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Effect of Aging Methods and Ultrasonication Treatment on the Sensory Profile of Beef *Longissimus lumborum* Muscle

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Abstract: Tenderness is one of the most appreciated quality characteristics in beef by consumers. Meat aging is the most recognized natural methodology to improve tenderness in beef. The current study was designed to evaluate if ultrasonication was able to simulate (ultrasonication alone) or to grant an additional effect (aging plus ultrasonication) to two different aging methods (dry and wet) on the sensory profile of the beef *Longissimus lumborum* muscle. The two aging methods (dry and wet), or ultrasonication for 40 min (US), had no effect ($p > 0.05$) in overall consumer acceptability. However, in terms of sensory attribute liking, the highest values ($p < 0.05$) were observed in the ultrasonicated and wet-aged meat for 10 d and the dry-aged meat for 10 d, without difference between them ($p > 0.05$). It is concluded that ultrasound offers the possibility to obtain tender meat without the cost and contamination risks implicated in the dry-aging method.

Keywords: beef muscle; aging; ultrasound; consumer acceptability; sensory traits

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1. Introduction

Tenderness, flavor, and juiciness of beef are improved by the process of aging, which is developed by storing the meat for a certain time at temperatures above freezing [1]. Generally, beef aging is developed in two different ways, wet-aging and dry-aging. In dry-aging, meat is exposed to ambient conditions under controlled temperature (−1 to 4 °C), relative humidity (RH, 65–85%), and air flow velocity (0.2–5 m/s). In this type of process, the meat naturally loses water, and, hence, it is called dry-aging; additionally, the oxygen-present conditions may represent a risk of bacterial contamination [2]. On the other hand, wet-aging means the storage of meat in vacuum packaging, allowing the tissue to preserve more water due to the lack of exposure to the flow of air and other fridge conditions [3]. Tenderization in meat by aging effect is mostly due to calpain-mediated proteolysis. Most proteolytic events mediated by the activity of calpains, primarily μ-calpain, occur between 3 and 14 d *postmortem* [3]. The effects of aging meat depend on different factors, such as age, sex, muscle type, and processing conditions (period, temperature, and humidity, among others) [4].

The concentrated compounds developed during dry-aging of beef, such as free amino acids (FAAs), are considered as the main components of beef flavor [5]. This process for flavor development might be due to the process of moisture evaporation in the beef at ambient conditions [6,7]. However, there are no tangible findings to differentiate the dry-aged and wet-aged beef sensory profiles as such [8]. Nevertheless, consumers are not able to find a clear difference in taste between the wet- and the dry-aged beef [9,10].

Ultrasonication is a modern method effective for improving meat tenderness without extreme negative effects. Low frequency (20–100 kHz) and high intensity (>10 W/cm^2) ultrasound (US) can disrupt meat at macro- and micro-levels of myofibrillar proteins [11,12]. The application of US in skeletal muscle results in fragmentation of the Z-line and disruption of the sarcoplasmic reticulum, mitochondria, and other cellular organelles [13,14]. The quality of fresh meat is improved by this disruptive effect of ultrasonication, which enhances its tenderness. Beef steaks subjected to US were more tender than controls, without color or water-holding capacity (WHC) detriment [15,16]. Additionally, through the application of US, the collagen solubility and textural properties of beef *M. semitendinosus* have been improved [17,18]. Furthermore, ultrasonication can disrupt the myofibrillar structure and stimulate the *postmortem* proteolysis [4,19]. Nevertheless, ultrasonication has not shown additional benefits on the sensorial parameters of dry-aged beef [20] or the physicochemical parameters of wet-aged or dry-aged beef for 10 d [21].

Sensory evaluation is a useful tool in quality control and shelf-life studies. It can be used to make informed decisions around the processing of food. The sensory tests of food allow us to know the preference score of a product. Sensory studies have a subjective character, and, for this reason, these tests must be conducted on a large number of panelists or consumers. The most common is the acceptability test, in which the panelists have to indicate the level of satisfaction related to the sample on a scale. In this test, panelists are asked to rate specific attributes of a food sample [22].

The aim of study was to determine if US was able to simulate aging or if it had additional effects on the wet-aging process by comparing the sensory changes in the *Longissimus lumborum* under two aging methods (dry-aging, DA, or wet-aging, WA) at two different periods (5 or 10 d), or only ultrasonication (I = 90 W/cm^2, F = 37 kHz) for 40 min.

2. Materials and Methods

2.1. Samples and Treatments

Four frozen m. *Longissimus lumborum* from 20 months old Angus × Brahman steers (520 kg) finished on feed lot were obtained from SuKarne, a Mexican multinational corporation based in Culiacan city, Mexico. After forty h *postmortem*, the loins were vacuum packed followed by air blast freezing (at −20 °C). This is a regular practice in Mexican meat companies. Loins were unpacked, and visible connective tissue and external fat were removed after three weeks [20]. Frozen loins were sliced to make steaks of 2.5 cm thickness, perpendicular to muscle fibers. Eight of the twelve steaks per loin were assigned to each of the eight treatments with four replicates. The four steaks left from each loin were randomly distributed into the treatments to accomplish the six replicates per treatment.

Steaks were individually vacuum packed and then thawed in water at 20 °C for 2 h. Steaks from the same loin were assigned to the eight treatments randomly.

The treatments are presented in Figure 1, including beef without ultrasound or aging (CON), ultrasonicated beef inside vacuum bags for 40 min (US), wet-aged beef for 5 d (WA5D), wet-aged beef for 10 d (WA10D), dry-aged beef for 5 d (DA5D), dry-aged beef for 10 d (DA10D), ultrasonicated and wet-aged beef for 5 d (USWA5D), and ultrasonicated and wet-aged beef for 10 d (USWA10D). Control samples were used for initial reference parameters. As such, further processes were not applied on control samples. To carry out the aging for treatment WA5D and WA10D, meat samples were kept in 10 × 12″ (70 mm, FLAIR®) vacuum packaging bags and stored at 1 °C.

