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THE USE OF HONEY AS A BIOACTIVE AGENT FOR OPTIMIZING THE BEEF MATURATION PROCESS AND THE IMPACT ON THE SENSORY PROPERTIES OF THE FINAL PRODUCT

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Abstract

In human health concerns and diet diversification, food science research focuses on developing functional products, using sustainable and health-promoting methods. Beef, an important source of nutrients, is often rejected due to its sensory characteristics and tough texture, which is a challenge for consumers with dental problems. This study aimed to evaluate the effectiveness of honey as a bioactive agent in optimizing the beef maturation process, considering its beneficial effects on health and the environment. Three different concentrations of honey (10%, 20%, and 30%) applied in the wet-aging process for 48 hours were tested, followed by a thermal process and a detailed sensory evaluation. The use of honey as a natural bioactive agent in the wet-aging process of beef significantly improves meat quality, both in terms of physicochemical and sensory attributes, in a dose-dependent manner, without affecting internal color stability, thus offering benefits for consumer acceptability and the development of functional and sustainable food products.

Key words*: beef, honey, maturation process, quality.*

INTRODUCTION

Beef is valued for its high protein content of high biological value, its significant intake of heme iron and zinc, and its rich sensory profile, defined by its intense umami taste and firm texture. However, it is often perceived to be tougher to digest, particularly in collagen-rich muscle pieces (Scollan et al., 2006; Boișteanu et al., 2024a). The addition of honey as a bioactive agent can enhance the marbling and tenderness of beef during the maturation process (Ciobanu et al., 2024). Research indicates that honey, when used in marinades, can significantly improve meat tenderness by affecting protein structures and enhancing flavor profiles. Honey contains enzymes and acids that can break down proteins, leading to increased tenderness in beef. Studies show that marinades with honey resulted in a notable reduction in hardness measurements of beef compared to control samples (Istrati et al., 2012; Istrati et al., 2015). The presence of honey in marinades also contributes to the hydrolysis of collagen and myofibrillar proteins, which are crucial for meat tenderness (Istrati et al., 2012). Marbling, or intramuscular fat (IMF), is essential for meat quality (Boișteanu et al., 2024b). Honey's nutritional components may influence adipogenic activity, promoting fat deposition in muscle tissues (Wandita et al., 2018). The combination of honey with other ingredients in marinades can enhance the overall flavor and moisture retention, which indirectly supports the development of marbling during the maturation process (Istrati et al., 2015). While honey shows promise in enhancing beef quality, it is essential to consider that excessive sweetness or improper ratios in marinades could potentially mask the natural flavors of the meat, leading to a less desirable product (Ciobanu et al., 2024). While feed management technologies play a critical role in minimizing environmental contaminants such as mineral oil hydrocarbons (MOH) at the farm level, post-harvest interventions, such as the use of natural bioactive agents like honey during beef maturation, offer complementary strategies to enhance both food safety and quality throughout the production chain (Matei et al., 2024). In beef sausage, concentrations of 5.0% to 7.5% honey were associated with improved sensory attributes, including color, aroma, and

texture, while also enhancing safety and storability (Mohammed et al., 2013).

For beef jerky, a concentration of 24% honey yielded optimal quality, affecting pH, moisture, and protein content positively (Karlina et al., 2022). This concentration was found to produce a desirable balance of flavor and texture. While higher concentrations of honey can enhance certain sensory properties, they may also lead to undesirable sweetness or color changes, as noted in some studies (Tolon et al., 2000). Thus, the optimal concentration should be tailored to the specific product and consumer preferences (Zugravu et al., 2017; Ciobanu et al., 2025; Manoliu et al., 2024).

This study aimed to assess the potential of honey as a bioactive agent for improving the beef maturation process, taking into account its health and environmental benefits. Three honey concentrations (10%, 20%, and 30%) were applied during a 48-hour wet-aging treatment, followed by thermal processing and comprehensive sensory evaluation.

MATERIALS AND METHODS

In accordance with the experimental protocol, three experimental samples were prepared with different honey additions (10%, 20%, and 30%), alongside a control sample, all subjected to a 48-hour wet-aging process aimed at improving the physicochemical and sensory parameters of the final product. The honey used in the experiment was sourced from a local producer holding the relevant quality certifications. To avoid potential conflicts of interest, the commercial identity of the supplier was kept anonymous.

