International Journal of Gastronomy and Food Science 35 (2024) 100889

Contents lists available at ScienceDirect

International Journal of Gastronomy and Food Science

journal homepage: www.elsevier.com/locate/ijgfs

Establishment of a tenderness screening index for beef cuts using instrumental and sensory texture evaluations

Sara Ricardo-Rodrigues [a], Marta Laranjo [a,b], Miguel Elias [a,c], Maria Eduarda Potes [a,b], Ana Cristina Agulheiro-Santos [a,c,*]

[a] MED-Mediterranean Institute for Agriculture, Environment and Development & CHANGE-Global Change and Sustainability Institute, IIFA-Instituto de Investigação e Formação Avançada, Universidade de Évora, Pólo da Mitra, Ap. 94, 7006-554, Évora, Portugal

[b] Departamento de Medicina Veterinária, Escola de Ciências e Tecnologia, Universidade de Évora, Pólo da Mitra, Ap. 94, 7006-554, Évora, Portugal

[c] Departamento de Fitotecnia, Escola de Ciências e Tecnologia, Universidade de Évora, Pólo da Mitra, Ap. 94, 7006-554, Évora, Portugal

ARTICLE INFO

Keywords:
Warner-bratzler shear force
Texture profile analysis
Hardness
Consumers
Tenderness threshold

ABSTRACT

Meat tenderness is important for assessing quality and can be defined as the ease to chew meat, depending on several factors. The aim of this study was to establish a tenderness screening index. Moreover, we also wanted to study the socio-demographic characteristics of consumers and understand their preferences and meat consumption habits. 192 consumers were called to perform a sensory analysis to evaluate beef tenderness after grilling and classify it according to distinct tenderness classes: 1-very hard; 2-hard; 3-ideal tenderness; 4-tender; 5-very tender. Chi-square analyses were used to analyse the consumers' survey and non-parametric tests were performed to assess differences between groups. A beef tenderness screening index was established based on Texture Profile Analysis (TPA) hard-ness and Warner-Bratzler Shear Force (WBSF), using a multiple regression analysis to establish the tenderness threshold. According to the validated model, a beef cut is tender when WBSF is below 39.60 N and simultaneously TPA hardness is below 31.89 N. In this study, tenderness thresholds for beef cuts were established through the relationship between instrumental and sensory consumer evaluations.

1. Introduction

Tenderness is a fundamental trait for meat quality. Meat tenderness can be defined as the easiness to chew meat. Moreover, connective tissue and cross-links, myofibrillar integrity, sarcomere length, protein denaturation and intramuscular fat can be considered as the major determinants of meat tenderness (Purchas, 2024; Warner et al., 2022).

According to several studies on meat, the main textural feature influencing the intention to buy again is meat tenderness, and the consumer is willing to pay a higher price for meat that is guaranteed tender (De Devitiis et al., 2023; Warner et al., 2022). However, tenderness has long been known as a highly variable property, depending on many intrinsic and extrinsic factors, as well as on their interaction (Bouton et al., 1978). Several studies have reported taste (flavour), tenderness, juiciness, freshness, and nutritional value as some of the most valued intrinsic quality attributes for beef (Almli et al., 2013). Moreover, animal breed, age, feed, and management have been reported as extrinsic factors (Destefanis et al., 2008). Therefore, meat hardness can be considered a limiting factor for consumer acceptability and a reason for dissatisfaction and reduced beef consumption. For this reason, the consumer's opinion is extremely important to establish value and justifying the purchase decision (Destefanis et al., 2008).

Establishing a tenderness threshold could serve as a precise quality control system at the retail level to guarantee tender meat and to ensure consumer acceptability. A threshold can be defined as a position on the sensory stimulus scale at which a transition occurs in a series of sensations or judgements (Holman and Hopkins, 2021).

Tenderness can be assessed by either instrumental methods (Warner-Bratzler Shear Force and Texture Profile Analysis) or sensory evaluation, in the latter case using untrained consumers or a trained panel (Sasaki et al., 2014; Van Wezemael et al., 2014; Warner et al., 2022). The Warner-Bratzler test measures the maximum shear force of cutting using a standard V-shaped blade through a meat sample perpendicular to the longitudinal positioning of the muscle fibres (Novaković and Tomašević, 2017). Texture Profile Analysis (TPA) is a compression technique that provides numerous primary parameters determined directly from the obtained force/time graph (hardness, adhesiveness, springiness and cohesiveness) and the secondary parameters are calculated from the

* Corresponding author. Departamento de Fitotecnia, Escola de Ciências e Tecnologia, Universidade de Évora, Pólo da Mitra, Ap. 94, 7006-554, Évora, Portugal.
E-mail address: acsantos@uevora.pt (A.C. Agulheiro-Santos).

https://doi.org/10.1016/j.ijgfs.2024.100889
Received 27 September 2023; Received in revised form 20 January 2024; Accepted 5 February 2024
Available online 10 February 2024
1878-450X/

primary parameters (gumminess, chewiness, and resilience) (Honikel, 1997; Szczesniak, 2002). The test mimics the mouth biting action by a two-cycle compression and is widely applied to food products, especially meat and meat products (Schreuders et al., 2021). Both Warner-Bratzler Shear Force (WBSF) and TPA are classical instrumental methods used to estimate meat tenderness (Novaković and Tomašević, 2017; Schreuders et al., 2021). In order to assure meat quality, it is necessary and urgent to standardise texture instrumental methodologies, between standard laboratory equipment and easy-to-use portable devices, and associate these with sensory evaluation (Agulheiro-Santos and Roseiro, 2012; Baldassini et al., 2021; Warner et al., 2021).

