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CATA-Based Sensory Profiling and Drivers of Liking of Beef Sirloin Steaks Marinated with *Moringa oleifera* Leaf Juice

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Abstract

The sensory effects of fresh *Moringa oleifera* leaf juice as a marinade for whole-muscle beef remain insufficiently characterised, particularly regarding the sensory attributes associated with product liking. This study aimed to characterise the sensory profiles of beef sirloin steaks marinated with different concentrations of fresh *Moringa oleifera* leaf juice, identify attributes associated with the ideal sensory profile and panellist liking, and evaluate selected physicochemical changes that may support interpretation of the sensory responses. Beef sirloin steaks were marinated for 30 min with aqueous *Moringa oleifera* leaf preparations at concentrations of 0, 10, 15, or 20%, using a completely randomised design with five replicates. Sensory evaluation was conducted with 30 untrained panellists using Check-All-That-Apply (CATA) profiling and a seven-point overall-liking scale. Correspondence analysis, ideal-product mapping, principal coordinate analysis, and penalty analysis were used to characterise sensory perception and attributes associated with liking. pH, instrumental colour, and total colour difference were additionally evaluated as supporting physicochemical parameters. Green colour, bloody flavour, Moringa leaf aftertaste, and the not-too-fatty attribute differed significantly among treatments. The 10% treatment was positioned relatively closest to the ideal sensory profile, whereas the 15% treatment showed the highest numerical frequency of juiciness and the highest frequency of Moringa leaf aftertaste. Tenderness, ease of chewing, juiciness, savoury flavour, and smoky aroma were identified as desirable attributes associated with higher liking, while toughness and a pronounced Moringa leaf flavour were associated with reduced liking. Increasing *Moringa oleifera* leaf juice concentration also progressively reduced pH, lightness, and redness and increased colour differences from the control. These findings demonstrate that *Moringa oleifera* leaf juice concentration shapes the sensory profile of beef sirloin steak and highlight the importance of balaning desirable eating-quality attributes with plant-derived sensory characteristics when developing Moringa-marinated beef products.

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Introduction

Beef eating quality is strongly influenced by sensory attributes such as appearance, tenderness, juiciness, aroma, and flavour, which collectively contribute to product acceptance (O'Quinn et al., 2018; Ramadhanti and Tamimi, 2025; Arwani et al., 2026; Tamimi et al., 2026). These characteristics may change during processing and cooking as a result of protein denaturation, moisture redistribution, pigment transformation, and the development of flavour compounds. Physicochemical properties such as pH and colour are also relevant because they are closely associated with protein functionality, water retention, meat appearance, and expected eating quality (Afidah et al., 2025; Rizquna et al., 2025). In particular, colour is one of the first characteristics perceived by consumers and may influence expectations of freshness, doneness, and overall product quality (Pérez-Juan et al., 2012; Mahaputra et al., 2023; Mortensen et al., 2024; Tamimi et al., 2025).

Plant-derived marinades have gained increasing attention as natural ingredients for modifying the

physicochemical and sensory properties of meat. Among these ingredients, *Moringa oleifera* leaves contain antioxidant, antimicrobial, and proteolytic compounds that may interact with muscle proteins, influence pigment stability, and modify meat quality characteristics (Jiang et al., 2023; Lungu and Idamokoro, 2024). The use of *Moringa oleifera* in a liquid marinade may facilitate direct contact between leaf-derived components and the meat surface during marination. However, the sensory effects of *Moringa oleifera* are likely to depend on the amount incorporated. Increasing its concentration may alter meat colour and pH while also introducing green pigmentation, characteristic herbal or leaf flavours, and a persistent aftertaste that may influence product liking (Muthukumar et al., 2014; Kartikasari et al., 2024; Mohamed et al., 2025). Thus, the potential technological benefits of *Moringa oleifera* must be considered together with the sensory characteristics that may determine whether the resulting product is acceptable to panellists.

This consideration is particularly relevant for whole-muscle beef steak, in which the characteristic appearance, texture, and beef flavour remain prominent components of product perception. Cooking may further modify the effects of the marinade through changes in muscle structure, moisture, and meat pigments (Karaman and Ceyhun Sezgin, 2024; Serdaroglu et al., 2024). Chlorophyll and other natural pigments derived from *Moringa oleifera* leaves may influence lightness, redness, yellowness, and the overall appearance of cooked meat, while leaf-derived flavour compounds may remain perceptible after cooking. Excessive green or dark colour and pronounced plant-derived flavour may potentially reduce acceptance, whereas desirable attributes such as tenderness, juiciness, savoury flavour, and ease of chewing may contribute positively to the eating experience (Mashau, Munandi, et al., 2021; Dubeni et al., 2025). Previous studies have demonstrated that *Moringa oleifera*, applied in forms including fresh leaves, leaf tea, powder, and extracts, can affect the colour, aroma, tenderness, and overall acceptability of meat products (Ardite et al., 2023; Kartikasari et al., 2024; Handari and Sembiring, 2025). Nevertheless, much of the available research has focused on ground or processed meat products and on powdered or extracted forms of *Moringa oleifera*. Consequently, information remains limited regarding how different concentrations of fresh *Moringa oleifera* leaf juice influence the detailed sensory profile of whole-muscle beef sirloin steak and which resulting attributes are associated with product liking.