The selection of these biocomponents aimed to simulate a realistic scenario, in line with applicable European regulations, such as Regulation (EC) No. 178/2002 on food safety, Regulation (EU) No. 1169/2011 on consumer information, and other relevant legal provisions in the field of food and natural product safety. The raw material (beef) was purchased from the local market and met the quality and traceability standards set by European regulations, including Regulation (EC) No. 854/2004 and Regulation (EU) No. 1169/2011. The experimental setup was designed in full compliance with these regulations. Beef muscle samples were treated with honey at concentrations of 10%, 20%, and 30% during the wet-aging process, which was carried out in embossed vacuum bags consisting of two layers: an inner layer of 60 µm polyethylene suitable for food contact, and an outer layer of 15 µm polyamide with UV filter. Sealing was performed using an ATM Machinery vacuum device (chamber power: 630 W), and the samples were stored at 2°C, protected from light, throughout the 48-hour aging period (Boișteanu et al., 2024a).

The influence of honey addition on the beef aging process was assessed by analyzing the colorimetric profile, textural properties, and pH at 24 and 48 hours. Color characteristics were measured using a Chroma Meter MINOLTA, model CR-410 (Konica Minolta, Osaka, Japan), according to the CIE Lab color system. The expressed color parameters were L* (lightness), a* (green-red component), and b* (blue-yellow component). The device was calibrated using a standard white reference plate, and CIELAB values were recorded at three distinct points on each sample.

Texture was assessed using a Lloyd Instruments TA1Plus texture analyzer (AMETEK, UK), equipped with a 500 N load cell. Tests were conducted at a constant speed of 100 mm/min, with an initial extension of 90 mm, controlled by software version 4.1.5.999 and embedded version 2.0.300. pH values were measured using a portable pH meter, Hanna Instruments, model HI99163. For each sample batch, five measurements were taken at different points to ensure data representativeness. After 48 hours of wet-aging, the samples were subjected to thermal treatments as detailed in Table 1. Subsequently, the experimental samples were analyzed for their moisture, protein, collagen, fat, and salt content using a versatile near-infrared (NIR) spectroscopic method, according to the protocol described by Gucianu et al. (2024). The analyses were performed using the Food Check meat analyzer (Bruins Instruments, Germany). For the sensory evaluation, the samples were cut into uniform pieces, anonymized through coding, and distributed to the tasting panel. The evaluation was carried out by a panel of 47 semi-trained participants (students and academic staff from the “Ion

Ionescu de la Brad" University of Life Sciences in Iași), aged between 20 and 42 years, in accordance with ISO 8586:2023. The participants assessed the four experimental variants using a 9-point hedonic scale, where a score of 1 corresponded to "dislike extremely" and a score of 9 to "like extremely". The evaluation was conducted based on six sensory attributes: texture, taste, odor, color, cross-sectional appearance, and overall appearance (Boișteanu et al., 2025). The distribution of data was assessed using IBM SPSS Statistics version 26.0 (IBM Corp., 2019). Statistical comparisons were conducted through one-way analysis of variance (ANOVA), followed by Tukey's post-hoc test, using IBM SPSS Statistics version 21. A significance threshold of $p < .05$ was applied for all analyses.

Table 1. The applied head tratament

Heat treatment stage	Time	Temperature inside the cell	Temperature in the thermal centre	Humidity
	minutes	°C	°C	%
Drying I	15	65	55	10
Smoking	30	65	55	10
Boiling	-	74	72	99
Drying II	20	80	72	10

RESULTS AND DISCUSSIONS

According to Table 2 pH analysis revealed a concentration-dependent modulation of acidification during wet-aging. While the control sample exhibited a significant decrease in pH over 48 hours ($p \leq 0.05$), honey-treated samples showed a more stabilized profile, particularly at 30% concentration, suggesting a potential antimicrobial and buffering effect of honey during maturation.

Table 2. pH variation of samples (SM, SH1, SH2, SH3) from 24 to 48 hours

Sample	Ph	
	24 h	48 h
SM	5.826 ± 0.037^{cA}	5.672 ± 0.063^{aB}
SH1	5.8 ± 0.036^{cA}	5.784 ± 0.100^{aA}
SH2	5.71 ± 0.054^{bA}	5.634 ± 0.027^{abB}
SH3	5.6 ± 0.018^{aA}	5.614 ± 0.088^{abA}

Different superscript letters (a, b, c, d) within the same column and (A, B, C, D, E, F) within the same row indicate statistically significant differences, as determined by one-way ANOVA followed by Tukey's multiple comparison test ($p \leq 0.05$); SM - sample control, SH1 - 10% honey; SH2 - 20% honey; SH3 - 30% honey.