Although mechanical tenderness is reported to be highly different than sensory tenderness of the muscle (Van Wezemael et al., 2014), previous reports indicate that TPA and WBSF have similar abilities to predict sensory assessment of tenderness and subjective characteristics of beef. Nevertheless, there is limited information for comparing these two instrumental methods under similar test conditions (Caine et al., 2003; Chinzorig and Hwang, 2018; Ruiz de Huidobro et al., 2005). A recent review has highlighted that although meat tenderness is usually assessed by WBSF, TPA is a better associated with sensory evaluation (Holman and Hopkins, 2021). One of the few studies to compare TPA parameters obtained using a flat-ended cylindrical compression probe and WBSF was that of Caine et al. (2003), which concluded that TPA parameters explained better the changes in sensory perception than WBSF. Similarly, Chinzorig and Hwang (2018) reported tenderness of the muscle to be likely related to TPA hardness for beef and that WBSF is not a good predictor for tenderness in tougher muscles. Moreover, WBSF values have may not fully agree with sensory evaluation (Warner et al., 2021). However, other authors have reported shear force to be a better predictor of tenderness than compression (Perry et al., 2001).

Early consumer studies have identified WBSF-based tenderness threshold levels (Miller et al., 2001; Shackelford et al., 1991). Furthermore, several studies have been conducted to establish meat tenderness indices through consumer perception (Destefanis et al., 2008; Rodas-González et al., 2009; Van Wezemael et al., 2014).

Additionally, the “Ranking of beef muscles for tenderness” of the “Cattlemen’s Beef Board and National Cattlemen’s Beef Association” (Sullivan and Calkins, 2011) (https://www.beefresearch.org/) considers three tenderness classes based on the WBSF values: tender (<38.25 N), intermediate (38.25–45.11 N), and tough (>45.11 N). According to this ranking, tenderloin is classed as tender, sirloin, and knuckle as intermediate, and silverside as tough.

On the other hand, the American Society for Testing and Materials (ASTM International) has set WBSF standards for tenderness certification, certifying beef with a WBSF value of 43.25 N or lower as “Certified Tender” and of 38.25 N and lower as “Certified Very Tender” (ASTM, 2011). Most tenderloin samples (~95%) used in the present study meet the WBSF criteria for the USDA “Certified Very Tender” claim.

The present study aims to establish a tenderness screening index with TPA and WBSF thresholds for beef cuts through the relationship between instrumental and sensory consumer evaluations. Although several reports in the literature have set a WBSF for tender beef, the present study also includes a socio-demographic survey on consumer preferences associated to beef consumption habits and preferences. The establishment of a beef tenderness screening index considering consumer preferences may allow the food industry to better decide on which destination to give each beef cut according to its instrumental texture.

2. Materials and methods

2.1. Sample preparation

Commercial beef cuts were purchased from local butchers in Évora, Portugal, in five different days and four specific beef cuts were intentionally chosen to cover a wide spectrum of tenderness. This procedure was adopted to ensure a fully independent set of samples, and to provide a broad range in tenderness, independent of meat origin and age. Apart from the existing differences between animals and carcasses from distinct breeds, there were also marked differences between beef cuts. Meat cuts reflect the gastronomic culture of each country or region and the preparations to which its consumers have become accustomed (for a visual comparison, please consult https://bifelovers.pt/bovino/versatilidade/carcacas-por-paises/).

In each day, one sample of each of the following beef cuts was used: tenderloin (psoas major), sirloin/striploin (longissimus thoracis et lumborum), knuckle (quadriceps femoris), and silverside (gluteobiceps and semitendinosus) (Fraústo da Silva et al., 1998). Each beef cut was sliced into eight steaks (2.5 cm thick), four for the evaluation of instrumental texture, and the other four for sensory analysis, in an interspersed order.

Briefly, the experimental design for instrumental analyses was as follows: 5 days * 4 meat cuts * 4 steaks * 12 replicates (6 for TPA and 6 for WBSF), making a total of 480 samples. Regarding sensory analyses, a panel of 223 consumers tasted one sample per meat cut, with the following experimental layout: 5 days * 4 steaks * 12 replicates, corresponding to 240 samples per meat cut.

2.2. Cooking method

The initial temperature of beef cuts was 4 ± 1 °C.