Conventional hedonic evaluation can indicate whether a product is liked or disliked, but it provides limited information regarding the specific sensory characteristics underlying that response (Nasution et al., 2026) . The Check-All-That-Apply (CATA) method offers a consumer-oriented approach for characterising products using sensory terms that can be readily understood by untrained panellists. CATA enables the identification of colour, aroma, texture, flavour, aftertaste, and mouthfeel attributes associated with individual products. When combined with overall-liking assessment, correspondence analysis, ideal-product mapping, and penalty analysis, this approach can provide further insight into the sensory attributes associated with desirable or undesirable product perceptions and those that may contribute to or limit liking. Similar consumer-based sensory approaches have been applied to meat and other food products to characterize differences in attributes including tenderness, juiciness, colour, aroma, and flavour (Hunaefi et al., 2022; Patinho et al., 2024). Such information is particularly relevant in the development of plant-based marinades, where increasing ingredient concentration may simultaneously produce desirable eating-quality characteristics and plant-derived sensory notes that are less preferred.

The novelty of the present study lies in characterising how different concentrations of fresh *Moringa oleifera* leaf juice shape the sensory profile and panellist perception of whole-muscle beef sirloin steak. Unlike previous studies that have primarily evaluated *Moringa oleifera* in processed or ground meat products using conventional sensory assessments, this study applied Check-All-That-Apply (CATA) profiling together with overall-liking assessment, ideal-product mapping, and penalty analysis to identify sensory attributes associated with product perception and acceptance. pH, instrumental colour, and total colour difference were additionally evaluated to provide physicochemical context for the observed sensory responses. This combined approach enables the identification of desirable and undesirable sensory attributes associated with different marinade concentrations and provides insight into the attributes that may drive or limit product liking. Therefore, this study aimed to characterise the sensory profiles of beef sirloin steaks marinated with different concentrations of fresh *Moringa oleifera* leaf juice, identify the attributes associated with the ideal sensory profile and panellist liking, and evaluate selected physicochemical changes that may support the interpretation of the sensory findings.

Materials and Methods

Materials and experimental design

The study was conducted at the Food and Nutrition Chemistry Laboratory and the Food and Agricultural Product Engineering Laboratory, Universitas Diponegoro, Semarang, Indonesia. Fresh post-mortem beef sirloin was obtained from a commercial meat supplier in Gayamsari, Semarang, Indonesia. The beef was obtained in a single batch and portioned into steaks of approximately 2–3 cm thickness, with each experimental unit weighing 100 g.

The experiment was arranged in a completely randomised design with four marination treatments and five replicates per treatment, resulting in 20 experimental units. The experimental units were randomly assigned to the four treatments. The treatments consisted of beef sirloin marinated for 30 min with aqueous *Moringa oleifera* leaf preparations at concentrations of 0% (T0, control), 10% (T1), 15% (T2), and 20% (T3).

Preparation of *Moringa oleifera* leaf juice

Fresh *Moringa oleifera* leaves were purchased from a local market in Semarang, Central Java, Indonesia. Fresh *Moringa oleifera* leaves were separated from the stems and weighed according to the formulation of each treatment. The leaf juice was

prepared using a method modified from the water-based preparation described by Desnilasari et al. (2021). The leaves were mixed with water and homogenised using a blender under identical blending conditions for all treatments.

The T1 marinade was prepared using 100 g of *Moringa oleifera* leaves and 900 mL of water, T2 using 150 g of leaves and 850 mL of water, and T3 using 200 g of leaves and 800 mL of water. These formulations were designated as 10, 15, and 20% aqueous *Moringa oleifera* leaf juice, respectively. The T0 treatment contained no *Moringa oleifera* leaf juice.

Each marinade was transferred to a separate container, and the beef sirloin samples were completely immersed in the corresponding formulation for 30 min under identical conditions. After marination, the samples were removed from the marinade container and prepared for cooking.

Preparation of beef sirloin steak

Beef sirloin steak preparation was adapted from Fathonah et al. (2021). Following marination, excess marinade was removed from the surface of the meat, and the samples were gently blotted with kitchen paper to minimise excess surface moisture, following the procedure described by Mutlu and Koç Terlemez (2024). All samples were subjected to the same seasoning and cooking procedures to minimise variation unrelated to the marination treatments.

Before cooking, the grill pan was preheated to approximately 200–220°C following Gardner et al. (2020). Each steak was cooked to a medium doneness level, for approximately 7 min until the internal temperature reached 63–68°C. Internal temperature was measured at the geometric centre of each steak using a food thermometer. After cooking, the marinated beef sirloin steaks were removed from the grill pan and allowed to rest for 10 min before physicochemical and sensory evaluations.

pH measurement

The pH of the cooked beef sirloin steak was measured using the slurry method according to (AOAC International (2019). Approximately 5 g of each steak sample was finely ground and mixed with 50 mL of distilled water. The mixture was homogenized to obtain a uniform suspension.

