10.1016/j.meatsci.2019.107963. PMid:31693966.

Guerra-Rivas, C., Vieira, C., Rubio, B., Martínez, B., Gallardo, B., Mantecón, A. R., Lavín, P., & Manso, T. (2016). Effects of grape pomace in growing lamb diets compared with vitamin E and grape seed extract on meat shelf life. *Meat Science*, 116, 221-229. http://dx.doi.org/10.1016/j.meatsci.2016.02.022. PMid:26908145.

Jørgensen, A. S., Christensen, M., & Ertbjerg, P. (2008). Marination with kiwifruit powder followed by power ultrasound tenderizes porcine M. biceps femoris. In *International Conference of Meat Science and Technology 2008. International Congress of Meat Science and Technology (ICoMST)*. Amsterdam: Elsevier.

Kang, D. C., Gao, X. Q., Ge, Q. F., Zhou, G. H., & Zhang, W. G. (2017). Effects of ultrasound on the beef structure and water distribution during curing through protein degradation and modification. *Ultrasonics Sonochemistry*, 38, 317-325. http://dx.doi.org/10.1016/j.ultsonch.2017.03.026. PMid:28633832.

Kodali, S. T., Kauffman, P., Kotha, S. R., Yenigalla, A., Veeraraghavan, R., Pannu, S. R., Hund, T. J., Satoskar, A. R., McDaniel, J. C., Maddipati, R. K., & Parinandi, N. L. (2020). Oxidative lipidomics: analysis of oxidized lipids and lipid peroxidation in biological systems with relevance to health and disease. In L. Berliner & N. Parinandi (Eds.), *Measuring oxidants and oxidative stress in biological systems. Biological magnetic resonance* (Vol. 34). Cham: Springer. https://doi.org/10.1007/978-3-030-47318-1_5.

Leal-Castañeda, E. J., Hernández-Becerra, J. A., Rodríguez Estrada, M. T., & García, H. S. (2017). Formation of cholesterol oxides in lipid medium during microwave heating. *European Journal of Lipid Science and Technology*, 118(4), 1-13.

Li, K., Kang, Z. L., Zou, Y. F., Xu, X. L., & Zhou, G. H. (2015). Effect of ultrasound treatment on functional properties of reduced-salt chicken breast meat batter. *Journal of Food Science and Technology*, 52(5), 2622-2633. http://dx.doi.org/10.1007/s13197-014-1356-0. PMid:25892760.

Liao, J., Xue, H., Li, J., & Peng, L. (2022). Effects of ultrasound frequency and process variables of modified ultrasound-assisted extraction on the extraction of anthocyanin from strawberry fruit. *Food Science and Technology (Campinas)*, 42, e20922. http://dx.doi.org/10.1590/fst.20922.

Lima, C. Q., Becker, J., Steinbach, J., Burgardt, V. C. F., Machado-Lunkes, A., Marchi, J. F., Cislaghi, F. P. C., & Mitterer-Daltoé, M. L. (2022). Understanding the sensory profile of cheese ripeness description by trained and unt5rained assessor. *Food Science and Technology (Campinas)*, 42, e09922. http://dx.doi.org/10.1590/fst.09922.

Malegori, C., Nascimento Marques, E. J., de Freitas, S. T., Pimentel, M. F., Pasquini, C., & Casiraghi, E. (2017). Comparing the analytical performances of Micro-NIR and FT-NIR spectrometers in the evaluation of acerola fruit quality, using PLS and SVM regression algorithms. *Talanta*, 165, 112-116. http://dx.doi.org/10.1016/j.talanta.2016.12.035. PMid:28153229.

Masuda, T., Akiyama, J., Fujimoto, A., Yamauchi, S., Maekawa, T., & Sone, Y. (2010). Antioxidation reaction mechanism studies of phenolic lignans, identification of antioxidation products of secoisolariciresinol from lipid oxidation. *Food Chemistry*, 123(2), 442-450. http://dx.doi.org/10.1016/j.foodchem.2010.04.065.

McDonnell, C. K., Allen, P., Morin, C., & Lyng, J. G. (2014). The effect of ultrasonic salting on protein and water–protein interactions in meat. *Food Chemistry*, 147, 245-251. http://dx.doi.org/10.1016/j.foodchem.2013.09.125. PMid:24206713.

Monteiro, S. F., Costa, E. L. N., Ferreira, R. S. B., & Chisté, R. C. (2022). Simultaneous extraction of carotenoids and phenolic compounds from pulps of orange and yellow peach palm fruits (*Bactris gasipaes)* by ultrasound-assisted extraction. *Food Science and Technology (Campinas)*, 42, e34021. http://dx.doi.org/10.1590/fst.34021.

Ojha, K. S., Keenan, D. F., Bright, A., Kerry, J. P., & Tiwari, B. K. (2016). Ultrasound assisted diffusion of sodium salt replacer and effect on physicochemical properties of pork meat. *Food Science and Technology (Campinas)*, 51, 37-45. https://doi.org/10.1111/ijfs.13001.

Ozuna, C., Puig, A., García-Pérez, J. V., Mulet, A., & Cárcel, J. A. (2013). Influence of high intensity ultrasound application on mass transport, microstructure and textural properties of pork meat (Longissimus dorsi) brined at different NaCl concentrations. *Journal of Food Engineering*, 119(1), 84-93. http://dx.doi.org/10.1016/j.jfoodeng.2013.05.016.

