https://doi.org/10.1590/1678-992X-2023-0033
ISSN 1678-992X
Scientia Agricola
Research article

Influence of micronized salt and high-power ultrasound on the quality of beef burgers

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Edited by: Adriano Costa de Camargo

Received Mar 06, 2023
Accepted July 04, 2023

ABSTRACT: The study aimed to evaluate the combined use of ultrasound (US) and incorporation of micronized salt (MS) as a strategy for reducing sodium without affecting the quality of beef burgers. Ten treatments were manufactured with varying MS content (0.75 %, 1.0 %, and 1.5 %) and ultrasound time (0, 5, and 10 min), with a control treatment manufactured at 1.5 % of regular salt without ultrasound. The beef burgers formulated with 0.75 % MS submitted to the US for 10 min (M0.75US10) reduced the salt content by 50 %, thereby efficiently maintaining texture profile (hardness, springiness, cohesiveness, and chewiness) and decreasing the cooking loss and diameter reduction compared to the control treatment. M0.75US10 treatment also preserved the color of samples after cooking, keeping myoglobin stable. Therefore, micronized salt coupled with ultrasound technology reduces sodium chloride content in beef burgers, enabling the application of clean technology to reduce sodium content in meat products efficiently.

Keywords: healthier meat products, texture profile, emerging technologies, color, sonification

Introduction

Sodium chloride (NaCl) is an essential food additive for processing, preservation, and flavor enhancement (Inguglia et al., 2017). However, the World Health Organization – WHO, (WHO, 2012) warned about excessive sodium consumption because of its association with the development of cardiovascular diseases, stomach cancer, stroke, and obesity (He et al., 2020).

Meat products represent 20 to 30 % of daily sodium intake, commonly as NaCl (Gullón et al., 2021). Of these, the beef burger is the most popular and is consumed worldwide, as it has sensory characteristics of great acceptance and practicality in preparation (Rios-Mera et al., 2019). In this context, academia and industry are looking for alternatives to reduce the sodium content in beef burgers, without compromising their technological and sensory quality (Carvalho et al., 2020; Barbosa et al., 2023; Santana Neto et al., 2023).

However, reducing the sodium content of burgers is a challenging task. Salt substitution and technologies used to reduce sodium must preserve the quality of the product at a low cost and comply with the country's current legislation. These issues were recently addressed through different strategies (Zhang et al., 2022). In this regard, the size reduction of salt particles (also called micronized salt) has shown promising results in meat products (Rios-Mera et al., 2019, 2020, 2021; Rosa et al., 2023) because it intensifies the salty taste of reformulated products as a result of the faster dissolution of salt in saliva. The micronized salt mixed 50 % in the fat and 50 % in the meat favored the reduction of NaCl in beef burgers from 1.5 % to 1 % without affecting sensory quality (Rios-Mera et al., 2021). On the other hand, these authors observed that a salt reduction of > 1.0 % affected the texture and increased the cooking loss. To overcome these issues by combining sodium reduction with ultrasound (US) technology seems promising (Rosa et al., 2023).

High-power US applied to meat products proved to be effective in reducing salt(the sonication of meat matrices favors the diffusion of salt) by improving the extraction of myofibrillar proteins from meat products with low sodium content and reducing technological defects (Pinton et al., 2022). Therefore, the present study proposes the incorporation of micronized salt coupled with US technology to reduce the sodium content while maintaining the physicochemical and textural properties of a beef burger.

Materials and Methods

The experiment was conducted at the Meat Quality and Processing Laboratory of the Escola Superior de Agricultura 'Luiz de Queiroz' at the Universidade de São Paulo (22°42′30″ S, 47°38′00″ W, altitude 546 m).

Raw materials and ingredients

The pork backfat, beef, and salt (NaCl) were purchased at the local market (Piracicaba, SP, Brazil). The Ibrac (Rio Claro, SP, Brazil) supplied the remaining ingredients. Micronized salt was obtained by sieving regular salt (RS) using a 60-mesh stainless steel sieve, resulting in a particle size of 168.86 ± 1.66 µm (Rios-Mera et al., 2019).