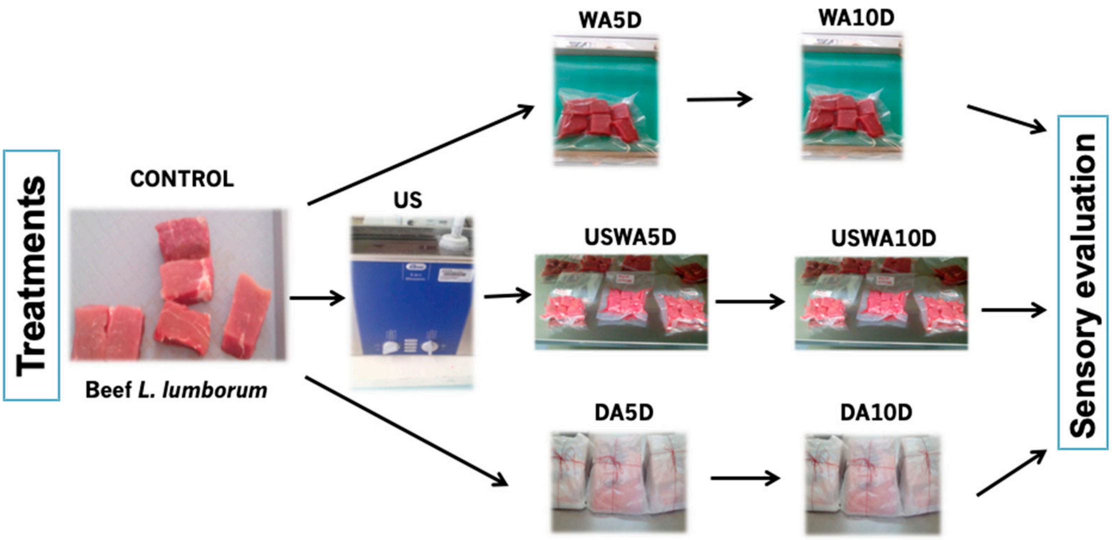

Figure 1. Treatments of the study. Control = beef without ultrasound or aging; US = ultrasound (90 W/cm^2, 37 kHz, 40 min); WA5D = wet-aging for 5 d; WA10D = wet-aging for 10 d; DA5D = dry-aging for 5 d; DA10D = dry-aging for 10 d; USWA5D = ultrasound and wet-aging for 5 d; USWA10D = ultrasound and wet-aging for 10 d.

2.2. High-Intensity Ultrasonication

The vacuum packaged steaks were ultrasonicated after thawed using an ultrasonicator bath Elmasonic (Elmasonic® Elma Schmidbauer GmbH, Singen, Germany) (I = 90 W/cm^2 and F = 37 kHz) for 40 min (twenty min per side of steak). A refrigeration probe (Julabo FT200) was used to keep the bath temperature at 4 °C during sonication. Samples of control group (without sonication) were submerged in ice cold water at 4 °C for 40 min until further analysis [20,21]. Ultrasound was applied before meat aging.

2.3. Sensory Analysis

2.3.1. Sensory Panel

The consumers who participated in both the ranking preference test and the acceptance test were 95 undergraduate or postgraduate students (age range 20–35 y old) of the Department of Animal Science and Ecology, with a gender ratio of 45:55 men–women. The recruitment process was conducted via classroom invitation. Consumers were recruited based on the following criteria: (a) a liking for beef, (b) consuming beef at least once a week, and (c) having an interest in participating in the study. The entire procedure adopted in the sensory test was explained in detail to the panelists taking part in the analyses, who signed a free and informed consent form. The analysis was performed in the Sensory Analysis Laboratory, equipped with 12 cabins and white-cold light (fluorescent).

The study was reviewed and approved by the Institutional Bioethics Committee of the Department of Animal Science and Ecology of the Autonomous University of Chihuahua, Mexico (Decision No. P/302/2017), and informed consent was obtained from each subject prior to their participation in the study.

2.3.2. Sensory Assessments

The aging methods and ultrasonication treatments on the sensory profile of the beef *Longissimus lumborum* muscle were evaluated by sensory analyses. The consumer acceptability was carried out through two analyses, namely a general acceptability test and a sensory attribute scoring [22]. Ten sessions were carried out with approximately ten different consumers each. Each consumer assessed eight samples (one sample per each treatment). Consistent results have been obtained when consumers evaluated 9 [23] or 12 meat samples [24], allowing a 5 min break when half of the samples have been tested. Samples were served in a different order to avoid a first sample and carry-over effect [25].

Samples were codified with random three-digit numbers and served in plastic dishes. Panelists were provided with spring water and salt-free bread to cleanse their palates between tastings. Panelists were free to re-taste as needed to allow them to confirm their assessment. Panelists were instructed to taste and evaluate the meat samples (30 g) using the provided scale shown on the evaluation sheet.

2.3.3. Acceptability Test

The consumer acceptability was analyzed using the nine-point test with three anchors of "dislike very much", "neither like nor dislike", and "like very much". The attributes evaluated were taste, smell, tenderness, and juiciness. Consumers evaluated eight samples in total. Consumers were given samples one through four and were instructed to taste and evaluate each using the scale provided. Consumers took a 1 min rest and rinsed with water between each evaluated sample. Upon completion of the fourth sample, samples five though eight were presented. Consumers took a 5 min break before evaluating the second set of samples. Samples were presented in a balanced design [25].

2.3.4. Preparation of Samples for the Sensory Test

Beef samples were cooked on electric grills (George Foreman®, Marshall, TX, USA) at 176 °C for 4 min 30 s approx. per side, until the geometrical center reached at 72 ± 0.2 °C. The temperature was monitored with a thermocouple probe. When the samples reached 55 °C, they were presented to the consumers on plastic dishes and in a random order.

2.4. Statistical Analysis

Data from the general acceptability test and sensory attribute liking test were transformed into numbers according to the assigned category (1 = dislike extremely to 9 = like extremely) and captured and analyzed in the SAS System 9.0 program. ANOVA was performed to detect statistical differences in the transformed data ($p < 0.05$). When statistical differences were detected with ANOVA, Tukey tests were performed to compared means, with a significance level of 0.05.