Control (SM) has the largest pH drop, which suggests uncontrolled natural maturation with potential risk of accelerated spoilage. Treatment with 10% and 20% honey (SH1, SH2) attenuates the pH drop and has a protective effect, but without completely inhibiting maturation. SH3 (30% honey) has the lowest initial value, but it does not decrease afterwards, which is why honey in high concentration can reduce microbiological activity, stabilizing the product. Statistically significant differences ($p \leq 0.05$) confirm the significant influence of honey concentration on the pH evolution over time. Textural parameters such as Hardness, Work of Cutting, and Tensile Strength showed significant variations depending on both the honey concentration and the maturation time (Table 3).

Table 3. Evolution of textural parameters during beef maturation with different honey concentrations (Hardness, Work of Cutting, Tensile Strength)

Sample	Hardness (N)		Work of Cutting (Nmm)		Tensile Strength (MPa)	
	24 h	48 h	24 h	48 h	24 h	48 h
SM	13.71 ± 0.401^{aA}	20.35 ± 0.269^{aB}	136.37 ± 2.093^{aC}	345.23 ± 2.399^{aD}	0.20 ± 0.072^{aF}	0.15 ± 0.044^{aE}
SH1	20.95 ± 0.351^{bA}	23.44 ± 0.450^{bB}	234.87 ± 3.694^{bC}	382.93 ± 2.004^{bD}	0.11 ± 0.038^{aE}	0.19 ± 0.036^{aF}
SH2	23.20 ± 0.168^{cA}	25.77 ± 0.453^{cB}	255.73 ± 3.385^{cC}	434.34 ± 1.696^{cD}	0.25 ± 0.119^{bF}	0.16 ± 0.065^{aE}
SH3	25.37 ± 0.159^{dA}	28.27 ± 0.489^{dB}	345.87 ± 2.111^{dC}	466.88 ± 1.485^{dD}	0.18 ± 0.058^{abF}	0.13 ± 0.027^{aE}

Different superscript letters (a, b, c, d) within the same column and (A, B, C, D, E, F) within the same row indicate statistically significant differences, as determined by one-way ANOVA followed by Tukey's multiple comparison test ($p \leq 0.05$); SM - sample control, SH1 - 10% honey; SH2 - 20% honey; SH3 - 30% honey.

After 48 hours of wet-aging, all samples treated with honey (SH1, SH2, SH3) exhibited significantly higher hardness values compared to the control (SM), indicating a firmer and more compact texture. The most notable increase was observed in SH3 (30% honey), suggesting that higher concentrations may promote protein cross-linking or dehydration effects, possibly enhanced during the subsequent thermal treatment. Similarly, the Work of Cutting increased progressively with honey concentration, reflecting greater resistance to mechanical breakdown.

This may be attributed to the interaction between honey constituents, such as sugars and phenolic compounds, and muscle proteins, which could contribute to the structural reinforcement of the meat matrix.

Tensile Strength showed a more variable trend: while SH2 reached the highest value at 24 h, a decrease was noted at 48 h, possibly due to enzymatic degradation over time.

These findings support the hypothesis that honey not only serves as a bioactive agent but also plays a role in modulating meat texture during maturation, offering new possibilities for customizing meat products based on target consumer preferences.

The color parameters of the beef surface (L, a, b*) were significantly influenced by both the honey concentration and the maturation time (Table 4).

The lightness value (L*) increased in all samples from 24 to 48 hours, with the highest values observed in SH3 (30% honey), suggesting that higher honey concentrations may enhance light scattering on the meat surface, possibly due to surface dehydration.

The control sample (SM) showed the lowest L* values, confirming that honey addition contributes to a lighter appearance of the meat over time.