Beef burger manufacture

Ten treatments of beef burgers (Table 1) were formulated: C = control formulation with 1.5 % regular salt, M1.5US0 = 1.5 % micronized salt without ultrasound; M1.0US0 = 1.0 % micronized salt without ultrasound; M0.75US0 = 0.75 % micronized salt without ultrasound; M1.5US5 = 1.5 % micronized salt with 5 min of ultrasound; M1.0US5 = 1.0 % micronized salt with 5 min ultrasound; M0.75US5 = 0.75 % micronized salt with 5 min ultrasound; M1.5US10 = 1.5 % micronized salt with 10 min ultrasound; M1.0US10 = 1.0 % micronized salt with 10 min ultrasound; and M0.75US10 = 0.75 % micronized salt with 10 min of ultrasound. The components of the beef burgers and their percentages were calculated according to Rios-Mera et al. (2019).Six beef burgers (100 g) were produced with each treatment.

Beef and pork backfat were ground separately into 0.8 cm discs. Subsequently, 50 % of the MS was mixed in with the beef for 2 min, and 50 % with the pork backfat. Regular salt was mixed in with the meat with the fat for 2 min for the control treatment to be incorporated, and the other ingredients were added and homogenized for 3 min. Next, 300 g of meat batter corresponding to each treatment was packed in water-impermeable packages and then placed in an ultrasonic bath (Q13/25, Ultronique) with a nominal power of 700 W, a frequency of 25 kHz and actual volumetric intensity of 37.33 W L^{-1}, calculated according to Cárcel et al. (2012) and the non-sonicated treatments remained in the ultrasonic bath at the same time and temperature with the equipment turned off. After the process, the beef burgers were molded into 100 g portions, vacuum packed (−97.222 Pa, vacuum packer Selovac 300 B) and kept at − 18 °C for further analysis.

Characterization of beef burgers

pH determination

The pH values of the cooked beef burgers were measured in triplicate using an adequately calibrated pHmeter (buffer 4.0, 7.0, and 10.0) equipped with an electrode with a temperature probe (Lucadema, LUCA-210 model).

Instrumental color

The instrumental color was measured using a MiniScan®XE Plus spectrophotometer (Hunter Associates Laboratory Inc.), calibrated with a white ceramic plate set to Y = 93.7, x = 0.3160, and y = 0.3323, measuring area 8 mm in diameter, observation angle of 10° and illuminant A10. Five readings were taken on the surface of raw and cooked beef burgers to determine the parameters of lightness (L*), redness (a*), yellowness (b*), chroma (C*), and hue (H*).

Relative myoglobin content

The relative content of myoglobin (MMb - metmyoglobin and OMb - oxymyoglobin) was then quantified according to the methodology described by the American Meat Science Association (AMSA, 2012). The reflectance (R) values at 473, 525, 572, and 700 nm were obtained from five readings taken on the surface of the raw beef burgers using the MiniScan®XE Plus portable spectrophotometer (Hunter Associates Laboratory Inc). Next, reflectance values (R) were converted into absorbance (A = log (1/R) and applied to the equations provided by AMSA (2012).

Table 1 – Formulations of beef burgers with sodium reduction.

	Treatments									
Ultrasound Time	C	M1.5US0	M1.0US0	M0.75US0	M1.5US5	M1.0US5	M0.75US5	M1.5US10	M1.0US10	M0.75US10
	0	0	0	0	5	5	5	10	10	10
					min					
Component (%)										
Beef	70	70	70	70	70	70	70	70	70	70
Pork Back Fat	20	20	20	20	20	20	20	20	20	20
Water	7.5	7.5	8.0	8.25	7.5	8.0	8.25	7.5	8.0	8.25
Regular Salt	1.5	–	–	–	–	–	–	–	–	–
Micronized Salt	–	1.5	1.0	0.75	1.5	1.0	0.75	1.5	1.0	0.75
Pepper	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
Garlic powder	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28
Onion powder	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28
Sodium erythorbate	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Monosodium glutamate	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28

C = control formulation; M1.5US0 = 1.5 % micronized salt without ultrasound; M1.0US0 = 1.0 % micronized salt without ultrasound; M0.75US0 = 0.75 % micronized salt without ultrasound; M1.5US5 = 1.5 % micronized salt with 5 min ultrasound; M1.0US5 = 1.0 % micronized salt with 5 min ultrasound; M0.75US5 = 0.75 % micronized salt with 5 min ultrasound; M1.5US10 = 1.5 % micronized salt with 10 min ultrasound; M1.0US10 = 1.0 % micronized salt with 10 min ultrasound; M0.75US10 = 0.75 % micronized salt with 10 min of ultrasound.