The general acceptability and attribute scoring tests were duplicated. The original data of the sensory analysis (categorical) were further analyzed using the chi-square (categorical) test using the FREC procedure of the 9.0 SAS System software [26]. When the association was significant ($p < 0.05$) or it showed a tendency toward significance, a correspondence analysis was applied to visualize the relationship between acceptance and treatments using the CORRESP procedure of SAS [26]. Correspondence analysis is an exploratory technique designed to analyze simple two-way contingency tables containing some degree of correspondence among variables that are spatially represented using this technique, allowing for a visual representation of the data. In this way, correspondence analysis not only helps to identify the existence of the relationship between variables but also shows how variables are related. All statistical analyses were performed using the 9.0 SAS System software [26].

3. Results and Discussion

3.1. Consumer Acceptability

Sensory studies were applied to determine if US was able to simulate aging or if it had additional effects on the wet-aging process by comparing the sensory changes in the *Longissimus lumborum* under two aging methods (dry-aging, DA, or wet-aging, WA) at two different periods (5 or 10 d), or only ultrasonication (I = 90 W/cm^2, F = 37 kHz) for 40 min. The sensory test measures the overall impression of the product, i.e., eating quality when consumed. In the present study, the acceptance test was carried out to measure the degree of liking of the products using consumer panelists. The hedonic method offers an assessment of the liking of the product being tested, using hedonic scales (nine-point hedonic) with three anchors of "dislike very much", "neither like nor dislike", and "like very much" [22]. In this scale, the panelists had to select the expression most in relation to their perception and acceptance of the product. The levels of acceptance for the purposes of the analysis were reduced using only the two extreme levels and the central level. Hence, the responses from 1 to 3 were grouped in the category "dislike very much", from 4 to 6 in "neither like nor dislike", and from 7 to 9 in "like very much".

Acceptability testing was applied to understand if treated meats differed in acceptability (smell, tenderness, juiciness, or overall liking) from each other. The results of the consumer acceptability test are shown in Table 1. An effect was noted for tenderness acceptance of the dry- and wet-aged meat for 10 d (DA10D) and the sonicated and wet-aged meat for 10 d (USWA10D) ($p < 0.05$). These two treatments received the highest value on the hedonic scale, being the most pleasing to the panelists. Regarding the acceptance of the other sensory attributes (taste, smell, juiciness, and overall acceptability), no significant differences ($p > 0.05$) were found. Meat aged for 10 d using the dry method (DA10D) or sonicated method (USWA10D) produced the most acceptable tenderness, most probably because it was more tender than the meat from the other treatments. We hypothesized that ultrasound induced tenderization which resulted in a significantly high consumer liking compared to the other beef attributes evaluated. Texture and tenderness have long been considered the most important of all the attributes of meat quality by consumers [27].

Table 1. Effect of aging method (wet and dry) and ultrasound (90 W/cm^2, 37 kHz, for 40 min) on consumer acceptability of bovine *Longissimus lumborum.* Mean values (±S.D.).

Treatment [1]	Taste	Smell	Tenderness	Juiciness	Overall Acceptability
Control	5.97 ± 0.20 ^{a}	6.24 ± 0.20 ^{a}	5.48 ± 0.2 ^{b}	5.47 ± 0.21 ^{a}	6.16 ± 0.33 ^{a}
US	5.57 ± 0.33 ^{a}	5.83 ± 0.33 ^{a}	5.59 ± 0.35 ^{b}	5.22 ± 0.35 ^{a}	5.92 ± 0.33 ^{a}
DA5D	5.57 ± 0.37 ^{a}	5.93 ± 0.36 ^{a}	5.10 ± 0.38 ^{b}	4.98 ± 0.39 ^{a}	6.22 ± 0.46 ^{a}
DA10D	6.02 ± 0.37 ^{a}	6.29 ± 0.36 ^{a}	6.35 ± 0.38 ^{a}	5.78 ± 0.39 ^{a}	5.92 ± 0.46 ^{a}
WA5D	5.58 ± 0.46 ^{a}	5.84 ± 0.45 ^{a}	5.08 ± 0.48 ^{b}	5.03 ± 0.49 ^{a}	5.58 ± 0.37 ^{a}
WA10D	5.71 ± 0.46 ^{a}	6.01 ± 0.45 ^{a}	6.14 ± 0.48 ^{b}	5.20 ± 0.49 ^{a}	6.43 ± 0.37 ^{a}
USWA5D	5.39 ± 0.45 ^{a}	5.68 ± 0.45 ^{a}	4.80 ± 0.47 ^{b}	4.73 ± 0.48 ^{a}	5.73 ± 0.46 ^{a}
USWA10D	5.56 ± 0.45 ^{a}	5.98 ± 0.45 ^{a}	6.40 ± 0.47 ^{a}	5.93 ± 0.48 ^{a}	6.10 ± 0.46 ^{a}

[1] Control = meat without ultrasound or aging; US = ultrasound (90 W/cm^2, 37 kHz, 40 min); WA5D = wet-aging for 5 d; WA10D = wet-aging for 10 d; DA5D = dry-aging for 5 d; DA10D = dry-aging for 10 d; USWA5D = ultrasound and wet-aging for 5 d; USWA10D = ultrasound and wet-aging for 10 d. Mean ± standard deviation. 1 = dislike very much, 9 = like very much. ^{a,b} Means within columns with different letter are significantly different ($p < 0.05$).

The overall acceptability of meat involves important relative contributions from beef sensory traits. The high liking of tenderness was not enough to impact the overall acceptability, probably because tenderness is not considered the most important contributor to overall liking. Instead, flavor liking is the most important contributor to overall liking, followed by tenderness and juiciness [28–30]. Consumers pay more attention to flavor liking than tenderness to score their ultimate satisfaction, with higher percentages of acceptability derived from flavor liking [29]. Likewise, low scores for flavor liking have the most important potential to cause acceptability failure of overall liking [30]. Similarly, the present study showed a significant difference for tenderness in DAD10 and USWA10D treatments, with no differences in overall acceptability. However, if there is no difference for overall acceptability among treatments ($p > 0.05$), it does not mean they have close acceptance or quality, as this global score can result from any combination of the other scores. Since flavor liking explains the most part of overall liking variability [30], it is most likely that meat without significant differences in flavor acceptability will not have significant differences in overall acceptability ($p > 0.05$). Finally, these results support the assumption that US can be used as an assistant technology in meat aging with similar results to dry-aging. Furthermore, steaks at the local market are sealed in plastic and are technically wet-aged, so a wet-aged steak tastes much more like the traditional steak flavor that most people are accustomed to.