Before measurement, the pH meter was calibrated using a standard buffer solution at pH 7.00. The electrode was subsequently immersed in the homogenized sample suspension. The measurement was allowed to stabilize, after which the pH value was recorded. The electrode was cleaned and rinsed with distilled water between measurements to prevent cross-contamination among samples.

Instrumental color analysis

Instrumental colour was evaluated according to the method described by Fadlilah et al. (2022). Approximately 5 g of each cooked steak sample was prepared for measurement. Before analysis, the colour reader was calibrated according to the manufacturer's instructions. The samples were positioned beneath the instrument sensor, and colour coordinates were recorded using the Commission Internationale de l'Éclairage (CIE) colour system.

The measured parameters were lightness (L*), redness/greenness (a*), and yellowness/blueness (b*). Three technical measurements were obtained at different points of each sample, and their mean was used for statistical analysis. Total colour difference (ΔE) was calculated according to Hasani et al. (2026) as:

$$\Delta E = \sqrt{[(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)} \quad (1)$$

where ΔL*, Δa*, and Δb* represent differences in lightness, redness/greenness, and yellowness/blueness coordinates, respectively, between treatments.

Check-All-That-Apply sensory evaluation

Sensory evaluation was conducted in two stages consisting of sensory-attribute development followed by the main Check-All-That-Apply (CATA) evaluation.

In the first stage, a focus group discussion was conducted to generate sensory attributes relevant to the beef sirloin steak samples. Seven untrained participants, including both male and female participants, comprising 3 males and 4 females, aged 19–24 years, took part in the discussion. All participants were familiar with beef steak and reported consuming it approximately once every 1–2 weeks. During the discussion, participants generated descriptive terms related to the colour, aroma, texture, flavour, aftertaste, and mouthfeel of the steak samples.

The terms generated during the focus group discussion were subsequently reviewed to remove redundant or ambiguous terms and combined where appropriate. The attributes were further refined with reference to sensory descriptors reported by Miller et al. (2022). This process resulted in a final set of 16 sensory attributes used to characterise beef sirloin steak marinated with *Moringa oleifera* leaf juice. The attributes and their operational definitions are presented in Table 1.

In the second stage, the main sensory evaluation was conducted using the CATA method according to Hunaefi et al. (2022). Thirty untrained panellists participated in the evaluation. Samples representing the four treatments were presented individually in food-grade containers labelled with random three-digit codes. The serving order was randomised among panellists to minimise order and carry-over effects. Drinking water was provided as a palate cleanser, and panellists were instructed to rinse their mouths between samples.

For each sample, panellists were provided with the same list of 16 sensory attributes and instructed to select all attributes they perceived as applicable to the sample. CATA responses were recorded as binary data, with a value of 1 assigned when an attribute was selected and 0 when it was not selected.

After completing the CATA assessment, panellists evaluated their overall liking of each sample using a seven-point hedonic scale ranging from 1 ("dislike extremely") to 7 ("like extremely"), with 4 representing "neither like nor dislike". CATA responses and overall-liking scores were subsequently used to examine the relationships between sensory attributes and panellist liking.

Table 1. CATA Sensory Attributes of Beef Sirloin Steak

Sensory Attribute	Description	Definition
Color	Brown	The characteristic brown colour of cooked beef.
	Red interior	The intensity of reddish colour in the internal portion of the steak, characterised by a light reddish-brown appearance.
	Green	A greenish tint or residual green colour associated with marination using *Moringa oleifera* leaf juice.
Aroma	No bloody aroma	The absence of a blood-like, serum-like, or metallic aroma in the cooked steak.
	Smoky	Aroma resulting from the steak grilling process.
	Beefy	The characteristic aroma of pure beef without the influence of marinade ingredients.
	Bloody aroma	A blood-like, serum-like, or metallic aroma perceived in the cooked steak.
Texture	*Juicy*	The perception of moisture or liquid released from the meat during chewing.
	Tender	The perception of softness and low resistance during chewing.
	Easy to chew	The ease with which the meat breaks down during chewing.
	Tough	Difficulty in chewing the meat.
Flavour	Savory	Slightly salty and savory taste.
	Bloody flavour	A blood-like, serum-like, or metallic flavour perceived during chewing.
	Moringa leaf flavour	The characteristic flavour of *Moringa oleifera* leaves perceived during chewing.
Aftertaste	Moringa leaf aftertaste	A lingering taste in the mouth after swallowing, characterized by a mild moringa leaf flavor.
Mouthfeel	Not too fatty	A relatively low oily or fatty sensation in which the meat sensation is more dominant than the fat sensation.

Ethical considerations

The sensory evaluation involved voluntary participation in a non-invasive tasting procedure using cooked food samples. Before participation, all participants were informed about the ingredients used in the samples, the sensory evaluation procedures, the voluntary nature of their participation, and their right to withdraw at any time. Informed consent was obtained from all participants before the evaluation. Individuals with known allergies or dietary restrictions related to beef or *Moringa oleifera* were excluded from participation.

Statistical analysis

Physicochemical data were expressed as mean ± standard deviation. The effects of *Moringa oleifera* leaf juice concentration on pH and instrumental colour parameters were evaluated using one-way analysis of variance (ANOVA). When a significant treatment effect was detected, Duncan's multiple range test was used to compare treatment means. CATA data were analysed using XLSTAT 2019 (Addinsoft, Paris, France). Cochran's Q test was used to determine whether the

Table 2. Effect of *Moringa oleifera* leaf juice concentration on the pH of beef sirloin steak.