Steaks (2.5 cm thick, with a surface area between 30 and 65 cm^2) of each beef cut were grilled in an electric grill (Grill Plancha 4743, FLAMA, Aveiro, Portugal) with a non-stick coating. Steaks were turned when the internal beef temperature reached 35 °C and removed when an internal cooking temperature of 71 °C was reached (medium degree of doneness) (Fabre et al., 2018; Wall et al., 2019). To monitor the internal steak temperature throughout the grilling, a portable digital thermometer TESTO 106 (Testo SE & Co. KGaA, Lenzkirch, Germany) was used.

Grilling was chosen as cooking method because it is normally used by consumers for cooking beef at home (Fabre et al., 2018).

To determine tenderness, samples for both instrumental tests and sensory analysis were grilled in the same day.

2.3. Sensory evaluation

Sensory evaluation was performed in five sessions, with four beef cuts per session, by 223 Portuguese consumers, differing in sex, age, and levels of education. Each consumer participated in only one session.

Samples were cooked following the abovementioned proceeding, and served warm (approximately 60 °C), immediately after cooking, in a covered white plate labelled with a three-digit code (Wall et al., 2019). After cooking, steaks were cut into cuboidal portions (1.0 x 1.0 × 2.5 cm), identical to the cores used for WBSF evaluation, taking care to avoid large pieces of fat or connective tissue.

Consumers were asked to rate beef consumption frequency, beef cooking methods, and beef overall likeness, prior to tasting. After tasting each sample, consumers were further asked to assess which tenderness category was most appropriate for each one of four different commercial beef cuts, considering an affective acceptance test through a 5-category hedonic scale (Destefanis et al., 2008): 1-Very Hard, 2-Hard, 3-Ideal Tenderness, 4-Tender and 5-Very Tender.

2.4. Instrumental texture evaluation

Two methods widely used for meat texture evaluation were considered: WBSF and TPA.

Samples were cooked following the abovementioned cooking method. After cooking, steaks were placed on trays and allowed to reach room temperature (20 ± 1 °C) before TPA and WBSF measurements.

In each of the five days, and for both methods, four steaks per beef cut were analysed, with six replicate measurements per steak, in a total of 480 samples.

2.4.1. Texture profile analysis

TPA was performed using a texture analyser TA. HD.Plus (©Stable Micro Systems Ltd., UK), equipped with a cylindrical flat-ended probe with an area of 1 cm^2. Steaks were compressed twice, perpendicular to the muscle fibre orientation, in two consecutive cycles of 50% compression, with 5 s intervals between cycles, at a constant speed of 1 mm s−1. Force-time curves were used to calculate TPA hardness, expressed in Newton (N), considered as the maximum force of the first compression cycle.

2.4.2. Warner-bratzler shear force

After TPA, six cores with a square cross-section (1.0 x 1.0 × 2.5 cm) were cut from each steak, parallel to the muscle fibre orientation (Silva et al., 2015). Each core was sheared perpendicular to the muscle fibres with a V-shaped cutting blade attached to a texture analyser TA. HD.Plus (©Stable Mycro Systems Ltd., UK) (Veiseth-Kent et al., 2018). A down stroke distance of 35 mm was considered for the probe to completely cut the core, at a speed of 1.0 mm s-1. The maximum shear force in N was recorded at the highest peak of the curve, corresponding to the maximum physical force required to cut through a beef sample.

2.5. Statistical analysis

All data were analysed using STATISTICA v.12.0 software from Statsoft (StatSoft Inc., 1984–2014, Tulsa, OK, USA). Outliers were detected using the Grubbs test for each meat cut separately (α = 0.05).

Chi-square analyses were used to test differences among beef consumption frequencies, beef cooking methods, and beef overall likeness between gender, age, and level of education groups.

A Principal Component Analysis (PCA) was carried out using all data from both sensory analysis and texture evaluation for all consumers.

The Kolmogorov-Smirnov test was applied to verify if the data follow a normal distribution, and the Levene statistics to evaluate the homogeneity of variances.

Non-parametric Kruskal-Wallis tests were performed to determine if there are statistically significant differences between groups. The Dunn-Bonferroni test was used as a post hoc procedure for pairwise multiple comparisons.

A multiple regression analysis of both TPA and WBSF values on the tenderness scores of consumers was applied to define a tenderness threshold considering the five sensory evaluation classes and both TPA hardness and WBSF. A total of 384 samples (96 per meat cut), was used to define the threshold, taking into account the sensory analysis carried out by 192 consumers. An independent set of 96 beef samples (24 per meat cut) was used to validate the proposed tenderness screening index. This validation was performed by a different consumer panel (n = 31).

3. Results

The consumer survey included a characterisation of individuals in terms of age, gender, and education level, as well as three questions regarding beef consumption. The results are shown in Table 1.

No association was found between beef consumption frequency and age (X^2 = 9.042, df = 15, p = 0.875), beef consumption frequency and gender (X^2 = 4.914, df = 5, p = 0.426), or beef consumption frequency and education level (X^2 = 13.829, df = 20, p = 0.839); beef cooking methods and age (X^2 = 11.371, df = 12, p = 0.497), beef cooking methods and gender (X^2 = 3.622, df = 4, p = 0.459), or beef cooking methods and education level (X^2 = 9.347, df = 16, p = 0.898); and beef overall likeness and age (X^2 = 9.720, df = 9, p = 0.374), beef overall likeness and gender (X^2 = 4.317, df = 3, p = 0.229), or beef overall likeness and education level (X^2 = 7.318, df = 12, p = 0.840).