Yield properties

The weight loss of burgers was analyzed by comparing the difference in weight before and after cooking, calculated according to Eq. (1) (Selani et al., 2016):

$$\%Cooking\ loss = \left[\frac{Raw\ weight - Cooked\ weight}{Raw\ weight} \right] \times 100 \quad (1)$$

The diameter reduction was calculated based on the difference in diameter between raw and cooked beef burgers, as shown in Eq. (2) (Sánchez-Zapata et al., 2010):

$$\%Diameter\ reduction = \left[\frac{Raw\ diameter - Cooked\ diameter}{Raw\ diameter} \right] \times 100 \quad (2)$$

Texture Profile

The textural properties of beef burgers were analyzed by texture profile analysis (TPA) in a TA-XT Texture analyzer (Stable Micro Systems), according to Selani et al. (2016). The beef burgers were standardized using a stainless steel cutter (2.5 cm in diameter and 1 cm in height). They were axially compressed to 75 % of their original height at a crosshead speed of 20 cm min^{-1} using a P/35 probe (Stable Micro Systems). The texture profile was determined according to Bourne (1978) and Saldaña et al. (2015) based on hardness (N), springiness (mm), cohesiveness (dimensionless), and chewiness (N).

Sodium content

Sodium was quantified following the methodology described by AOAC (2016) and Almeida et al. (2016). Initially, ~5 g shredded beef burgers were muffled at 525 °C. The ashes obtained were cooled to room temperature and then solubilized in 15 mL of nitric acid (250 mL of HNO_3 in 750 mL of distilled water). For calculation purposes, a blank sample was used as a control. Readings were triplicate in a flame photometer (Digimed brand, model DM63).

Data analysis

From a univariate perspective, the results were submitted to an analysis of variance (ANOVA) followed by the Tukey test for pairwise comparison. For both analyses, a significance level of $\alpha = 0.05$ was considered.

To obtain a synthetic representation of variables and individuals (multivariate perspective), a Principal Component Analysis (PCA) based on the correlation matrix was elaborated, followed by a hierarchical cluster analysis (HCA) on the first five coordinates of PCA based on the Euclidian distance between samples (Granato et al., 2018). The dendrogram was constructed with Ward's linkage criterion to show the cluster of samples with similar characteristics. All analyses were carried out using the R software.

Results

Color and pH parameters

The instrumental color and pH of beef burgers are shown in Table 2. There were variations in the lightness of raw beef burgers between the treatments. On the other hand, treatments with 33 % and 50 % salt reduction submitted to ultrasound (5 and 10 min) presented lightness results

Table 2 – Instrumental color of beef burgers.

Parameter	Treatments											
	C	M1.5US0	M1.0US0	M0.75US0	M1.5US5	M1.0US5	M0.75US5	M1.5US10	M1.0US10	M0.75US10	SEM	*p*-value
Raw burger												
Metmyoglobin (%)	34.86	31.05	33.84	42.60	44.71	42.23	45.03	36.54	39.51	41.59	1.22	0.07
Oxymyoglobin (%)	70.50	75.51	71.53	62.29	59.88	62.06	60.39	67.67	63.59	62.34	1.36	0.08
Lightness (L*)	49.74[bcd]	52.61[a]	50.17[abc]	49.74[abcd]	50.44[abc]	51.28[ab]	49.12[bcd]	51.08[ab]	47.88[cd]	47.19[d]	0.32	0.03
Redness (a*)	21.04	23.11	21.68	17.57	17.05	18.71	17.04	20.91	19.43	19.19	0.54	0.11
Yellowness (b*)	20.77	21.51	20.27	20.06	19.88	20.13	19.98	21.39	21.00	21.78	0.21	0.33
Chroma (C*)	29.58	31.58	29.69	27.12	25.66	28.69	25.66	27.37	29.81	28.50	0.48	0.08
Hue (H*)	44.69	42.95	43.20	48.92	49.54	47.77	49.66	45.85	47.28	48.78	0.60	0.09
Cooked burger	C	M1.5US0	M1.0US0	M0.75US0	M1.5US5	M1.0US5	M0.75US5	M1.5US10	M1.0US10	M0.75US10	SEM	*p* -value
pH	6.03	6.085	6.07	6.11	6.19	6.09	6.10	6.09	6.14	6.15	0.01	0.57
Lightness (L*)	41.99	44.97	46.58	45.90	44.80	42.51	47.13	41.92	44.35	42.10	0.50	0.08
Redness (a*)	11.06[c]	13.21[bc]	12.31[bc]	12.95[bc]	12.31[bc]	13.92[ab]	13.37[bcd]	13.90[ab]	13.29[b]	15.98[a]	0.24	<.0001
Yellowness (b*)	15.49[c]	22.03[ab]	21.16[b]	20.86[b]	18.69[bc]	22.30[ab]	21.16[b]	23.07[ab]	22.05[ab]	26.46[a]	0.55	<.0001
Chroma (C*)	16.78[c]	23.82[ab]	23.51[b]	22.61[b]	20.21[bc]	24.28[ab]	22.99[b]	24.99[ab]	23.86[ab]	28.85[a]	0.61	<.0001
Hue (H*)	54.45[b]	59.04[a]	59.21[a]	58.16[a]	56.63[ab]	57.99[a]	57.66[a]	58.93[a]	58.93[a]	58.69[a]	0.29	0.02

