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Research Article

Dentition-based age influences physicochemical, nutritional and sensory quality of cooked Sahiwal crossbred cattle hide

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Abstract

Cattle hide is a collagen-rich slaughter co-product with potential for food use, yet the effect of animal maturity on its quality is poorly characterized. This study evaluated cooked neck-hide from male Sahiwal crossbred cattle classified by dentition as T_1 (2-tooth; one pair of permanent incisors; n=12) or T_2 (4-tooth; two pairs; n=12). Physicochemical properties, proximate composition, calculated energy value, and trained-panel sensory attributes were determined using standardized laboratory procedures. Raw sample-level data were analyzed by one-way ANOVA, and selected instrumental-sensory relationships were examined using Pearson correlation. Compared with T_1, T_2 hide had higher pH (7.646 vs 6.768), drip loss (12.163 vs 8.354%), cooking loss (15.992 vs 4.589%), and shear force (258.481 vs 154.627 N; P<0.001), while CIE a* and b* did not differ. T_1 contained more crude protein (33.465 vs 29.528%) and dry matter (36.193 vs 34.184%), whereas T_2 contained more moisture, ether extract, ash, and carbohydrate. All trained-panel scores favored T_1, including texture (4.275 vs 2.542), juiciness (4.467 vs 2.900), and overall acceptability (4.042 vs 2.683; P<0.001). Shear force was strongly inversely related to texture within both T_1 (r=-0.921) and T_2 (r=-0.947), and cooking loss was inversely related to juiciness (r=-0.939 and -0.988, respectively). These findings demonstrate that dentition-based maturity is strongly associated with the processing and eating quality of cooked cattle hide. Younger hide showed the more favorable profile for direct culinary use, although collagen chemistry, digestibility, microbiological safety, and broader consumer acceptance require further investigation before nutritional or commercial recommendations are made.

Introduction

Efficient use of slaughter co-products is increasingly important for resource efficiency, environmental management, and value creation in animal-food systems. Meat processing generates hides, blood, bones, organs, and other materials that can be converted into food, feed, biomaterials, or functional ingredients rather than treated as waste (Lee et al., 2025; Alibekov et al., 2024; Hashem et al. 2024a and 2024b; Mullen et al., 2017). In Bangladesh, cattle hide also has major economic relevance through the leather supply chain, but raw-hide value can be vulnerable to seasonal oversupply, handling limitations, and price instability (Roy et al., 2023). Identifying scientifically defensible food or ingredient applications for suitable hides could therefore complement conventional leather utilization rather than simply increase disposal pressure. Cattle hide differs fundamentally from skeletal muscle because the dermis is dominated by a dense extracellular collagen network. Collagen provides tensile strength and mechanical stability through its triple-helical architecture and intermolecular organization (Shoulders and Raines, 2009; Han et al., 2021; Matinong et al., 2022). With increasing physiological maturity, connective tissues generally develop more stable collagen cross-links and greater resistance to thermal or mechanical disruption. Although the present experiment did not directly quantify collagen cross-link density, such age-related matrix maturation provides a plausible framework for interpreting changes in hide toughness and water retention (Purslow, 2005; Ahmad et al., 2024).

Edible cattle hide is already consumed in several food cultures and may be prepared by scalding, singeing, scraping, boiling, or combinations of these operations. Published studies have reported substantial variation in its protein, fat, ash, moisture, and sensory properties depending on processing conditions and product type (Akwetey et al., 2013; Ademola et al., 2022; Ogunlade-Anibasa and Ogwuiche, 2023; Mensah-Agyei et al., 2024). Sensory work on cooked beef hide further shows that processing can materially influence color, flavor, texture, and overall acceptability (Maguipa et al., 2022; Afuye and Ogunyemi, 2022; Ojinnaka et al., 2023). Bovine hide is also an established source of gelatin and collagen-derived ingredients with relevant hydration, gelling, and textural functions (Nunez et al., 2020; Liu et al., 2023; Li et al., 2025). Animal age is routinely approximated in cattle using eruption of permanent incisors when exact birth records are unavailable. Studies in Bangladeshi cattle have shown that dental age can influence meat pH, color, cooking behavior, proximate composition, and other quality traits (Islam et al., 2023a; Islam et al., 2023b; Liza et al., 2024; Bristy et al., 2025). Age also changes the quantity and economic profile of slaughterhouse by-products (Ahmed et al., 2025). However, direct information on how dentition-based maturity affects the physicochemical, nutritional, and sensory quality of edible cattle hide is limited. The present study therefore compared cooked hide from 2-tooth and 4-tooth Sahiwal crossbred cattle. It was hypothesized that the younger dentition group would show lower mechanical toughness and moisture loss, higher protein concentration, and better trained-panel sensory quality.