A sensory analysis of grilled beef samples was conducted with consumers that evaluated several independent beef samples from four distinct beef cuts. The results are shown in Fig. 1. No outliers were identified.

Table 1
Demographic characteristics and beef purchasing habits of consumers (n = 223) who participated in sensory panels.

Variable/Question asked	Response	Percentage (%)
Gender	Male	53.8
	Female	46.2
Age (in years)	15–21	29.1
	22–30	21.8
	31–45	25.9
	46–71	23.2
Education level	Non-high school graduate	10.9
	High-school graduate	42.5
	Bachelor's degree	27.1
	Master's degree	8.6
	PhD degree	10.9
Beef consumption frequency	Never	0.9
	Less than once a month	9.9
	1 to 2 times a month	31.0
	1 to 2 times a week	41.7
	3 times or more a week	15.2
	Everyday	1.3
Beef cooking method	Roasted	22.1
	Boiled	13.2
	Grilled	53.3
	Fried	9.7
	Another	1.7
Beef overall likeness	I like it a lot	50.2
	I like it slightly	40.4
	I neither like it nor dislike it	6.7
	I don't like it	2.7
	I can't eat	0.0

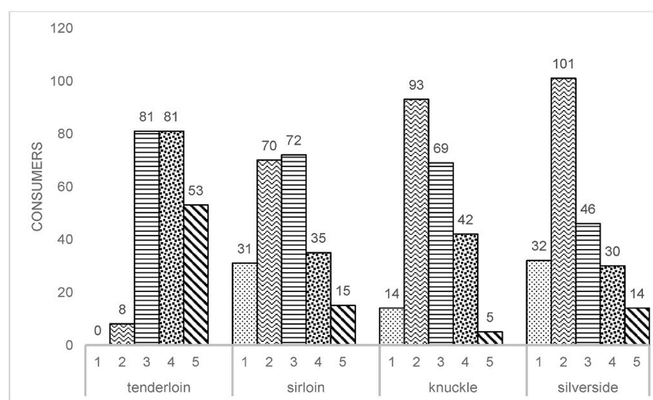

Fig. 1. Sensory tenderness evaluation by consumers (n = 223) for the different beef cuts, according to the scale mentioned below the graph.

Most consumers considered the tenderloin (96.4%), the sirloin (54.7%), and the knuckle (52.0%) to be tender (ideal tenderness, tender, or very tender). Nevertheless, there are huge differences between these three beef cuts, with the tenderloin definitely being recognised as the most highly valued and tender beef cut (Van Wezemael et al., 2014; Vaskoska et al., 2020). Moreover, it should be noted that some of the knuckle cuts used for both instrumental analysis and sensory evaluation were reported as being particularly tender to what can be expected as usual from this beef cut. On the other hand, most consumers considered the silverside to be hard or very hard (59.6%).

Regarding instrumental texture analysis, WBSF values varied between 11.24 and 71.24 N, while TPA hardness values varied between 0.84 and 105.50 N, all beef cuts considered (Table 2). No outliers were identified.

Both WBSF and TPA hardness values were not normally distributed, and the variances were not homogeneous. Therefore, nonparametric statistics were used to analyse data. The Kruskal-Wallis test indicated that both WBSF and TPA hardness significantly discriminated among samples (p < 0.001) (Table 2).

Table 2
Descriptive statistics and tenderness thresholds for different beef cuts.

Beef cuts	Instrumental evaluation (n = 384)				Multiple Regression	
	Hardness (N)		Shear Force (N)		Hardness (N)	Shear Force (N)
	mean ± std	range (min-max)	mean ± std	range (min-max)		
tenderloin (n = 96)	14.43 [a] ± 5.61	6.10–30.10	27.58 [a] ± 6.86	11.24–48.53	31.89	39.60
sirloin (n = 96)	23.42 [c] ± 14.97	2.46–91.06	35.18 [b] ± 12.94	13.84–67.60		
knuckle (n = 96)	19.58 [b] ± 10.43	0.84–44.50	35.56 [b] ± 8.63	19.80–60.44		
silverside (n = 96)	29.27 [c] ± 19.52	4.42–105.50	33.66 [b] ± 12.11	16.69–71.24		

In the same column, different letters (a, b, and c) represent significantly different means ($p < 0.05$).

Regarding TPA hardness, tenderloin is the most tender beef cut, which was awaited. The beef cut expected to be next in tenderness should be sirloin, however, the variability observed within sirloin samples resulted in some knuckle samples being tender than sirloin (Table 2).

According to the proposed multiple regression model, a beef cut is tender when WBSF is below 39.60 N and simultaneously TPA hardness is below 31.89 N (Table 3). Both parameters are used to establish a tenderness screening index for beef samples. Moreover, the validation results showed a correlation between the sensory and instrumental evaluation of beef tenderness.

Furthermore, this study found an association between WBSF values and consumer tenderness scores ($R^2 = 0.64$).