The meat aged for 10 d scored the highest numerical levels of acceptability for all the attributes evaluated (taste, smell, tenderness, and juiciness), regardless of the type of aging (wet or dry) and the application of ultrasound (Table 1). Dry- or wet-aged meat with or without ultrasound and stored for 5 or 10 d did not change the consumer acceptability of *Longissimus lumborum* beef ($p > 0.05$). An important observation was that all treatments received scores higher than 5, suggesting that they had "good" acceptance, because they were above the mean of the 9-point hedonic scale.

A descriptive sensory analysis where minimal differences can be perceived by a trained panel could help in choosing the most appropriate descriptors for a sensory test with consumers. In this regard, Peña-González et al. [31] found that the application of ultrasound (40 kHz, 11 W/cm^2) increased the perception of tenderness in bovine *L. dorsi*. In the present study, meat from the USWA10D treatment presented the highest acceptability in terms of tenderness. Peña-González et al. [32] showed that stored (7 and 14 d) and ultrasonicated beef was perceived softer and with a higher flavor intensity than the untreated beef, but with an oilier flavor. In the present study, meat flavor was not significant among treatments ($p > 0.05$). This was probably because we used consumer panelists, whereas Peña-González et al. [32] used trained judges. The tenderness of meat by ultrasound treatment is affected by several factors, such as frequency, intensity, time, and the type of collagen in meat samples. Chang et al. [33] demonstrated that there was no effect of ultrasonication on collagen content in beef, however, protein aggregates formed in the extracellular spaces, could contribute to the tenderization of beef by ultrasound treatment [34].

3.2. Correspondence Analysis

The existence of statistical differences among the acceptability liking of beef samples was tested by means of a chi-square statistic. Additionally, simple correspondence analysis (CA) was performed in order to better visualize the information given by the panelists. CA is a popular graphical tool that is used to explore the symmetric association structure between categorical variables [35]. In the present study, correspondence maps were obtained to visualize association, firstly among treatments and consumer liking and, later, among the attributes evaluated (taste, smell, tenderness, and juiciness) and acceptability.

Figure 2 shows the correspondence analysis plot based on the treatments and acceptability of *Longissimus lumborum*. The two axes represented 99.46% (dimension 1, 71.29% and dimension 2, 28.71%) of association between treatments and responses by the consumer.

This plot demonstrates the association between the treatment and the level of consumer liking. Ultrasound (US) treatment was associated with the "neither like nor dislike" category, while the wet-aging for 5 d (WA5D) treatment was associated with "dislike very much". Furthermore, the dry-aging for 10 d (DA10D) and ultrasound and wet-aging for 10 d (USWA10D) treatments were both shown to be associated with the "like very much" category.

As mentioned above, significant differences were observed between treatments in the acceptability of the attributes (Table 1). Meat from DA10D and USWA10D treatments was scored as the most tender meat ($p < 0.05$). In addition, these two treatments were better numerically scored for smell, juiciness, and acceptability than the other treatments, although the differences were not significant ($p > 0.05$) (Table 1). The correspondence analysis showed that the ultrasound (US) treatment without aging was associated with the "neither like nor dislike" category. This relationship evidenced the importance of aging to increase consumer liking of meat. In contrast, the WA5D meat was positioned near the "dislike very much" category, probably because aging for five days was not enough to develop the consumers' desired tenderization of meat.

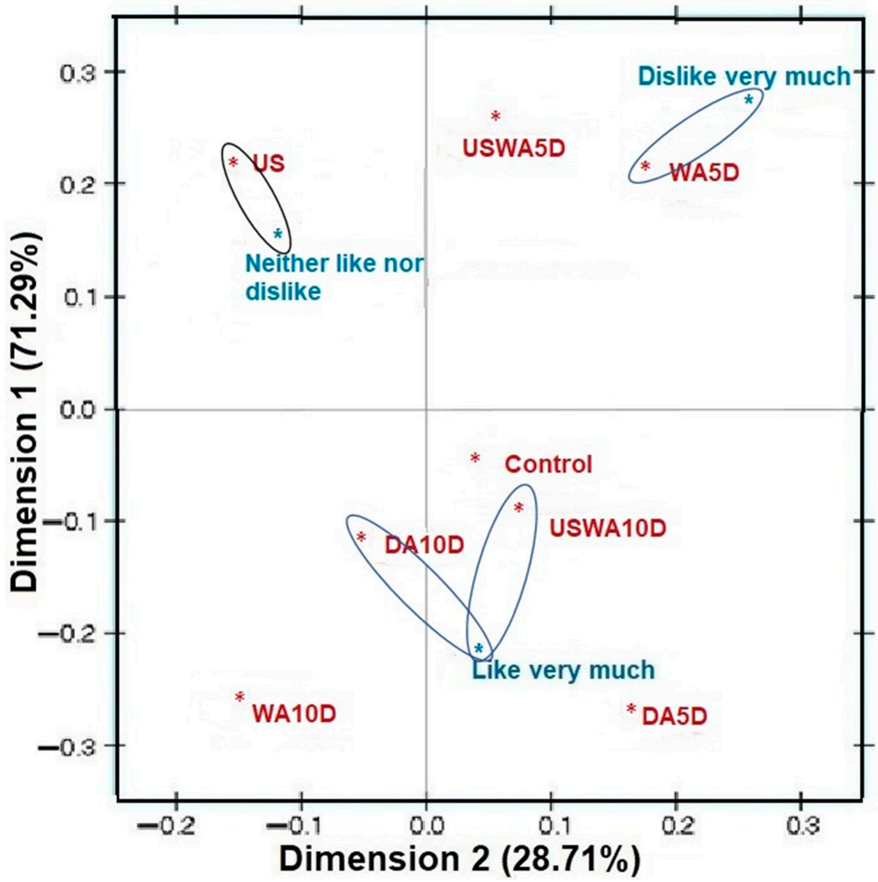

Figure 2. Correspondence analysis plot based on the treatments and general acceptability of *Longissimus lumborum* with two types of aging and ultrasound. (Control = meat without ultrasound or aging; US = ultrasound (90 W/cm^2, 37 kHz, 40 min); WA5D = wet-aging for 5 d; WA10D = wet-aging for 10 d; DA5D = dry-aging for 5 d; DA10D = dry-aging for 10 d; USWA5D = ultrasound and wet-aging for 5 d; USWA10D = ultrasound and wet-aging for 10 d). * Treatment (red), * Acceptability score (blue).