Treatment	Moringa Leaf Juice Concentration(%)	pH
T0	0	5.96 ± 0.01[a]
T1	10	5.90 ± 0.01[b]
T2	15	5.88 ± 0.01[c]
T3	20	5.82 ± 0.01[d]

Notes: T0: 0% moringa leaf juice, T1: 10% moringa leaf juice, T2: 15% moringa leaf juice, and T3: 20% moringa leaf juice. Values are presented as mean ± standard deviation (n = 5). Different superscript letters within the same column indicate significant differences among treatments ($p < 0.05$)

frequency of selection of each sensory attribute differed among treatments. Where applicable, post-hoc pairwise comparisons were conducted following a significant Cochran's Q test. Correspondence analysis was used to visualize relationships between the steak samples and sensory attributes. Principal coordinate analysis was used to examine the relative positions of sensory attributes and overall-liking responses within the sensory space. Penalty and mean-drop analyses were performed to identify sensory attributes associated with increases or decreases in overall liking. Statistical significance was set at $\alpha = 0.05$.

Results and Discussion

pH of beef sirloin steak

The concentration of *Moringa oleifera* leaf juice significantly affected the pH of cooked beef sirloin steak (Table 2). The pH decreased progressively from 5.96 in the control treatment (T0) to 5.90, 5.88, and 5.82 in steaks marinated with 10% (T1), 15% (T2), and 20% (T3) *Moringa oleifera* leaf juice, respectively. Different superscript letters among treatments indicate significant differences ($p < 0.05$), demonstrating a consistent concentration-dependent reduction in steak pH. The decrease in pH may be associated with the mildly acidic characteristics of *Moringa oleifera* leaves. Previous studies have reported a pH of approximately 4.6 for *Moringa oleifera* leaf preparations (Wahyudi et al., 2019; Pratiwi et al., 2025). The leaves also contain naturally occurring acidic constituents, including ascorbic acid and various phenolic acids, which may contribute to the acidity of the marinade. During marination, these water-soluble compounds may diffuse or migrate from the marinade into the surface layers of the meat, thereby contributing to the progressive decrease in pH observed as the proportion of *Moringa oleifera* leaf material increased (Kartikasari et al., 2023; Asmaq et al., 2024). Acidic compounds may also interact with ionisable groups in muscle proteins and alter the acid–base environment of the muscle matrix. Meat pH is an important physicochemical characteristic because it is associated with muscle protein behaviour, water distribution, pigment stability, colour development, and several characteristics related to eating quality (Moon et al., 2015; Sharedeh et al., 2015; Hasani et al., 2026). Changes in the ionic environment surrounding muscle proteins may influence protein–water interactions and structural properties of the meat, which can subsequently affect characteristics perceived during consumption. Therefore, the concentration-dependent decrease in pH observed in the present study may provide relevant physicochemical context for interpreting changes in instrumental colour and sensory characteristics of the marinated steaks. The pH values observed in the present study remained within the range commonly reported for beef. Beef measured approximately 24–48 h post-mortem generally exhibits pH values of approximately 5.40–5.80 (Yang et al., 2021), while cooked beef steak has been reported to exhibit pH values within approximately 5–6. (Purwasih and Azzahra, 2018; Haider et al., 2020). Thus, although increasing the concentration of *Moringa oleifera* leaf juice significantly reduced steak pH, the magnitude of the reduction was relatively small and the values remained within a range generally associated with beef products. The findings therefore suggest that *Moringa oleifera* leaf juice altered the acid–base environment of the steak without producing an extreme change in pH, while providing physicochemical context for the accompanying differences in colour and sensory perception.

Color of Beef Sirloin Steak

The concentration of *Moringa oleifera* leaf juice significantly influenced the instrumental color of beef sirloin steak (Table 3). The L* value decreased steadily from 15.47 in the control to 11.40 in the 20% treatment. The different superscript letters indicate that each treatment differed significantly from the others, showing that higher concentrations of *Moringa oleifera* leaf juice consistently reduced steak lightness.

The decline in L* may be associated with the incorporation of dark green chlorophyll pigments from *Moringa oleifera* leaves into the meat surface and tissue. As the concentration of the marinade increased, a greater amount of plant pigment may have been deposited on or absorbed by the steak, partially masking the natural color of the beef and producing a darker appearance (Kartikasari et al., 2024). A similar pattern was observed for redness. The a* value decreased from 3.23 in T0 to 1.10 in T3, indicating a reduction in the red color intensity of the steak. However, T2 and T3 were not significantly different, suggesting that the decline in redness became less pronounced when the concentration exceeded 15%.