A Principal Component Analysis (PCA) was run for both instrumental texture parameters (WBSF and TPA hardness) and sensory evaluation to further validate our tenderness screening index, using the whole set of consumer evaluations (n = 223) (Fig. 2).

Two principal components were extracted, which explain 99.47% of the observed variance: PC1 accounted for 87.22%, and PC2 for 12.25%. The first component (PC1) divided tenderloin samples from all other beef cuts. The second component (PC2) separated silverside from sirloin and knuckle, which are both on the same quadrant. Moreover, PCA revealed an association between tenderloin and tenderness evaluated by consumers. Additionally, there is a negative correlation between tenderness and both instrumental parameters (WBSF and TPA hardness). Regarding instrumental parameters, the PCA projection of variables revealed a very close relationship between hardness evaluated by TPA and the silverside, and between WBSF and both sirloin and knuckle. It seems that both instrumental tests exhibited a higher accuracy to evaluate less tender beef samples.

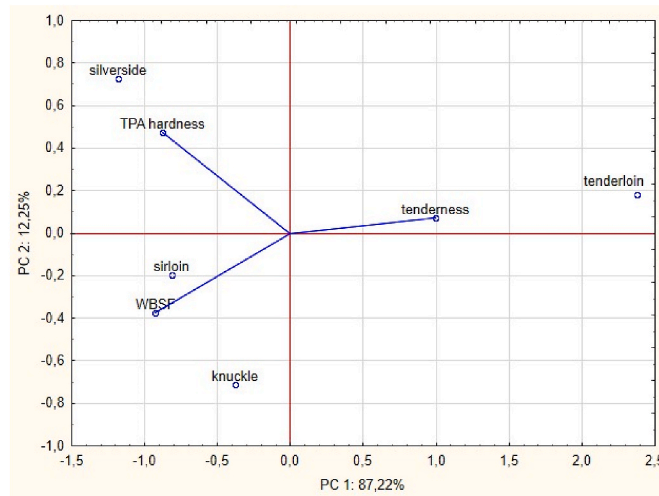

Fig. 2. Principal Component Analysis (PCA). Projection of variables (TPA hardness, WBSF and sensory tenderness) and samples on the factor-plane, considering the different beef cuts.

4. Discussion

Several studies have been published on the socio-demographic characterisation of consumers regarding beef consumption preferences (Almli et al., 2013; Paiva et al., 2022; Reicks et al., 2011; Strydom et al., 2019). The results of the present study showed that there is no association between beef consumption frequency, beef cooking method, or beef overall likes, and age, gender, or education level. In agreement with our findings, Sasaki et al. (2014) also reported age and gender not to influence beef consumption preferences. On the contrary, other authors have reported an association between age, gender or education level and the beef consumption preferences of consumers (Reicks et al., 2011; Yang et al., 2021). Reicks et al. (2011) reported tenderness as being more important for women than for men in the decision to buy beef steaks. Moreover, consumers over 41 years considered tenderness as an important motivation for buying beef steaks more than younger consumers (Reicks et al., 2011).

Table 3
Validation of the tenderness screening index model for different beef cuts using instrumental and sensory texture evaluations.

Beef cuts	Instrumental evaluation		Predicted tenderness[a]	Sensory evaluation (n = 31) Percentage of agreement (%)
	Hardness (N)	Shear Force (N)		
tenderloin	13.56 [a] ± 7.74	18.86 [a] ± 4.81	tender	100%
sirloin	41.45 [b] ± 12.40	40.06 [b] ± 14.41	hard	68%
knuckle	18.99 [a] ± 9.89	32.02 [ab] ± 14.59	tender	45%
silverside	44.15 [b] ± 3.40	31.67 [ab] ± 7.44	hard/**tender**[b]	29%/**71%**

[a] Predicted result according to the Multiple Regression model.
[b] Different results according to either TPA or WBSF.

A similar broad range of WBSF values has been reported by other authors for beef striploin samples (13.3–83.5 N) (Holman et al., 2020).

A similar relationship between sensory and instrumental evaluation of beef tenderness was also reported by Miller et al. (2001) who found out that consumers were able to distinguish meat into different tenderness categories and could detect changes in tenderness similar to those found with WBSF. Nevertheless, a correct definition of the threshold must always consider both instrumental evaluation methods, WBSF and TPA, which is justified by the chewing process occurring in the mouth, during which the food is broken down into small particles by a combination of compressive, shear and tensile forces (Szczesniak, 2002).

Rodas-González et al. (2009) used a simple linear regression to establish a tenderness threshold for beef steaks and considered them to be tender for WBSF values equal to or less than 37.98 N, which is very similar to the threshold proposed in the present study.

According to our model, a beef cut is considered tender when WBSF is below 39.60 N and simultaneously TPA hardness is below 31.89, which allows us to classify the tested beef samples in decreasing order of tenderness as follows: tenderloin, knuckle, sirloin, and silverside. This was unexpected and is probably due to the high variability observed within sirloin samples, which resulted in knuckle samples being generally tender than sirloin. This is in agreement with Sullivan and Calkins (2011), that ranked tenderloin as tender, sirloin and knuckle as intermediate, and silverside as tough.