Different letters between mean values at the same row means statistical differences (α = 0.05). C = control formulation; M1.5US0 = 1.5 % micronized salt without ultrasound; M1.0US0 = 1.0 % micronized salt without ultrasound; M0.75US0 = 0.75 % micronized salt without ultrasound; M1.5US5 = 1.5 % micronized salt with 5 min ultrasound; M1.0US5 = 1.0 % micronized salt with 5 min ultrasound; M0.75US5 = 0.75 % micronized salt with 5 min ultrasound; M1.5US10 = 1.5 % micronized salt with 10 min ultrasound; M1.0US10 = 1.0 % micronized salt with 10 min ultrasound; M0.75US10 = 0.75 % micronized salt with 10 min of ultrasound. SEM = Standard error of the mean.

like the control treatment (C). The other responses of raw beef burgers were not affected by salt reduction nor ultrasound application. Using ultrasound on cooked beef burgers (Table 2) did not modify the pH nor the lightness. The pH of the cooked samples remained within the normal range for cooked meat products (Hereu et al., 2012).

Similar behavior was observed in redness, yellowness, chroma, and hue in the treatments with sodium reduction by 33 % and 50 % submitted to 10 min of ultrasound. The combination of MS and US technologies contributed to the preservation of beef burger pigments after cooking.

Yield properties, texture profile and sodium

The control treatment presented the most significant cooking loss. The treatments which added 1.5 % of micronized salt without ultrasound showed the lowest cooking loss. The treatments with added RS and MS presented similar diameter reductions. However, MS combined with the US reduced sodium content by up to 50 % without technological losses (Table 3).

Variations in sodium content between treatments were observed. There was no difference between the RS and MS treatments added at the same concentration. Nevertheless, as the salt content was reduced, the sodium content in the beef burger samples was reduced accordingly. The application of ultrasound did not affect the sodium content in the beef burgers. All treatments were similar regarding the texture properties such as springiness, cohesiveness, and chewiness. Hardness varied from 65.61 to 95.66 N, corroborating similar values for this product type, as reported by Rios-Mera et al. (2020, 2021).

Multivariate analysis of variables

For further data compression, a multiple factor analysis (MFA) on yield properties, instrumental color, instrumental texture, and pH in cooked beef burgers was carried out (Figure 1A). The first two dimensions accounted for 69.60 % of the original data. According to the HCA, three groups of treatments were identified. The first cluster comprised the control treatment and M1.0US5 (Figure 1B), characterized by the lowest values of the response variables, except for the diameter reduction, which presented the highest values. Treatments M1.5US5 and M0.75US10 were part of the second cluster. Both presented similarities for several variables; however, the M0.75US10 treatment stood out on account of its high values of instrumental color and diameter reduction values. The third cluster comprised treatments M1.5US0, M1.0US0, M0.75US0, M0.75US5, M1.5US10 and M1.0US10. The treatments showed low values for hardness, chewiness, and springiness and high values for increasing lightness (L*). It is suggested that this behavior originates from losing water molecules and myoglobin. The M0.75US10 treatment showed the best performance, postulating that the MS combined with the US allowed for salt reduction by up to 50 % without affecting color parameters, yield, nor instrumental texture.