Piyasena, P., Mohareb, E., & Mckellar, R. (2003). Inactivation of microbes using ultrasound: a review. *International Journal of Food Microbiology*, 87(3), 207-216. http://dx.doi.org/10.1016/S0168-1605(03)00075-8. PMid:14527793.

Rezende, Y. R. R. S., Nogueira, J. P., & Narain, N. (2018). Microencapsulation of extracts of bioactive compounds obtained from acerola (*Malpighia emarginata* DC) pulp and residue by spray and freeze drying: Chemical, morphological and chemometric characterization. *Food Chemistry*, 254, 281-291. http://dx.doi.org/10.1016/j.foodchem.2018.02.026. PMid:29548455.

Saath, K. C. O., & Fachinello, A. L. (2018). Crescimento da demanda mundial de alimentos e restrições do fator terra no Brasil. *Revista de Economia e Sociologia Rural*, 56(2), 195-212. http://dx.doi.org/10.1590/1234-56781806-94790560201.

Shah, M. A., Bosco, S. J., & Mir, S. A. (2014). Plant extracts as natural antioxidants in meat and meat products. *Meat Science*, 98(1), 21-33. http://dx.doi.org/10.1016/j.meatsci.2014.03.020. PMid:24824531.

Sikes, A. L., Mawson, R., Stark, J., & Warner, R. (2014). Quality properties of pre- and post-rigor beef muscle after interventions with high frequency ultrasound. *Ultrasonics Sonochemistry*, 21(6), 2138-2143. http://dx.doi.org/10.1016/j.ultsonch.2014.03.008. PMid:24690296.

Silva, C., Monteiro, M. L. G., Ribeiro, R. O. R., Guimaraes, C. F. M., Mano, S. B., Pardi, H. S., & Marsico, E. T. (2009). Presenca de aditivos conservantes (nitrito e sulfito) em carnes bovinas moidas, comercializadas em mercados varejistas. *Revista Brasileira de Ciência Veterinária*, 16(1), 33-36. http://dx.doi.org/10.4322/rbcv.2014.166.

Silva, P. B., Duarte, C. R., & Barrozo, M. A. S. (2019). A novel system for drying of agro-industrial acerola (*Malpighia emarginata* DC) waste for use as bioactive compound source. *Innovative Food Science & Emerging Technologies*, 52, 350-357. http://dx.doi.org/10.1016/j.ifset.2019.01.018.

Silva, R. A. M., Pacheco, G. D., Vinokurovas, S. L., Oliveira, E. R., Gavioli, D. F., Lozano, A. P., Agostini, P. S., Bridi, A. M., & Silva, C. A. (2015). Associação de ractopamina e vitaminas antioxidantes para suínos em terminação. *Ciência Rural*, 45(2), 311-316. http://dx.doi.org/10.1590/0103-8478cr20140048.

Singla, M., & Sit, N. (2021). Application of ultrasound in combination with other technologies in food processing: a review. *Ultrasonics Sonochemistry*, 73, 105506. http://dx.doi.org/10.1016/j.ultsonch.2021.105506. PMid:33714087.

Stadnik, J., Dolatowski, Z. J., & Baranowska, H. M. (2008). Effect of ultrasound treatment on water holding properties and microstructure of beef (m. semimembranosus) during ageing. *Lebensmittel-Wissenschaft + Technologie*, 41(10), 2151-2158. http://dx.doi.org/10.1016/j.lwt.2007.12.003.

Stadnik, Z. J., & Dolatowski, Z. J. (2011). Influence of sonication on Warner-Bratzler shear force, colour and myoglobin of beef (*m. semimembranosus*). *European Food Research and Technology*, 233(4), 553-559. http://dx.doi.org/10.1007/s00217-011-1550-5.

Wang, A., Kang, D., Zhang, W., Zhang, C., Zou, Y., & Zhou, G. (2018). Changes in calpain activity, protein degradation and microstructure of beef M. semitendinosus by the application of ultrasound. *Food Chemistry*, 245, 724-730. http://dx.doi.org/10.1016/j.foodchem.2017.12.003. PMid:29287433.

Xiong, G., Fu, X., Pan, D., Qi, J., Xu, X., & Jiang, X. (2020). Influence of ultrasound-assisted sodium bicarbonate marination on the curing efficiency of chicken breast meat. *Ultrasonics Sonochemistry*, 60, 104808. http://dx.doi.org/10.1016/j.ultsonch.2019.104808. PMid:31568999.

Xu, M., Shen, C., Zheng, H., Xu, Y., Xue, C., Zhu, B., & Hu, J. (2020). Metabolomic analysis of acerola cherry (Malpighia emarginata) fruit during ripening development via UPLC-Q-TOF and contribution to the antioxidant activity. *Food Research International*, 130, 108915. http://dx.doi.org/10.1016/j.foodres.2019.108915. PMid:32156365.

Yeung, C. K., & Huang, S. C. (2017). Effects of ultrasound pretreatment and ageing processing on quality and tenderness of pork loin. *Journal of Food and Nutrition Research*, 5(11), 809-816. http://dx.doi.org/10.12691/jfnr-5-11-3.