Table 4. Surface color parameters during beef maturation (24-48 h) with varying honey concentrations (10%, 20%, and 30%)

Sample	Surface					
	L*(D65)		a*(D65)		b*(D65)	
	24 h	48 h	24 h	48 h	24 h	48 h
SM	31.376 ± 0.261^{aA}	32.062 ± 0.662^{aB}	17.016 ± 0.298^{bC}	17.434 ± 0.332^{bC}	3.58 ± 0.065^{aD}	3.608 ± 0.380^{aD}
SH1	34.868 ± 0.491^{bA}	35.358 ± 3.858^{aB}	17.298 ± 2.149^{bC}	16.748 ± 1.811^{bD}	6.058 ± 1.973^{bE}	3.392 ± 2.810^{aF}
SH2	33.87 ± 0.786^{bA}	35.036 ± 1.544^{aB}	12.866 ± 0.780^{aD}	11.646 ± 1.128^{aC}	4.628 ± 0.617^{bF}	3.974 ± 1.151^{aE}
SH3	34.418 ± 1.254^{bA}	36.78 ± 0.784^{bB}	13.77 ± 1.065^{aC}	13.42 ± 1.195^{aC}	5.678 ± 1.396^{bF}	3.798 ± 1.054^{aE}

Different superscript letters (a, b, c, d) within the same column and (A, B, C, D, E, F) within the same row indicate statistically significant differences, as determined by one-way ANOVA followed by Tukey's multiple comparison test ($p \leq 0.05$); SM - sample control, SH1 - 10% honey; SH2 - 20% honey; SH3 - 30% honey.

The parameter a*(D65) showed distinct behavior, while SM and SH1 maintained higher values at both time points, SH2 and SH3 displayed significantly lower redness levels. This could be due to partial pigment degradation or antioxidant interactions between honey phenolics and myoglobin, reducing oxymyoglobin stability in higher honey concentrations. Interestingly, SH1 maintained stable a* values between 24-48 h, indicating moderate honey levels may preserve red coloration better. Regarding the parameter b*(D65), values were highest at 24 h in SH1 and SH3, suggesting early-stage honey-protein interactions or pigment contributions from honey itself. However, a general decrease in b* was noted at 48 h in all honey-treated groups, potentially due to pigment oxidation or moisture migration affecting surface reflectance. These findings underline the role of honey not only as a bioactive agent for texture enhancement, but also as a modulator of visual quality. From a consumer perspective, brighter and more uniform meat color may improve product appeal, particularly in populations sensitive to meat freshness indicators. Section color parameters (L, a, b*) of beef sections showed limited but noteworthy variation depending on honey concentration and maturation time (Table 5). The lightness values (L*) remained statistically unchanged across all samples and time points, indicating that honey application did not significantly affect internal light reflection or water distribution in the muscle matrix after 48 hours of wet-aging and thermal treatment. This stability in L* suggests that the maturation process did not cause notable discoloration or internal browning. The control sample (SM) experienced an increase in a*(D65) from 24 to 48 hours, consistent with typical oxygenation and blooming of myoglobin in non-treated beef. However, honey-treated samples (SH1-SH3) demonstrated a decline in a* values over time, especially in SH3 (30% honey). This may reflect the antioxidant activity of honey, which

can limit oxymyoglobin formation and promote metmyoglobin stabilization, leading to reduced red intensity in the meat interior. The slight but significant reductions in a* at higher honey concentrations may also suggest deeper interactions between phenolic compounds and muscle pigments (Anchidin et al., 2023). From a consumer standpoint, this suggests that the honey-assisted maturation process preserves the internal visual quality of beef, which is particularly important for cooked or sliced products where interior appearance is relevant (Ciobanu et al., 2023a). Overall, these results highlight that while surface color is more susceptible to changes from honey addition and exposure to oxygen, sectional color remains more stable, with subtle pigment interactions becoming evident primarily in redness values. The parameter b*(D65) remained relatively stable across all treatments and time points, with no significant differences. This suggests that the wet-aging process with honey did not alter the chromatic balance between red and yellow tons in the inner meat, supporting the visual homogeneity of the final product.

Table 5. Section color parameters during beef maturation (24-48 h) with varying honey concentrations (10%, 20%, and 30%)

Sample	Section					
	L*(D65)		a*(D65)		b*(D65)	
	24 h	48 h	24 h	48 h	24 h	48 h
SM	31.931 ± 0.386^{aA}	31.991 ± 0.366^{aA}	18.492 ± 0.822^{bB}	19.056 ± 1.312^{cC}	4.142 ± 0.787^{aD}	4.792 ± 1.747^{aD}
SH1	33.392 ± 2.665^{aA}	33.382 ± 2.665^{aA}	19.648 ± 1.656^{bD}	17.84 ± 0.507^{abcC}	4.566 ± 0.988^{aE}	4.11 ± 0.664^{aE}
SH2	32.962 ± 0.618^{aA}	32.952 ± 0.618^{aA}	17.562 ± 0.829^{abD}	16.73 ± 0.851^{aC}	3.78 ± 0.642^{aE}	3.668 ± 0.674^{aE}
SH3	33.912 ± 1.475^{aA}	33.900 ± 1.475^{aA}	17.856 ± 0.659^{bC}	16.186 ± 0.605^{aB}	4.324 ± 0.538^{aF}	3.936 ± 0.418^{aE}

Different superscript letters (a, b, c, d) within the same column and (A, B, C, D, E, F) within the same row indicate statistically significant differences, as determined by one-way ANOVA followed by Tukey's multiple comparison test ($p \leq 0.05$); SM - sample control, SH1 - 10% honey; SH2 - 20% honey; SH3 - 30% honey.