If the acceptability of meat improves with 10 d of wet-aging, we could hypothesize that ultrasound treatment produces effects on muscle quality that are dependent on storage time. Thus, for example, Alarcon-Rojo et al. [36] and Carrillo-Lopez et al. [37] reported an increase in muscle toughness immediately after ultrasound treatment (16–90 W/cm^2, 20 or 40 min), and subsequent tenderization with storage time (7 d). The ultrasound-treated meat becomes more tender as a result of the proteolysis caused by the ultrasonication after *postmortem* aging [36].

In addition, CA was used to compare multivariate configurations from the sensory attributes (taste, smell, tenderness, and juiciness) and liking scores (“dislike very much”, “neither like nor dislike”, and “like very much”) to assess the association between the perceptual maps obtained by these two sets of data. The association among Control, WA5D, DA5D, WA10D, and DA10D was significant ($p < 0.05$), and the CA results are shown in Figures 3–7. Correspondence analysis shows substantial differentiation among categories of consumer liking and sensory attributes. In general, the acceptability of attributes clearly distinguished one from the other. The sensory attributes (taste, smell, tenderness, and juiciness) were placed close to the consumers’ liking, indicating similarity in consumer answers.

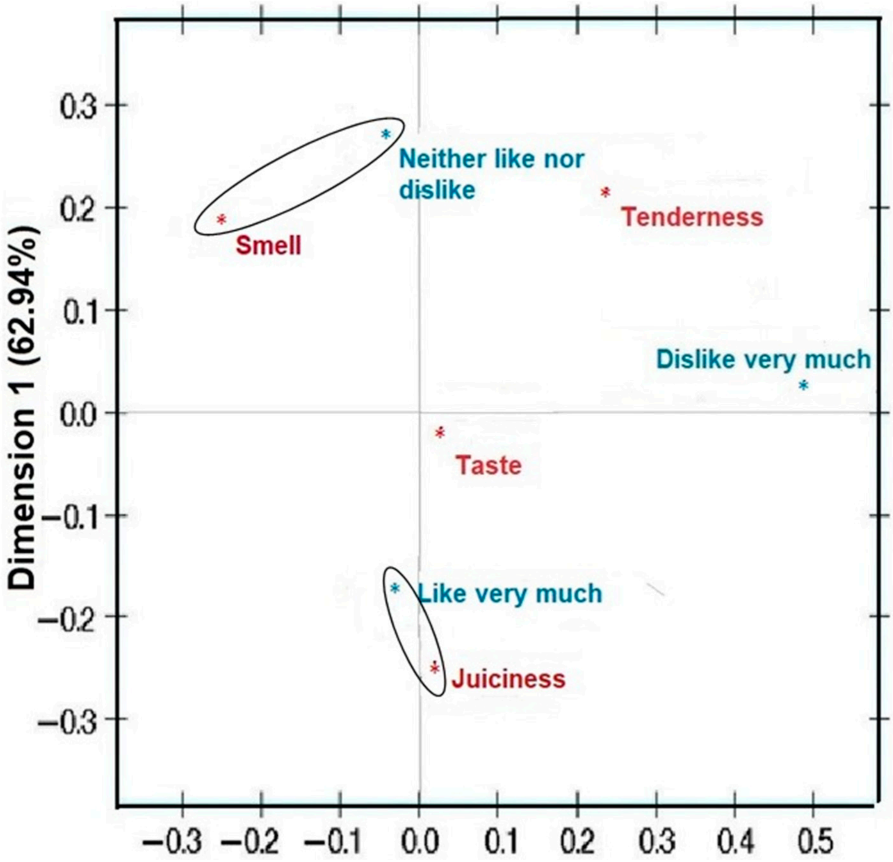

Figure 3. Correspondence analysis showing the two-dimensional plot (dimension 1 versus dimension 2) created using acceptability ("dislike very much", "neither like nor dislike", and "like very much") and sensory attributes (taste, smell, tenderness, and juiciness) as identified by consumers for the bovine *Longissimus lumborum* of the Control treatment (meat without ultrasound or aging). * Sensory attribute (red), * Acceptability score (blue).

The association among the US, USW5D, and USW10D treatments and the sensory attribute liking was not significant ($p > 0.05$), indicating that this association does not contribute to the discrimination of treatments, nor to grouping them according to the degree of consumer acceptability. Therefore, the correspondence tests of US, USW5D, and USW10D treatments are not shown in this document.

Figure 3 shows the two-dimensional plot created using acceptability and sensory attributes identified by consumers for the bovine *Longissimus lumborum* of the Control treatment (meat without ultrasound or aging). The two axes represented 100% of the total variance of the attribute liking (dimension 1, 62.94%, and dimension 2, 37.06%). There was a high association between consumer liking and sensory attribute. The juiciness of the Control meat was associated with the highest liking ("liked very much"), while its smell was associated with the "neither like nor dislike" sensory category. Likewise, the acceptability of the Control's juiciness was among the highest observed (5.47 ± 0.21, Table 1), although it was not significant ($p > 0.05$).

The correspondence analysis plot based on the consumer liking and sensory attributes as identified by consumers for the wet-aged for 5 d (WA5D) treatment is presented in Figure 4. The two axes accounted for 100% of the total variance (dimensions 1 and 2 with 84.27% and 15.73%, respectively). The CA shows that the tenderness of the WA5D meat sample was associated with the "neither like nor dislike" category, whereas the smell of that meat was the closest to the "like very much" category. This corroborates the results shown in Figure 2, where WA5D meat was also positioned near 'the 'dislike very much" category. This could be due to the low tenderization effect of storage at 5 d. The acceptability score of the smell of WA5D meat was not significantly different, but it showed a high numerical value (5.84) among treatments (Table 1). Beef smell was closely located to the "like very much" score; however, it was not highly influential in overall consumer acceptability, since smell was not significantly different (Table 1).