A recent study has reported a tenderness threshold of 26 N, assuring that beef samples would at least be moderately juicy (Martinez et al., 2023).

Other authors have considered beef striploin samples to be inacceptable in terms of tenderness for most consumers with WBSF values above 42.6 N (Holman et al., 2020). It should be noted that this value is higher than the one proposed in the present study.

Liang et al. (2016) considered beef striploin samples to be of acceptable tenderness for 50% of Chinese consumers when their WBSF values were below 41.4 N.

Caine et al. (2003) evaluated beef striploin samples using both TPA and WBSF with values between 40.11 and 82.57 N for TPA hardness, and 30.69–117.09 N for WBSF. Regarding TPA hardness values, our data range is wider, although the mean values obtained by Caine et al. (2003), 59.2 N, were considerably above ours. On the other hand, concerning WBSF values, the ones obtained in the present study are considerably below those of Caine et al. (2003).

Other authors have reported that the relationship between TPA parameters and consumer scores, regarding beef tenderness, were stronger than that of WBSF values, which is in agreement with our data, where TPA also distinguishes beef cuts tenderness better than WBSF (Caine et al., 2003; Chinzorig and Hwang, 2018; Stephens et al., 2004).

Only a few studies were found in the literature that assessed beef tenderness with instrumental analyses, both TPA and WBSF, and sensory evaluation (Caine et al., 2003; Chinzorig and Hwang, 2018; de Huidobro et al., 2005).

Several factors could explain the reasons for the discrepancies between the different texture values obtained in the distinct studies, namely the different juiciness of beef samples, but also the different grilling temperatures used for sensory evaluation. Higher grilling temperatures and longer grilling periods will decrease juiciness with the consequent decrease in meat tenderness (Martinez et al., 2023).

In the present study, we used beef meat samples to perform both instrumental (TPA and WBSF) and sensory analyses for comparison purposes. A tenderness screening index, that can be used for evaluating beef carcasses at the slaughterhouse or beef cuts or beef steaks in retail markets, is proposed.

5. Conclusions

The establishment of beef tenderness thresholds has enabled the proposal of a rapid screening index for beef samples, using both instrumental parameters, WBSF and TPA hardness, taking into account the sensory evaluation made by consumers.

According to this rapid screening index, a beef cut is considered to be tender when WBSF is below 39.60 N and TPA hardness below 31.89 N, simultaneously.

The establishment of a beef tenderness screening index considering consumer preferences could potentially be useful for producers to evaluate beef cuts or beef steaks using these methodologies. Thus, tender beef cuts could be economically valorised, according to the obtained results.

Large producers or associations of producers that have texturometers could apply our methodology directly using the reported test settings to evaluate meat tenderness. However, there are several moderately priced, portable, and easy-to-use devices available that could allow even small producers to objectively measure meat tenderness replicating settings and using the appropriate probes. Nevertheless, a comparison between the values obtained with these devices and those obtained through tests carried out with standardised methods is recommended.

To our knowledge, this is the first study considering TPA hardness to explain consumer thresholds for tenderness, which are currently unavailable. Moreover, our study included a survey on consumer preferences associated to beef consumption.

Funding

This research was supported by project PDR 2020–1.0.1-FEADER-030803, funded by national funds through Fundação para a Ciência e a Tecnologia (FCT)/MCTES and co-funded through the European Regional Development Fund (ERDF), and by project UIDB/05183/2020 (MED) financed by national funds through FCT. Sara Ricardo-Rodrigues acknowledges a PhD grant from FCT (2021.07663. BD).

Ethical statement

Participants gave informed consent via the statement “I am aware that my responses are confidential, and I agree to participate in this survey” where an affirmative reply was required to enter the survey. They were able to withdraw from the survey at any time without giving a reason. The products tested were safe for consumption.

Implications for gastronomy

Tenderness is a fundamental trait for meat quality. Meat tenderness can be defined as the easiness to chew meat. Meat tenderness is very important for assessing meat quality. In the current study we evaluated the tenderness of beef cuts to establish a tenderness screening index. Tenderness thresholds for beef cuts were established through the relationship between instrumental and sensory consumer evaluations. Establishing a tenderness threshold could serve as a precise quality control system at the retail level to guarantee tender meat and to ensure consumer acceptability. This tenderness screening index could potentially be useful for producers to evaluate beef cuts or beef steaks using these methodologies. Thus, tender beef cuts could be economically valorised, according to the obtained results. To our knowledge, this is the first study considering instrumental texture to explain consumer thresholds for tenderness, which are currently unavailable. Moreover, in the Materials and methods section, detailed procedures, and temperatures on how meat should be cooked, to ensure optimum tenderness and avoid complaints, are given. Consumers, chefs, and restaurant owners frequently receive complaints about meat tenderness, which may arise from meat quality but also from inadequate meat cooking, mostly over cooking. The current study tried to answer a real problem reported by some chefs and provides a valuable tool to access meat tenderness if appropriately prepared/cooked.