Discussion

Considering the importance of salt in meat products and the current public demand for healthier foods, combining US and MS is an effective strategy for making healthier beef burgers. Therefore, from the point of view of sensory appeal, it has already been reported that MS can maintain sensory quality and acceptability with reductions of up to 33 % in beef burgers (Rios-Mera et al., 2019, 2020). However, higher reductions have given rise to detrimental technological effects, which pave a way for accepting US technology as a viable strategy. The interesting aspect of the strategy of this work is that it does not require the inclusion of other ingredients and/

Table 3 – Yield and texture properties of beef burgers.

Parameter	Treatments											
Yield properties (%)	C	M1.5US0	M1.0US0	M0.75US0	M1.5US5	M1.0US5	M0.75US5	M1.5US10	M1.0US10	M0.75US10	SEM	*p*-value
Cooking loss	31.33[a]	18.25[d]	22.59[cd]	25.61[bc]	24.07[c]	29.62[ab]	24.58[c]	23.25[c]	22.43[cd]	22.40[cd]	0.74	<.0001
Diameter reduction	15.42[abc]	13.26[abc]	16.19[abc]	16.92[abc]	14.34[abc]	19.66[a]	10.01[c]	18.20[ab]	18.29[ab]	11.15[bc]	0.69	0.004
Sodium (g $100g^{-1}$)	0,69[a]	0.72[a]	0.58[b]	0.39[c]	0.76[a]	0.52[b]	0.44[c]	0.72[a]	0.56[b]	0.42[c]	0.46	<.0001
Texture properties	C	M1.5US0	M1.0US0	M0.75US0	M1.5US5	M1.0US5	M0.75US5	M1.5US10	M1.0US10	M0.75US10	SEM	*p*-value
Hardness (N)	95.24[a]	72.40[ab]	73.28[ab]	85.34[ab]	97.17[a]	93.38[a]	79.41[ab]	65.61[ab]	75.08[ab]	95.66[a]	2.44	<.0001
Springiness	0.74	0.64	0.63	0.69	0.63	0.71	0.63	0.57	0.61	0.63	0.01	0.091
Cohesiveness	0.34	0.32	0.34	0.36	0.32	0.37	0.34	0.30	0.31	0.42	0.09	0.087
Chewiness (N)	26.04	15.00	16.11	21.66	20.32	25.54	17.33	11.36	14.60	25.54	1.21	0.016

Different letters between mean values at the same row means statistical differences (α = 0.05). C = control formulation; M1.5US0 = 1.5 % micronized salt without ultrasound; M1.0US0 = 1.0 % micronized salt without ultrasound; M0.75US0 = 0.75 % micronized salt without ultrasound; M1.5US5 = 1.5 % micronized salt with 5 min ultrasound; M1.0US5 = 1.0 % micronized salt with 5 min ultrasound; M0.75US5 = 0.75 % micronized salt with 5 min ultrasound; M1.5US10 = 1.5 % micronized salt with 10 min ultrasound; M1.0US10 = 1.0 % micronized salt with 10 min ultrasound; M0.75US10 = 0.75 % micronized salt with 10 min of ultrasound. SEM = Standard error of the mean.