The physicochemical profile of thermally treated beef samples revealed significant variations influenced by the concentration of honey applied during wet-aging (Table 6). The protein content showed a clear trend, with the highest value recorded in SH2 (20% honey, 21.10%), followed by the control sample (SM), SH1 (10%), and the lowest in SH3 (30%). This indicates that moderate honey concentrations (20%) may help preserve or even slightly enhance protein integrity, possibly due to reduced proteolysis and water loss during thermal processing. Conversely, the lower protein percentage in SH3 could be attributed to higher fat content and reduced moisture, leading to relative protein dilution.

Table 6. Physicochemical parameters (Protein %, Moisture %, Fat %, Lipid %) determined for the analysed batches after thermal treatment

Sample	Protein, %	Moisture, %	Fat, %	Lipid, %
SM	20.84 ± 0.054^{c}	72.18 ± 0.192^{c}	6.42 ± 0.228^{b}	19.12 ± 0.109^{c}
SH1	20.46 ± 0.056^{b}	71.18 ± 0.589^{b}	7.78 ± 0.637^{c}	18.74 ± 0.089^{b}
SH2	21.1 ± 0.070^{d}	73.06 ± 0.114^{d}	5.4 ± 0.123^{a}	19.46 ± 0.054^{d}
SH3	19.84 ± 0.054^{a}	68.48 ± 0.268^{a}	10.98 ± 0.130^{d}	18.06 ± 0.114^{a}

Different superscript letters (a, b, c, d) within the same column indicate statistically significant differences, as determined by one-way ANOVA followed by Tukey's multiple comparison test ($p \leq 0.05$); SM - sample control, SH1 - 10% honey; SH2 - 20% honey; SH3 - 30% honey.

Moisture content followed a similar trend, with SH2 exhibiting the highest value (73.06%), while SH3 had the lowest (68.48%). The higher moisture retention in SH2 could suggest a protective effect of the 20% honey matrix against water loss during cooking, possibly by forming a light coating that reduced evaporation. In contrast, the drop in moisture at 30% honey may reflect excessive sugar-induced protein crosslinking, leading to firmer structure and more water expulsion. Fat and lipid contents varied significantly. SH3 exhibited the highest fat (10.98%) and the lowest lipid percentage (18.06%), while SH2

had the lowest fat content (5.4%) and the highest lipid retention (19.46%). These differences suggest that honey concentration influences the distribution and release of intramuscular fat during thermal treatment. SH2 may promote better emulsification and stabilization of lipids during cooking, while SH3's higher fat value might reflect less efficient lipid retention and a more compact, fat-rich matrix. The optimal honey concentration appears to be 20% (SH2), balancing protein preservation, moisture retention, and lipid stability during cooking. In contrast, excessive honey (30%) may negatively affect physicochemical properties by altering water and protein dynamics, despite increasing fat retention. These findings support the use of honey not only for sensory improvement but also for modulating the nutritional and technological properties of beef products. Sensory evaluation results (Table 7; Figure 1) revealed a generally positive impact of honey addition on the organoleptic quality of beef samples, as evidenced by the improved scores for appearance, color, texture, and taste in all honey-treated variants compared to the control. The enhancements suggest that honey not only contributes to flavor development but may also positively influence texture and visual appeal, making the final product more acceptable and appealing to consumers.