CRediT authorship contribution statement

Sara Ricardo-Rodrigues: Conceptualization, Formal analysis, Investigation, Writing – original draft. **Marta Laranjo:** Supervision, Writing – original draft. **Miguel Elias:** Funding acquisition, Project administration, Supervision. **Maria Eduarda Potes:** Writing – review & editing. **Ana Cristina Agulheiro-Santos:** Investigation, Supervision.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Acknowledgments

The authors thank G. Pias for technical assistance.

References

Agulheiro-Santos, A.C., Roseiro, C., 2012. Physical Properties of Foods: Novel Measurement Techniques and Applications, Rheological Properties of Foods. Taylor & Francis Group, pp. 23–52.
Almli, V.L., Van Wezemael, L., Verbeke, W., Ueland, Ø., 2013. One technology does not fit all: profiling consumers of tender and tenderised beef steaks. Meat Sci. 93, 361–370.
ASTM, 2011. Standard Specification for Tenderness Marketing Claims Associated with Meat Cuts Derived from Beef. American Society for Testing and Materials (ASTM) International, United States, p. 3.
Baldassini, W.A., Machado Neto, O.R., Fernandes, T.T., de Paula Ament, H., Luz, M.G., Santiago, B.M., Curi, R.A., Chardulo, L.A.L., 2021. Testing different devices to assess the meat tenderness: preliminary results. J. Food Sci. Technol. 58, 2441–2446.
Bouton, P.E., Ford, A.L., Harris, P.V., Shorthose, W.R., Ratcliff, D., Morgan, J.H.L., 1978. Influence of animal age on the tenderness of beef: muscle differences. Meat Sci. 2, 301–311.
Caine, W.R., Aalhus, J.L., Best, D.R., Dugan, M.E.R., Jeremiah, L.E., 2003. Relationship of texture profile analysis and Warner-Bratzler shear force with sensory characteristics of beef rib steaks. Meat Sci. 64, 333–339.
Chinzorig, O., Hwang, I., 2018. Mechanical texture profile of Hanwoo muscles as a function of heating temperatures. J. Anim. Sci. Technol. 60, 22.
De Devitiis, B., Viscecchia, R., Seccia, A., Nardone, G., Carlucci, D., Albenzio, M., Sevi, A., Marino, R., 2023. Improving meat tenderness using exogenous process: the consumer response. Meat Sci. 200, 109164.
de Huidobro, F.R., Miguel, E., Blázquez, B., Onega, E., 2005. A comparison between two methods (Warner–Bratzler and texture profile analysis) for testing either raw meat or cooked meat. Meat Sci. 69, 527–536.
Destefanis, G., Brugiapaglia, A., Barge, M.T., Dal Molin, E., 2008. Relationship between beef consumer tenderness perception and Warner–Bratzler shear force. Meat Sci. 78, 153–156.
Fabre, R., Dalzotto, G., Perlo, F., Bonato, P., Teira, G., Tisocco, O., 2018. Cooking method effect on Warner-Bratzler shear force of different beef muscles. Meat Sci. 138, 10–14.
Fraústo da Silva, M., Cardoso Lemos, J.P., Monteiro, L.S., Vaz Portugal, A., 1998. Studies on growth and form: multivariate analysis of distribution of muscle and fat in Portuguese cattle breeds. Livest. Prod. Sci. 55, 261–271.
Holman, B.W.B., Collins, D., Kilgannon, A.K., Hopkins, D.L., 2020. Using shear force, sarcomere length, particle size, collagen content, and protein solubility metrics to predict consumer acceptance of aged beef tenderness. J. Texture Stud. 51, 559–566.
Holman, B.W.B., Hopkins, D.L., 2021. The use of conventional laboratory-based methods to predict consumer acceptance of beef and sheep meat: a review. Meat Sci. 181, 108586.
Honikel, K.-O., 1997. Reference methods supported by OECD and their use in Mediterranean meat products. Food Chem. 59, 573–582.
Liang, R.R., Zhu, H., Mao, Y.W., Zhang, Y.M., Zhu, L.X., Cornforth, D., Wang, R.H., Meng, X.Y., Luo, X., 2016. Tenderness and sensory attributes of the longissimus lumborum muscles with different quality grades from Chinese fattened yellow crossbred steers. Meat Sci. 112, 52–57.
Martinez, H.A., Miller, R.K., Kerth, C., Wasser, B.E., 2023. Prediction of beef tenderness and juiciness using consumer and descriptive sensory attributes. Meat Sci. 205, 109292.
Miller, M.F., Carr, M.A., Ramsey, C.B., Crockett, K.L., Hoover, L.C., 2001. Consumer thresholds for establishing the value of beef tenderness. J. Anim. Sci. 79, 3062–3068.
Novaković, S., Tomašević, I., 2017. A comparison between Warner-Bratzler shear force measurement and texture profile analysis of meat and meat products: a review. IOP Conf. Ser. Earth Environ. Sci. 85, 012063.