The reduction in a* may be related to changes in meat pigments during marination and cooking. Organic acids present in *Moringa oleifera* leaves may affect myoglobin stability, while green leaf pigments may visually interact with the red and brown pigments formed in cooked beef (Muthukumar et al., 2014) . These combined effects may contribute to the darker and less reddish appearance of the marinated steaks. Comparable changes in the visual color of beef treated with *Moringa oleifera* leaf extract were reported by

Table 3. Effect of *Moringa oleifera* Leaf Juice Concentration on the Color of Beef Sirloin Steak

Treatment	*Moringa oleifera* Leaf Juice Concentration (%)	L*	a*	b*
T0	0	15.47 ± 0.31[a]	3.23 ± 0.40[a]	2.83 ± 0.87[a]
T1	10	14.47 ± 0.06[b]	2.30 ± 0.10[b]	3.43 ± 0.40[a]
T2	15	12.60 ± 0.10[c]	1.57 ± 0.40[c]	1.30 ± 0.26[b]
T3	20	11.40 ± 0.40[d]	1.10 ± 0.40[c]	0.47 ± 0.29[b]

Note: T0: 0% moringa leaf juice, T1: 10% moringa leaf juice, T2: 15% moringa leaf juice, and T3: 20% moringa leaf juice.. L* represents lightness, a* represents redness, and b* represents yellowness. Values are presented as mean ± standard deviation (n = 5). Different superscript letters within the same column indicate significant differences among treatments ($p < 0.05$)

Beti et al. (2020).

The b* value showed a different response from L* and a*. It increased numerically from 2.83 in T0 to 3.43 in T1, although the difference was not significant. The value subsequently decreased to 1.30 in T2 and 0.47 in T3, with no significant difference between the two higher-concentration treatments. This pattern indicates that the reduction in yellowness became evident at concentrations of 15 and 20%, rather than occurring gradually across all treatments. Chlorophyll pigments and other bioactive compounds present in *Moringa oleifera* leaves may have contributed to changes in the yellow color component of the steak (Mwankunda et al., 2023). These results show that increasing the concentration of *Moringa oleifera* leaf juice produced darker and less reddish steaks, while the reduction in yellowness was more apparent at the two highest concentrations. The instrumental color response therefore depended on the concentration of the marinade applied to the beef sirloin steak.

Total Color Difference of Beef Sirloin Steak

The total color difference analysis showed that increasing the concentration of *Moringa oleifera* leaf juice generally produced greater color differences relative to the control (Table 4). The ΔE value between T0 and T1 was 1.49 and was classified as category II. This relatively small ΔE reflects the combined changes in L*, a*, and b* coordinates between the control and the 10% treatment, indicating that the overall color difference was still limited. This result indicates that the color difference between the control and the 10% treatment was relatively small and could primarily be detected by experienced observers.

The ΔE value between T0 and T2 was 3.65 and was classified as category IV, indicating a clear visual difference between the control and the 15% treatment. The highest ΔE value was observed between T0 and T3, reaching 5.16. This result indicates that marination with 20% *Moringa oleifera* leaf juice produced the most pronounced color change compared with the control. The increasing color difference may be associated with the greater contribution of chlorophyll pigments from *Moringa oleifera* leaves as the marinade concentration increased. Greater absorption or deposition of these pigments may have altered the original color of the beef, producing more noticeable differences compared with the control treatment (Molina et al., 2023).

The comparison between T1 and T2 resulted in a ΔE value of 2.93 and was classified as category III. This finding indicates that the color difference between steaks marinated with 10 and 15% *Moringa oleifera* leaf juice could be detected by untrained observers. The ΔE value between T1 and T3 was 4.43 and was classified as category IV, indicating a clear color difference between the 10 and 20% treatments. In contrast, the ΔE value between T2 and T3 was only 1.53 and was classified as category II. This value was lower than those observed in the other comparisons and indicates that the difference between the 15 and 20% treatments was relatively small. Although L* differed significantly between T2 and T3, a* and b* did not. The 1.20-unit difference in L* accounted for approximately 61% of the squared ΔE between these treatments, indicating that the small overall color difference was mainly related to lightness rather than redness or yellowness. This

Table 4. Total Color Difference Among Beef Sirloin Steak Treatments

	T0	T1	T2	T3
T0		II	IV	IV
T1	1.49		III	IV
T2	3.65	2.93		II
T3	5.16	4.43	1.53	

Notes: T0: 0% moringa leaf juice, T1: 10% moringa leaf juice, T2: 15% moringa leaf juice, and T3: 20% moringa leaf juice. The total color difference (ΔE) categories are expressed using Roman numerals, where I ($0 < \Delta E < 1$) indicates no noticeable difference, II ($1 \leq \Delta E < 2$) indicates that the difference can only be detected by experienced observers, III ($2 < \Delta E < 3.5$) indicates that the difference can be detected by untrained observers, and IV (≥ 3.5) indicates a clear color difference.