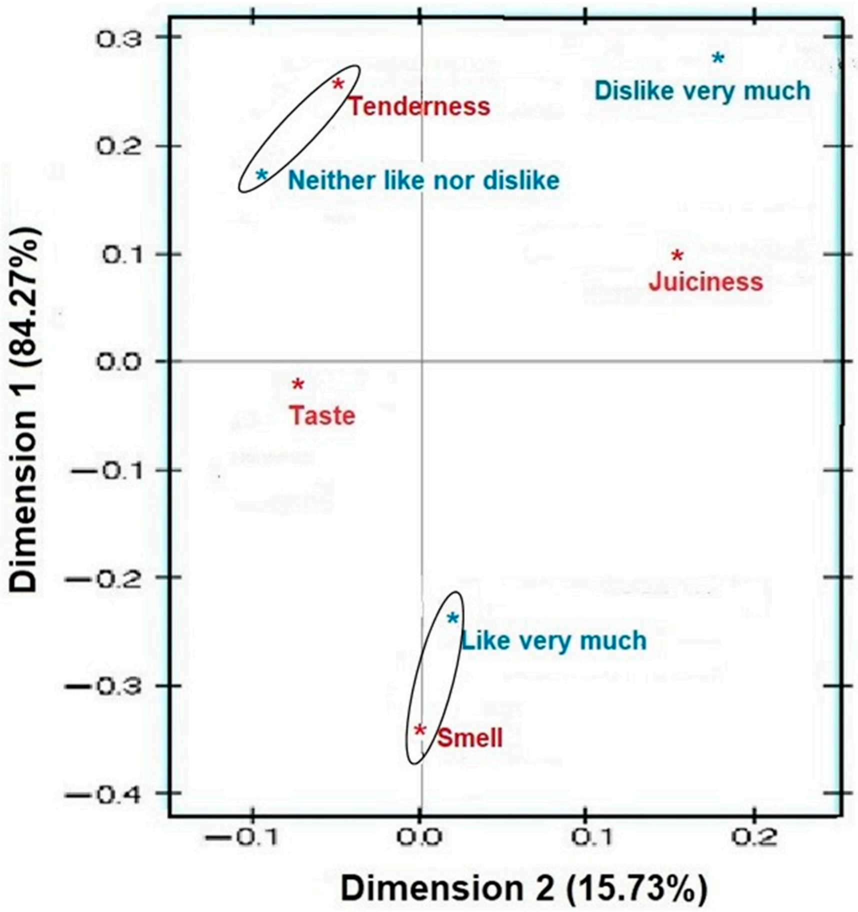

Figure 4. Correspondence analysis showing the two-dimensional plot (dimension 1 versus dimension 2) created using acceptability ("dislike very much", "neither like nor dislike", and "like very much") and sensory attributes (taste, smell, tenderness, and juiciness) as identified by consumers for the bovine *Longissimus lumborum* wet-aged for 5 d (WA5D). * Sensory attribute (red), * Acceptability score (blue).

The correspondence analysis plot based on consumer liking and sensory attributes of meat for the DA5D is shown in Figure 5. The two axes accounted for 100% of the total variance. Dry-aging is designed to improve taste and tenderness. The process is one of the oldest methods of keeping meat fresh. Dry-aged meat is suspended in a humidity-controlled environment to ensure exposure of all sides of the meat, allowing airflow around the entire cut of meat. Typically, the duration of dry-aging steak can be from 7 to 30 days or even months. In general, meat stored for 5 days under either dry- or wet-aging did not receive high acceptability scores (Figure 2). This is corroborated in Figure 5. The process of tenderization is initiated through calpain-mediated degradation. During meat storage, many proteolytic processes take place due to calpains—particularly μ-calpain—but this process can take up to 14 days [38].

Dimension 1 explains most of the variability (86.48%) in 5 d dry-aged beef (Figure 5). According to the categories that discriminate the most, for the 5 d dry-aged meat (DA5D), the odor was described as "dislike very much" ($p < 0.05$). The other categories were quite close to the origin and presented little association (juiciness, tenderness, and taste) with the level of liking. Beef carcasses that are dry-aged are directly stored under controlled environmental conditions while maintaining the temperature, relative humidity, and air flow [3]. By maintaining these factors, dry-aging can be achieved with maximum organoleptic characteristics [1,16]. A previous study showed that dry-aged beef has a different volatile profile from that of wet-aged beef [11,15]. Dry aging longer than 40 d is considered to have negative impact on the quality of beef due to lipid oxidation and microbial spoilage [9,20]. Dry-aged samples of beef contain a higher content of odorous compounds; specifically, the aromatic profile of dry-aged beef is characterized by higher earthy (acetone, 2-methylpropnanal), meaty (3,5-diethyl-2-methyl-pyrazine), barbecue (E-2-nonenal), roasted (2-acetyl-2-thiazoline), and fatty (p-cresol) odors [39,40].