Paiva, T., Jacinto, T.A., Sarraguça, M.C., Coutinho, P., 2022. Beef consumers behaviour and preferences—the case of Portugal. Sustainability 14, 2358.
Perry, D., Thompson, J.M., Hwang, I.H., Butchers, A., Egan, A.F., 2001. Relationship between objective measurements and taste panel assessment of beef quality. Aust. J. Exp. Agric. 41, 981–989.
Purchas, R.W., 2024. Tenderness measurement. In: Dikeman, M. (Ed.), Encyclopedia of Meat Sciences, third ed. Elsevier, Oxford, pp. 313–322.
Reicks, A.L., Brooks, J.C., Garmyn, A.J., Thompson, L.D., Lyford, C.L., Miller, M.F., 2011. Demographics and beef preferences affect consumer motivation for purchasing fresh beef steaks and roasts. Meat Sci. 87, 403–411.
Rodas-González, A., Huerta-Leidenz, N., Jerez-Timaure, N., Miller, M.F., 2009. Establishing tenderness thresholds of Venezuelan beef steaks using consumer and trained sensory panels. Meat Sci. 83, 218–223.
Ruiz de Huidobro, F., Miguel, E., Blázquez, B., Onega, E., 2005. A comparison between two methods (Warner-Bratzler and texture profile analysis) for testing either raw meat or cooked meat. Meat Sci. 69, 527–536.
Sasaki, K., Motoyama, M., Narita, T., Hagi, T., Ojima, K., Oe, M., Nakajima, I., Kitsunai, K., Saito, Y., Hatori, H., Muroya, S., Nomura, M., Miyaguchi, Y., Chikuni, K., 2014. Characterization and classification of Japanese consumer perceptions for beef tenderness using descriptive texture characteristics assessed by a trained sensory panel. Meat Sci. 96, 994–1002.
Schreuders, F.K.G., Schlangen, M., Kyriakopoulou, K., Boom, R.M., van der Goot, A.J., 2021. Texture methods for evaluating meat and meat analogue structures: a review. Food Control 127, 108103.
Shackelford, S.D., Morgan, J.B., Cross, H.R., Savell, J.W., 1991. Identification of threshold levels for Warner-Bratzler shear force in beef top loin steaks. J. Muscle Foods 2, 289–296.
Silva, D.R.G., Torres Filho, R.A., Cazedey, H.P., Fontes, P.R., Ramos, A.L.S., Ramos, E.M., 2015. Comparison of Warner–Bratzler shear force values between round and square cross-section cores from cooked beef and pork Longissimus muscle. Meat Sci. 103, 1–6.
Stephens, J.W., Unruh, J.A., Dikeman, M.E., Hunt, M.C., Lawrence, T.E., Loughin, T.M., 2004. Mechanical probes can predict tenderness of cooked beef longissimus using uncooked measurements. J. Anim. Sci. 82, 2077–2086.
Strydom, P., Burrow, H., Polkinghorne, R., Thompson, J., 2019. Do demographic and beef eating preferences impact on South African consumers' willingness to pay (WTP) for graded beef? Meat Sci. 150, 122–130.
Sullivan, G.A., Calkins, C.R., 2011. Ranking beef muscles for Warner–Bratzler shear force and trained sensory panel ratings from published literature. J. Food Qual. 34, 195–203.
Szczesniak, A.S., 2002. Texture is a sensory property. Food Qual. Prefer. 13, 215–225.
Van Wezemael, L., De Smet, S., Ueland, Ø., Verbeke, W., 2014. Relationships between sensory evaluations of beef tenderness, shear force measurements and consumer characteristics. Meat Sci. 97, 310–315.
Vaskoska, R., Ha, M., Naqvi, Z.B., White, J.D., Warner, R.D., 2020. Muscle, ageing and temperature influence the changes in texture, cooking loss and shrinkage of cooked beef. Foods 9, 1289.
Veiseth-Kent, E., Pedersen, M.E., Rønning, S.B., Rødbotten, R., 2018. Can postmortem proteolysis explain tenderness differences in various bovine muscles? Meat Sci. 137, 114–122.
Wall, K.R., Kerth, C.R., Miller, R.K., Alvarado, C., 2019. Grilling temperature effects on tenderness, juiciness, flavor and volatile aroma compounds of aged ribeye, strip loin, and top sirloin steaks. Meat Sci. 150, 141–148.
Warner, R., Miller, R., Ha, M., Wheeler, T.L., Dunshea, F., Li, X., Vaskoska, R.S., Purslow, P., 2021. Meat tenderness: underlying mechanisms, instrumental measurement, and sensory assessment. Meat and Muscle Biology 4.
Warner, R.D., Wheeler, T.L., Ha, M., Li, X., Bekhit, A.E.-D., Morton, J., Vaskoska, R., Dunshea, F.R., Liu, R., Purslow, P., Zhang, W., 2022. Meat tenderness: advances in biology, biochemistry, molecular mechanisms and new technologies. Meat Sci. 185, 108657.
Yang, L., Arnold, N.L., Drape, T., Williams, R.C., Archibald, T., Chapman, B., Boyer, R., 2021. A survey of United States consumer awareness, purchasing, and handling of mechanically tenderized beef products. Food Control 120.