Table 7. Sensory attributes assessed for the beef samples following treatment

Sample	Overall Appearance	Section Layout	Color	Texture	Smell	Taste
SM	7.31±2.475^{a}	6.74±2.471^{a}	7.74±2.471^{a}	7.72±2.570^{a}	7.96±2.268^{a}	7.54±2.421^{a}
SH1	7.80±2.544^{a}	7.16±2.341^{b}	8.06±2.341^{b}	8.84±2.607^{b}	8.44±2.517^{b}	8.81±2.685^{b}
SH2	8.21±2.589^{b}	7.56±2.252^{b}	8.46±2.252^{b}	8.96±2.724^{b}	8.28±2.322^{b}	8.13±2.780^{b}
SH3	7.91±2.336^{a}	7.95±2.130^{b}	8.79±2.130^{b}	8.56±2.598^{b}	7.08±2.296^{a}	8.88±2.560^{b}

Different superscript letters (a, b, c, d) within the same column indicate statistically significant differences, as determined by one-way ANOVA followed by Tukey's multiple comparison test ($p \leq 0.05$); SM - sample control, SH1 - 10% honey; SH2 - 20% honey; SH3 - 30% honey.

Sensory evaluation results indicate that the addition of honey in the beef maturation process significantly influenced most sensory attributes ($p \leq 0.05$), especially texture, color and taste. Compared to the control (SM), all honey-treated samples (SH1, SH2, SH3) recorded significantly higher scores for color, texture, and taste, showing a perceptible improvement in product acceptability. Sample SH2 (20% honey) had the highest scores for overall appearance (8.21 ± 2.589) and texture (8.96 ± 2.724), suggesting an optimal combination of honey concentration and sensory profile. SH3 (30% honey) stood out with the highest score for color (8.79 ± 2.130) and taste (8.88 ± 2.560), although it had a lower value for smell (7.08 ± 2.296), which may suggest a more intense or atypical aromatic impact. The control sample (SM) obtained the lowest scores for all attributes, confirming the potential of honey as a bioactive agent to improve the sensory characteristics of matured meat.

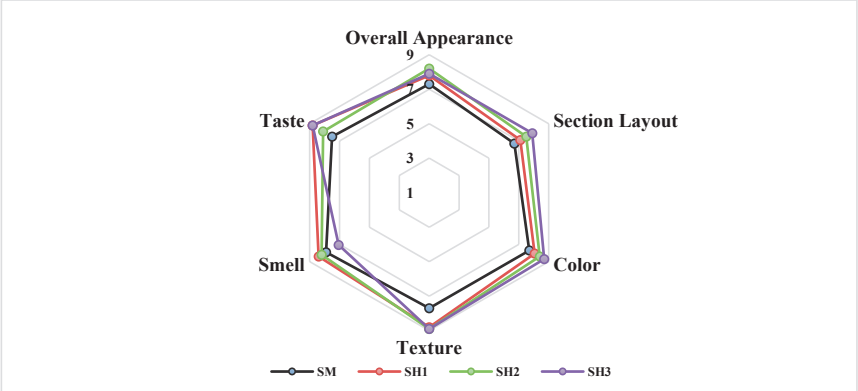

Figure 1. Graphical representation of sensory attribute results for the analyzed samples

The control sample (SM) recorded the lowest scores across all evaluated sensory attributes, including appearance, section layout, color, texture, smell, and taste. This outcome highlights the limited sensory appeal of beef that has not undergone enhancement through natural bioactive agents. In contrast, the samples treated with honey, particularly those with higher concentrations (20% and 30%), demonstrated significantly improved scores, suggesting a notable enhancement in consumer-perceived quality. These findings support the hypothesis that honey, due to its natural bioactive compounds, can positively influence the maturation process, leading to improved organoleptic properties. The consistent increase in sensory scores across treated samples underscores honey's potential as a sustainable and health-promoting alternative for optimizing meat products (Ciobanu et al., 2023b).

CONCLUSIONS

The results of this study demonstrate that honey, used as a natural bioactive agent in the beef wet-aging process, exerts a significant and multifunctional influence on meat quality. Its incorporation during maturation led to measurable improvements in physicochemical parameters, such as protein retention, moisture content, and fat balance, while enhancing sensory attributes like texture, color, taste, and overall appearance. These improvements were most pronounced at higher concentrations (20-30%), suggesting a dose-dependent response where the bioactive components in honey actively interact with muscle proteins and lipids. Importantly, despite the surface-level changes in brightness and chromatic values, internal color stability was preserved, indicating that the structural integrity and oxidative balance of the meat matrix were not adversely affected by honey exposure. From a consumer acceptability perspective, the improved tenderness and flavor, combined with a visually more appealing product, offer clear advantages for market diversification, particularly for vulnerable groups such as the elderly or individuals with masticatory difficulties. Consequently, honey-assisted maturation not only aligns with the growing demand for clean-label and functional foods but also provides a sustainable and health-conscious approach to enhancing meat processing technologies.

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