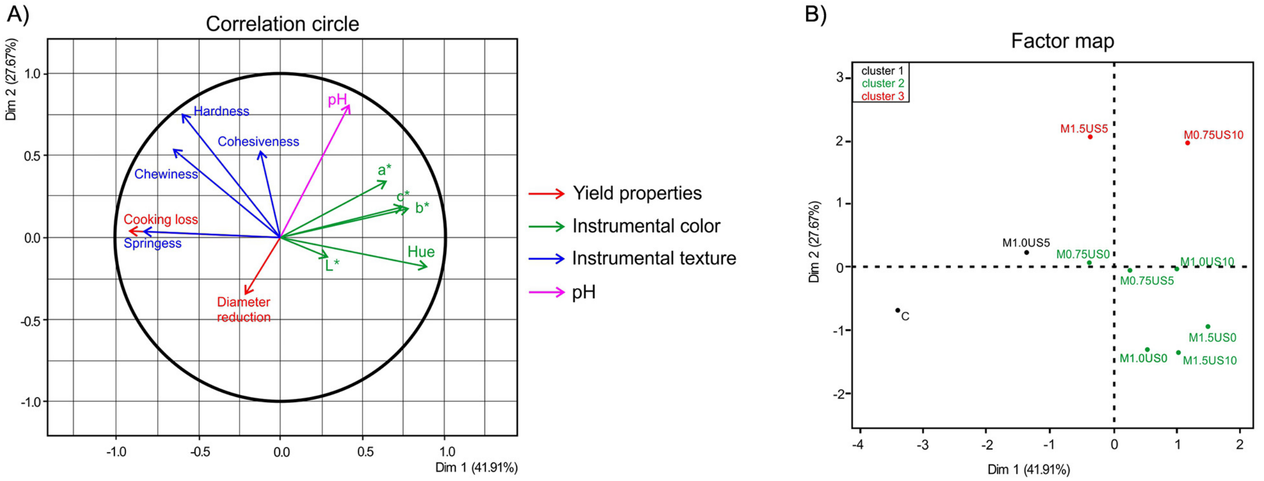

Figure 1 – Multiple factor analysis (MFA) of the beef burgers. A) representation of response variables after cooking. B) distribution of beef burger treatments in the first two dimensions of MFA. C = control formulation; M1.5US0 = 1.5 % micronized salt without ultrasound; M1.0US0 = 1.0 % micronized salt without ultrasound; M0.75US0 = 0.75 % micronized salt without ultrasound; M1.5US5 = 1.5 % micronized salt with 5 min ultrasound; M1.0US5 = 1.0 % micronized salt with 5 min ultrasound; M0.75US5 = 0.75 % micronized salt with 5 min ultrasound; M1.5US10 = 1.5 % micronized salt with 10 min ultrasound; M1.0US10 = 1.0 % micronized salt with 10 min ultrasound; M0.75US10 = 0.75 % micronized salt with 10 min of ultrasound.

or additives, which usually accompanies the use of maskers and flavor enhancers when different chlorides are used as sodium chloride replacers, which makes the MS + US a clean sodium reduction strategy.

As regards the color after cooking (Table 2), the application of ultrasound probably caused the formation of microchannels within the beef burger batter, favoring heat penetration, a reduction in cooking time and myoglobin denaturation, and preservation of burger color. In this regard, it was observed that the faster the burger reached its internal temperature, the greater its stability during the process, with the preservation of the red color (Yang et al., 2022). The combination of MS and US decreased the oxidation of myoglobin, even with reduced salt content, while increasing the flow of salt into the microstructure of the beef burger batter as well as modifying the structure of the protein, making it the heme group that is more protected during cooking, retarding the formation of metmyoglobin. The change in the red color of cooked meat products is related to the heating temperature and denaturation of myoglobin, which exposes the heme group of the molecule, the most unstable protein part (Suman et al., 2016).

Micronized salt (MS) alone decreases cooking losses (Table 3), a behavior attributable to faster diffusion of salt particles on beef burger batter, which improves the extraction of myofibrillar proteins and increases the ability to retain water in meat products during cooking. It was observed that fine flake NaCl crystals (0.55 mm) dissolved quickly and had great penetration in dry-cured pork (Aheto et al., 2019).

Beef burgers with a reduction more than 33 % in micronized salt increased cooking loss and diameter reduction (Rios-Mera et al., 2019, 2020). These defects resulted from the denaturation of the proteins responsible for binding water and fat (Carvalho et al., 2019). In this study, the application of ultrasound allowed us to overcome these issues. Several studies with ultrasound in meat products report improvements in technological aspects compared to treatments without ultrasound (Barretto et al., 2020; Leães et al., 2020; Araújo et al., 2022; Pinton et al., 2022; Rosa et al., 2023).

Adding MS and applying US for 10 min allowed for a 50 % reduction in sodium content in beef burgers without affecting the instrumental color, yield properties, and texture. Treatment M0.75US10 provided superior results compared to the others. Future studies are thus suggested on the oxidative process of the product over storage time, as well as the sensory properties based on consumer perception.

Acknowledgments

The authors thank Sealed Air Corporation for packaging materials used in this study and the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES), who granted the Doctorate scholarship (grant number 88887.637004/2021-00).

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KC, Saldaña E. **Formal analysis:** Araújo CDL, Saldaña E. **Methodology:** Araújo CDL, Saldaña E, Contreras Castillo CJ. **Project administration:** Saldaña E, Contreras Castillo CJ. **Funding acquisition:** Contreras Castillo C.J. **Writing – original draft:** Araújo CDL, Krauskopf MM, Rio-Mera JD, Saldaña E, Contreras Castillo CJ. **Writing – review & editing:** Araújo CDL, Krauskopf MM, Rio-Mera JD, Saldaña E, Contreras Castillo CJ.

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