Table 5. Cochran's Q Test for the Sensory Attributes of Beef Sirloin Steak

Attribute	p-value	T0	T1	T2	T3
Brown	0.29	0.77[a]	0.70[a]	0.80[a]	0.87[a]
Red interior	0.21	0.13[a]	0.03[a]	0.03[a]	0.13[a]
Green	0.05	0.23[a]	0.57[b]	0.40[ab]	0.37[ab]
No bloody aroma	0.25	0.53[a]	0.67[a]	0.60[a]	0.50[a]
Smoky	0.73	0.67[a]	0.77[a]	0.70[a]	0.73[a]
Beefy aroma	0.88	0.50[a]	0.43[a]	0.50[a]	0.47[a]
Bloody aroma	0.13	0.13[a]	0.07[a]	0.03[a]	0.20[a]
Juicy	0.06	0.40[a]	0.50[a]	0.67[a]	0.43[a]
Tender	0.76	0.40[a]	0.47[a]	0.47[a]	0.37[a]
Easy to chew	0.53	0.57[a]	0.67[a]	0.67[a]	0.53[a]
Tough	0.12	0.43[a]	0.30[a]	0.33[a]	0.57[a]
Savory	0.33	0.63[a]	0.80[a]	0.77[a]	0.77[a]
Bloody flavour	0.04	0.20[a]	0.03[a]	0.03[a]	0.13[a]
Moringa leaf flavour	0.22	0.37[a]	0.43[a]	0.60[a]	0.43[a]
Moringa leaf aftertaste	0.02	0.23[a]	0.40[ab]	0.60[b]	0.37[ab]
Not too fatty	0.01	0.70[ab]	0.83[b]	0.60[a]	0.57[a]

Notes: T0: 0% *Moringa oleifera* leaf juice; T1: 10% *Moringa oleifera* leaf juice; T2: 15% *Moringa oleifera* leaf juice; and T3: 20% *Moringa oleifera* leaf juice. Values represent the proportion of panellists who selected each sensory attribute (n = 30). The p-values indicate the overall treatment effect obtained using Cochran's Q test. Within the same row, values followed by different superscript letters differ significantly according to post hoc pairwise comparisons, whereas values sharing at least one superscript letter are not significantly different ($p \leq 0.05$). A significant overall Cochran's Q test may occur even when no individual pairwise comparison is significant after adjustment for multiple comparisons

This relatively small instrumental color difference was also consistent with the sensory color responses. Brown color was selected by 80 and 87% of panellists for T2 and T3, respectively, while green color was selected by 40 and 37%, with no significant differences between these treatments. Therefore, although T2 and T3 differed instrumentally in lightness, this difference did not result in a clear difference in the CATA color attributes perceived by the panellists.

Check-All-That-Apply Sensory Profile of Beef Sirloin Steak

Cochran's Q test showed that the sensory attributes were perceived at different frequencies across treatments (Table 5). T0 had the highest selection frequency for bloody flavour. T1 was most frequently associated with green colour, no bloody aroma, smoky aroma, savoury flavour, and a not-too-fatty mouthfeel. T2 showed the highest frequencies for juiciness, Moringa leaf flavour, and Moringa leaf aftertaste, whereas T3 was most frequently associated with brown colour, bloody aroma, and toughness.

At a significance level of 5%, green colour, bloody flavour, Moringa leaf aftertaste, and the not-too-fatty attribute differed significantly among treatments. For green colour, T1 had the highest selection frequency and differed significantly from T0, while T2 and T3 showed intermediate responses. These findings indicate that *Moringa oleifera* marination altered the perception of green colour, although the response was not linear across increasing marinade concentrations.

Bloody flavour showed a significant overall treatment effect, with the highest frequency observed in T0 and the lowest in T1 and T2. However, the pairwise comparisons showed no significant differences among individual treatments, as indicated by the same superscript letter. Therefore, the significant Cochran's Q result indicates that the selection frequencies were not homogeneous across all treatments, but no specific treatment pair can be considered significantly different.

Moringa leaf aftertaste was selected most frequently for T2, which differed significantly from T0. T1 and T3 showed intermediate values. The not-too-fatty attribute was selected most frequently for T1 and was significantly higher than in T2 and T3, while T0 did not differ significantly from the other treatments. Juiciness, tenderness, and ease of chewing did not differ significantly among treatments. Although T2 showed the highest numerical frequency for juiciness and T1 and T2 were more frequently associated with ease of chewing, these findings should be regarded as descriptive tendencies rather than confirmed treatment effects.

T1 showed the highest frequency of green colour despite containing the lowest concentration of *Moringa oleifera* leaf juice among the marinated treatments. This sensory response did not follow the same pattern as the

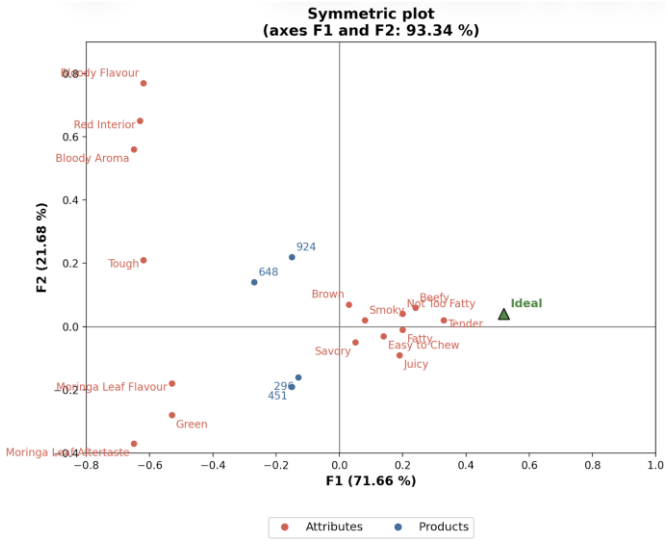


Figure 1. Symmetric plot of the Check-All-That-Apply sensory attributes and beef sirloin steak samples (Note: 924 represents T0, steak marinated with 0% *Moringa oleifera* leaf juice; 296 represents T1, steak marinated with 10% *Moringa oleifera* leaf juice; 451 represents T2, steak marinated with 15% *Moringa oleifera* leaf juice; and 648 represents T3, steak marinated with 20% *Moringa oleifera* leaf juice.)