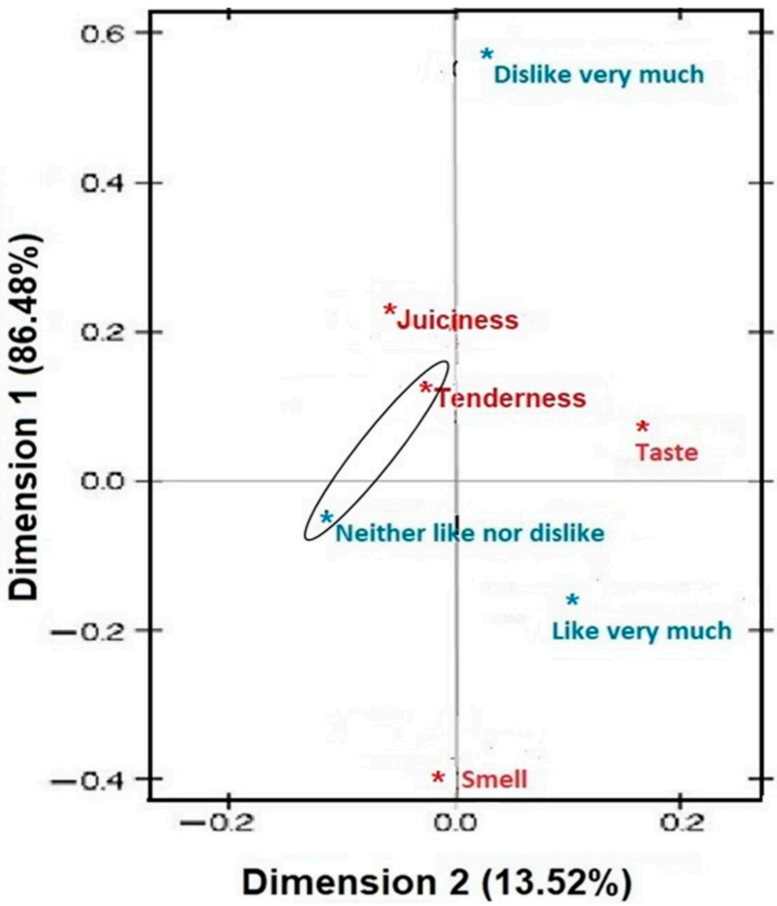

Figure 5. Correspondence analysis showing the two-dimensional plot (dimension 1 versus dimension 2) created using acceptability ("dislike very much", "neither like nor dislike", and "like very much") and sensory attributes (taste, smell, tenderness, and juiciness) as identified by consumers for the bovine *Longissimus lumborum* dry-aged for 5 d (DA5D). * Sensory attribute (red), * Acceptability score (blue).

In wet-aged meat for 10 d, the dimension 1 explains 96.40% of the variability (Figure 6). For WA10D, the juiciness was associated with the "neither like nor dislike" scoring ($p < 0.05$), and taste and smell were the closest to the "dislike very much" category. According to Table 1, this treatment had the highest general acceptability, although it was not statistically significant ($p > 0.05$). Increased level of fats in beef steaks which are wet-aged are responsible for producing a better flavor profile than in the dry-aged beef steaks. The reason is not fully understood, even in both methods where the loss of moisture concentrates the protein and fat. Both dry-aged and wet-aged beef samples show different chemically produced volatile compounds due to two different ways of aging, but it is important to note that compounds have different (positive or negative) flavor/odor notes to different consumers [41]. Wet-aged meat presents a mild flavor, fresh taste, tender, and juicy texture, which is due to the aging meat essentially sitting in its own juices. Both dry-aged and wet-aged meat enhance the taste and texture of the meat. In the process of wet-aging, the portioned beef is placed in vacuum-sealed bags and kept at a low temperature just above freezing. The wet-aging process typically lasts up to 10 d. During this time, the naturally occurring enzymes are able to tenderize the meat [36].

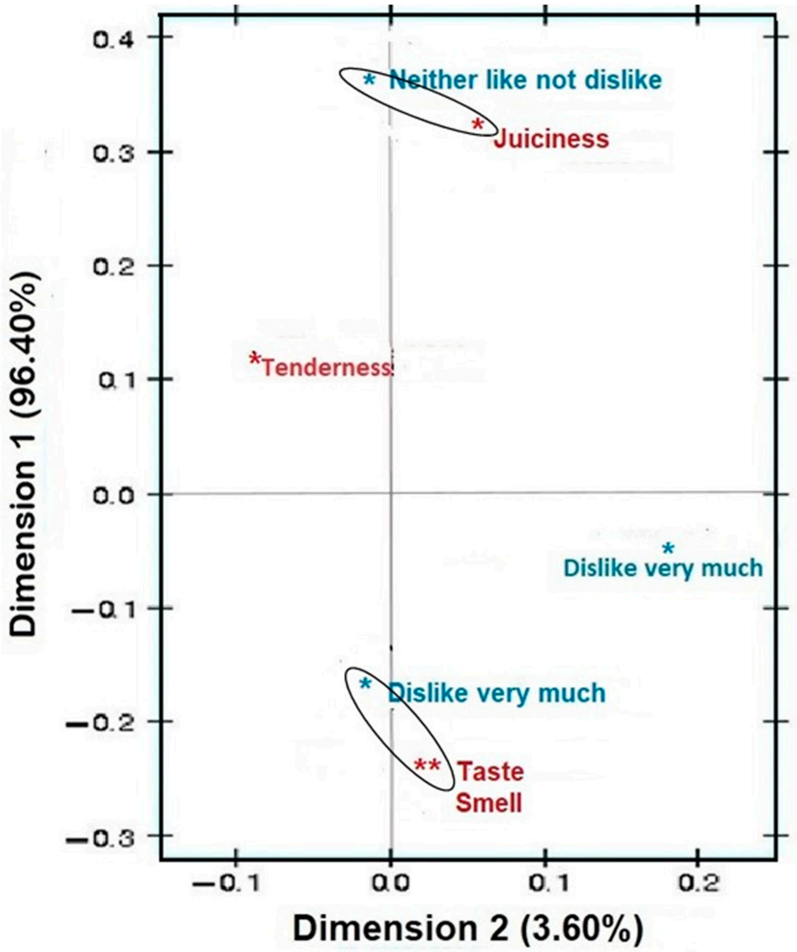

Figure 6. Correspondence analysis showing the two-dimensional plot (dimension 1 versus dimension 2) created using acceptability ("dislike very much", "neither like nor dislike", and "like very much") and sensory attributes (taste, smell, tenderness, and juiciness) as identified by consumers for the bovine *Longissimus lumborum* wet-aged for 10 d (WA10D). * Sensory attribute (red), * Acceptability score (blue).

The flavor development of cooked meat is enhanced through aging [41]. During meat aging, several chemical changes are observed in numerous chemical constituents, such as sugars, organic acids, peptides, free amino acids, and nucleotide metabolites. Daszkiewicz et al. [41] reported a more intense taste in beef samples of m. *Longissimus lumborum* conditioned at 0–2 °C and stored for longer periods of time (10–14 d), in comparison to those conditioned for 3–7 d [42,43]. Although no changes in moisture content by muscle type (top round and shank) or aging method (dry or wet) have been observed, the free fatty acids and amino acids present in aged meat [44], as well as flavors, such as umami and salty, could influence the low acceptance in the juiciness of the meat aged for 5 d.