instrumental colour measurements. Instrumentally, a* decreased with increasing *Moringa oleifera* concentration, indicating a progressive reduction in redness, whereas the CATA green descriptor reached its highest frequency at T1 rather than at T2 or T3. This suggests that perceived green colour was not determined solely by the instrumental a* value. At a moderate concentration, chlorophyll may remain visually detectable without being strongly affected by pigment degradation, oxidation, or interactions with other compounds during cooking. *Moringa oleifera* leaves contain phenolic compounds, including flavonoids and phenolic acids, which may affect pigment stability and product colour during processing (Rocchetti et al., 2020).

T3 showed the highest numerical frequencies for brown colour and toughness, although these attributes did not differ significantly among treatments. Its lower juiciness frequency compared with T2 may indicate a tendency towards a drier and tougher sensory profile. However, cooking loss and water-holding capacity were not measured; therefore, these differences cannot be directly attributed to moisture loss or excessive protein denaturation. Thus, the lower juiciness and higher toughness frequencies observed for T3 should be considered only as a possible sensory pattern rather than evidence that increasing *Moringa oleifera* concentration caused moisture loss or toughness. Changes in cooking conditions may influence tenderness and juiciness through their effects on cooking loss (Li, 2025; Hasani et al., 2026)

Overall, T0 was more frequently associated with bloody flavour, whereas the marinated treatments showed lower numerical frequencies for this attribute. Bioactive and antioxidant compounds in *Moringa oleifera* leaves may influence the chemical and sensory characteristics of beef products (Shah et al., 2015). Nevertheless, because no significant pairwise differences were identified for bloody flavour, this interpretation should be treated cautiously.

The first two dimensions explained 93.34% of the total variation, indicating that the symmetric plot adequately represented the relationships among treatments, sensory attributes, and the ideal product (Figure 1). The ideal product was associated with brown colour, smoky and beefy aromas, tenderness, juiciness, savoury flavour, ease of chewing, and a not-too-fatty mouthfeel. In contrast, bloody flavour, bloody aroma, red interior, and toughness were positioned far from the ideal point. In correspondence analysis, shorter distances indicate stronger associations, but not statistical significance (Amorim et al., 2023; Lee and Ju, 2024)

T0 was associated with bloody flavour, bloody aroma, and red interior, whereas T3 was positioned closer to toughness. T1 and T2 were associated with green colour, Moringa leaf flavour, and Moringa leaf aftertaste. The position of T2 was consistent with its lower a* and b* values, although positive a* values indicate reduced redness rather than an instrumentally green colour. The perceived green colour may be related to chlorophyll and other pigments from *Moringa oleifera* leaves (Mashau, Ramatsetse, et al., 2021; Hasizah et al., 2023). None of the treatments occupied the same region as the ideal product; therefore, the correspondence analysis should be interpreted together with the overall-liking and penalty analyses.

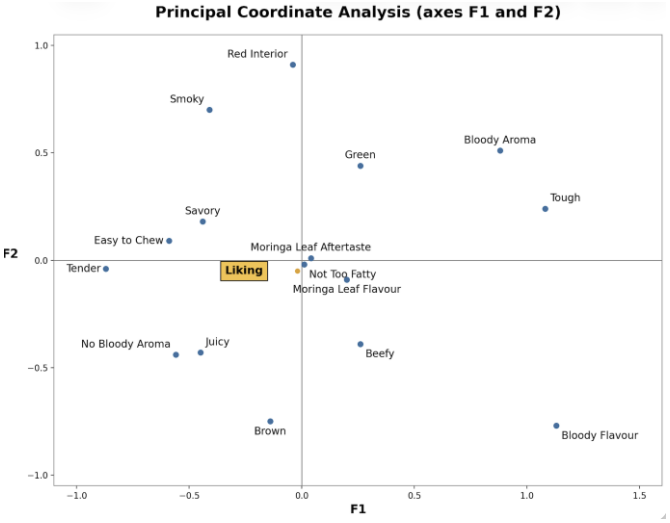


Figure 2. Principal coordinate analysis of the sensory attributes and liking of beef sirloin steak

Principal coordinate analysis showed that overall liking was positioned in the lower-left region of the sensory space (Figure 2). Tenderness was located closest to liking, followed by ease of chewing, savoury flavour, juiciness, and no bloody aroma, indicating positive associations with panellist preference. Brown colour was located in the same general region but farther from liking, whereas bloody aroma, tough texture, and bloody flavour were positioned far from liking, indicating negative associations with acceptance. This pattern was generally consistent with the sensory characteristics identified in the ideal-product map (Tarancón et al., 2020)

The mean-drop analysis classified smoky aroma, juiciness, tenderness, ease of chewing, and

Table 6. Summary of penalty analysis for the sensory attributes of beef sirloin steak

Must have	Nice to have	Does not influence	Does not harm	Must not have
Smoky	Not too fatty	Brown	Red interior	Tough
Juicy		No bloody aroma	Green	Moringa leaf flavour
Tender		Beefy aroma	Moringa leaf aftertaste	
Easy to chew				
Savoury				

savoury flavour as must-have attributes (Figure 3). These attributes were selected by more than 20% of the panellists and produced positive mean-drop values, indicating that their presence was associated with higher overall liking. Tenderness produced the largest positive mean drop, followed by ease of chewing, savoury flavour, juiciness, and smoky aroma. The not-too-fatty attribute was classified as nice to have because it positively influenced liking but was not essential to the expected sensory profile (Tarancón et al., 2020).

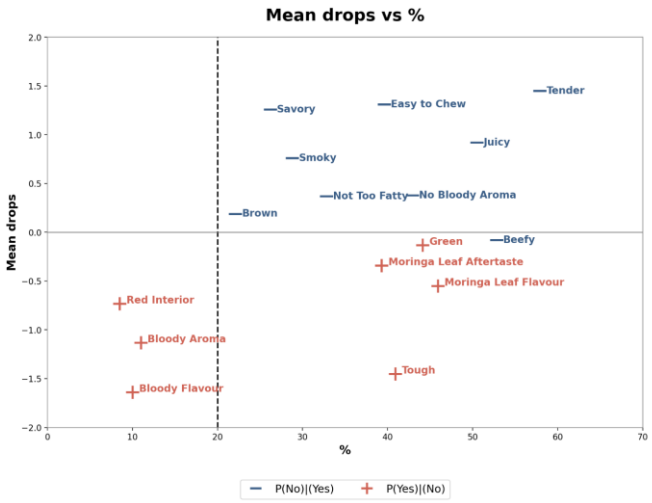


Figure 3. Mean-drop analysis of the sensory attributes of beef sirloin steak

As summarised in Table 6, brown colour, no bloody aroma, and beefy aroma were classified as attributes that did not substantially influence liking. Red interior, green colour, and Moringa leaf aftertaste were classified as attributes that did not harm liking. This result suggests that green colour and a mild Moringa leaf aftertaste were tolerated by the panellists under the conditions evaluated. In contrast, tough texture and Moringa leaf flavour were classified as must-not-have attributes in Table 6. Toughness produced the largest negative mean drop, indicating the strongest negative influence on overall liking. A clearly perceptible Moringa leaf flavour also reduced liking and should therefore be minimised in the development of beef steak marinated with *Moringa oleifera* leaf juice. Bloody aroma and bloody flavour produced negative mean-drop values but were selected by fewer than 20% of the panellists. Consequently, they were not included in the must-not-have category in Table 6, although their positions in the principal coordinate analysis indicated negative associations with liking.

Overall, tenderness, ease of chewing, juiciness, savoury flavour, and smoky aroma were the attributes most closely associated with panellist acceptance. Conversely, toughness and a pronounced Moringa leaf flavour negatively affected liking, whereas green colour and a mild Moringa leaf aftertaste did not substantially penalise the products. From a formulation perspective, these findings suggest that the development of *Moringa oleifera*-marinated beef sirloin should focus on maintaining desirable texture, juiciness, and savoury characteristics while limiting toughness and an overly pronounced Moringa leaf flavour.

Conclusion

Different concentrations of *Moringa oleifera* leaf juice produced distinct sensory profiles in beef sirloin steak. Among the evaluated attributes, green colour, bloody flavour, Moringa leaf aftertaste, and the not-too-fatty mouthfeel differed significantly among treatments. The 10% *Moringa oleifera* leaf juice treatment was positioned relatively closest to the ideal sensory profile, whereas higher concentrations were increasingly associated with characteristic Moringa-derived sensory attributes. Sensory mapping and penalty analysis indicated that tenderness, ease of chewing, juiciness, savoury flavour, and smoky aroma were the principal desirable attributes associated with higher liking, while toughness and a pronounced Moringa leaf flavour were associated with reduced liking. Green colour and a mild Moringa leaf aftertaste, in contrast, did not substantially penalise product liking.

Increasing *Moringa oleifera* leaf juice concentration also produced a progressive reduction in pH, lightness, and redness and increased the overall colour difference from the control, providing physicochemical context for the changes observed in product perception. Overall, the findings indicate that the physicochemical properties changed progressively with increasing *Moringa oleifera* leaf juice concentration, while sensory responses varied among treatments. Successful development of Moringa-marinated beef steak therefore requires balancing desirable eating-quality attributes with potentially undesirable plant-derived sensory characteristics. Further statistical comparison of overall-liking scores among treatments would be necessary before identifying an optimum marinade concentration. Further studies should also evaluate cooking loss, instrumental texture, oxidative stability, microbial quality, and consumer acceptance to provide a more comprehensive assessment of the effects of *Moringa oleifera* leaf juice on beef steak quality.

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