The willingness of consumers to purchase dry- or wet-aged steaks of choice striploin is not different or dependent upon sensorial tenderness [45]. Meanwhile, in other beef quality cuts, such as prime striploin, the wet-aged striploin was more tender than the dry-aged striploin. When compared by consumer liking, the prime wet-aged loins were more liked by consumers than prime dry-aged loins, based on all sensory traits, such as smell, juiciness, and tenderness, among others [46]. Similar results of acceptability were obtained in the present study for the meat wet-aged for 10 d.

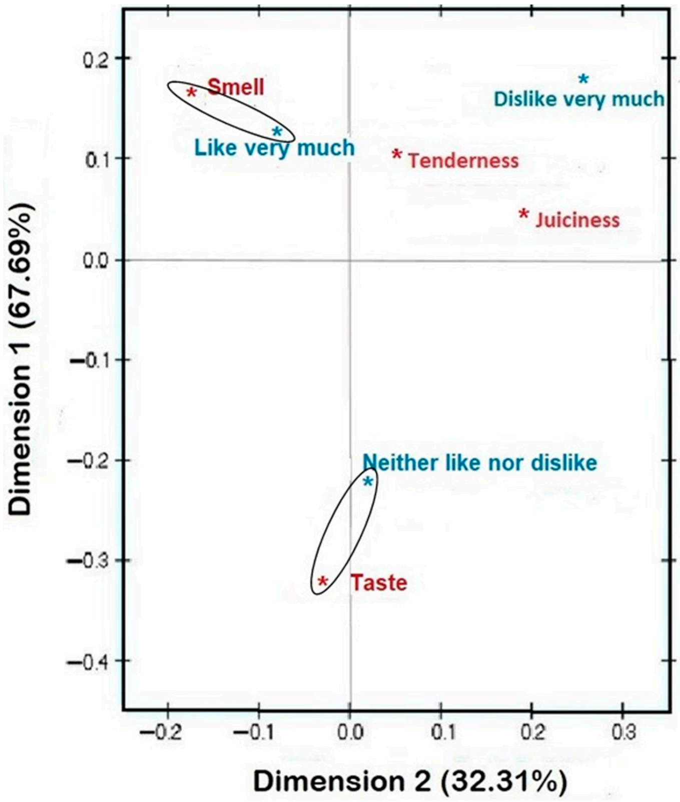

Figure 7. Correspondence analysis showing the two-dimensional plot (dimension 1 versus dimension 2) created using acceptability ("dislike very much", "neither like nor dislike", and "like very much") and sensory attributes (taste, smell, tenderness, and juiciness) as identified by consumers for the bovine *Longissimus lumborum* dry-aged for 10 d (DA10D). * Sensory attribute (red), * Acceptability score (blue).

In the dry-aged beef for 10 d (DA10D) the most noticeable result ($p < 0.05$) was the "neither like nor dislike" of taste (Figure 7), although it has been reported that dry-aging for up to 28 d improves consumer acceptability [47]. In Mexico, the consumption of dry-aged beef is not common, so sensory characteristics associated with the increase in flavor and aroma due to the release of free fatty acids that react with proteins and other precursors may decrease aroma acceptability [48]. One of the reasons for the taste development in dry-aging beef is the high concentration of many compounds responsible for flavor as a result of humidity losses [45]. The process of dry-aging produces fully tender, highly flavored beef which has pure beefy notes. With this process, the shear force and compression shear decline, leading to increased tenderness, juiciness, pH, and increase in flavor compound concentration [49]. The mentioned changes in dry-aged meat are the reasons consumers are attracted to this beef no matter the cost [5].

It is considered that dry-aging develops unique and distinct flavors, facilitates oxidative changes in lipids, enhances formation of volatile compounds, and enhances moisture loss during aging, which may contribute to the development of a more pronounced meat flavor resulting from the concentration of meat flavor compounds in dry-aged meats [42]. The latter assessment was not supported in this study, since consumers were not able to detect taste differences between treatments, including the wet- and the dry-aging methods.

In Latin American countries, beef carcasses are marketed within 2–7 d *postmortem* without the use of aging to improve their palatability [29]. Consequently, the beef in domestic markets has excessive variation in palatability, and it is difficult to target desired levels of tenderness and product consistency. Under these production and commercialization conditions, it is difficult to guarantee consumer satisfaction with beef [50]. In the present study, the two aging methods had the same acceptability and similar perceptions of taste, juiciness, and smell characteristics (Table 1). This suggests that consumers are only able to perceive important differences in the texture characteristic.

Although wet-aging is a faster process, the enzymes do not have enough time to change the meat as substantially as in the dry-aging process. The result is that wet-aged meat is tender but not as tender as dry-aged meat. However, ultrasonication could help to achieve similar tenderization to the one obtained with the dry-aging method. This effect was observed in the present experiment (Table 1), where the tenderness of beef aged for 10 d with the wet- or dry method received the highest consumer acceptability.

Based on the results of the present study, it is important to consider analytical measurements of odor and flavor components in the aged samples. Furthermore, the complementation of this results with a trained panel analysis would allow us to explore in more detail the acceptability of the sensory attributes of meat subjected to ultrasound and different aging methods.

4. Conclusions

The most relevant conclusion is that ultrasonicated and wet-aged meat for 10 d yields the same tenderness liking as the dry-aged meat for 10 d. Since the wet-aging process is much more cost-effective and affordable, ultrasound offers the possibility to obtain tender meat without the cost/risk implications of the dry-aging method. In this way, sonicated aged beef will make the meat less expensive, and still produce the value of a similar aging to dry-aged beef. It is still important to understand the effect of ultrasonication on the aged meat to illustrate the mechanisms responsible for modifications in proteins, affecting the sensory quality of meat. Evaluation of the samples by a trained sensory panel is suggested to look for specific characteristics that determine the acceptability of sonicated and wet-aged meat. The low level of liking in the acceptability of smell and taste of aged meat (dry or wet) seems to be associated with the low consumption of aged meat in Mexico.

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