Materials and Methods

Sample collection and experimental design

The experiment was conducted in the Animal Science Laboratory, Department of Animal Science, Bangladesh Agricultural University (BAU), Mymensingh, Bangladesh. Fresh hide samples were obtained from the neck region of apparently healthy male Sahiwal crossbred cattle slaughtered in Islampur, Jamalpur. Samples were classified by permanent-incisor eruption into T_1 (2-tooth; one pair of permanent incisors; n=12) and T_2 (4-tooth; two pairs of permanent incisors; n=12), giving 24 biological experimental units in a completely randomized design. Collection occurred during Eid-ul-Adha and routine slaughter periods; collection period was not treated as an experimental factor. Sample preparation and storage

Immediately after slaughter, visible blood and debris were removed. Hides were washed in hot water (approximately 60-70°C), dehaired, and trimmed to remove excess fat and loose connective tissue. Prepared samples were frozen at -18°C and transported under a maintained cold chain. Before analysis, samples were thawed at 4°C for approximately 24 h, washed, blotted, and cut into uniform portions. Physicochemical, compositional, and sensory analyses were performed under standardized laboratory conditions.

Physicochemical measurements

pH measurement

The pH of each prepared hide sample was measured using a calibrated Hanna digital pH meter. Before measurement, the instrument was standardized with pH 4.0 and 7.0 buffer solutions. The electrode was inserted directly into the hide until a stable reading was obtained. Measurements were performed in triplicate and the mean was used as the sample value.

Instrumental color measurement

Surface color was measured at three positions using a Konica Minolta CR-400 colorimeter under Illuminant D65 with a 10° standard observer. Results were expressed in the CIE L* (lightness), a* (redness), and b* (yellowness) color space following established meat-color measurement principles (King et al., 2023). The three technical readings were averaged for each biological sample.

Drip loss measurement

Drip loss was determined after 24 h at 4°C. Each sample was weighed initially, suspended inside a sealed plastic bag without direct contact with exuded fluid, refrigerated for 24 h, gently blotted, and reweighed. Drip loss was calculated as:

$$Drip\ loss\ (\%) = \frac{W_1 - W_2}{W_1} \times 100$$

where W_1 is the initial sample weight and W_2 is the sample weight after 24 h refrigerated suspension.

Cooking loss measurement

Cooking loss was determined by recording the initial raw weight of each sample, heating the sample in a water bath at 80°C for 40 min, cooling briefly, blotting surface moisture, and recording the cooked weight. Cooking loss was calculated as:

$$Cooking\ loss\ (\%) = \frac{W_1 - W_2}{W_1} \times 100$$

where W1 is the sample weight before cooking and W2 is the sample weight after cooking.

Shear force measurement

After boiling, samples were cut into approximately 1 × 1 × 2.5 cm strips and positioned perpendicular to the blade of a Warner-Bratzler-type shear device. Peak cutting force was recorded in newtons (N). Three technical measurements were obtained from each biological sample and averaged to represent shear force value.

Proximate composition and calculated energy value

Dry matter and moisture determination

Dry matter (DM) was determined in triplicate following AOAC procedures (AOAC International, 2023). A known mass of hide was placed in a pre-weighed porcelain crucible, dried at 105°C for 24 h, cooled in a desiccator, and reweighed. Dry matter was calculated as:

$$Dry\ matter\ (\%) = \frac{W_3 - W_1}{W_2 - W_1} \times 100$$

where W_1 is the empty crucible weight, W_2 is the crucible plus fresh sample weight, and W_3 is the crucible plus dried sample weight. Moisture was calculated from the complement of dry matter:

$$Moisture\ (\%) = 100 - Dry\ matter\ (\%)$$

Crude protein determination

Crude protein (CP) was determined in triplicate by the micro-Kjeldahl method following AOAC procedures (AOAC International, 2023). Organic nitrogen was digested with concentrated sulfuric acid in the presence of K_2SO_4, $CuSO_4$, and selenium catalyst. After alkalization with NaOH, liberated ammonia was distilled into boric acid and titrated with standardized HCl. Total nitrogen was converted to crude protein using the factor 6.25:

$$Crude\ protein\ (\%) = Nitrogen\ (\%) \times 6.25$$

Ether extract determination

Ether extract (EE) was determined in triplicate using a Soxhlet apparatus with diethyl ether as the extraction solvent. Approximately 2 g of ground hide was extracted at 40-45°C for 6-7 h. After solvent removal, the recovered lipid was dried, cooled, and weighed. Ether extract was calculated as:

$$Ether\ extract\ (\%) = \frac{Weight\ of\ extracted\ fat}{Weight\ of\ sample} \times 100$$

Ash determination

Ash was determined in triplicate following AOAC procedures (AOAC International, 2023). Samples in pre-weighed porcelain crucibles were incinerated in a muffle furnace at 550°C for 6 h, cooled in a desiccator, and weighed. Ash content was calculated as:

$$Ash\ (\%) = \frac{Weight\ of\ ash}{Weight\ of\ sample} \times 100$$

Carbohydrate determination

Carbohydrate was not measured directly; it was estimated by difference from the wet-basis proximate composition:

$$Carbohydrate\ (\%) = 100 - [Moisture + CP + EE + Ash]$$

Calculated energy value

Energy was not measured by bomb calorimetry. A calculated energy value was estimated from protein, fat, and carbohydrate using the general Atwater factors described by Capuano et al. (2018):

$$Calculated\ energy\ (kcal/100\ g) = (CP \times 4) + (EE \times 9) + (Carbohydrate \times 4)$$

Sensory evaluation

Cooked hide samples were evaluated by a trained panel of five assessors recruited from postgraduate students and faculty members of the Department of Animal Science, BAU. Panelists were oriented to the attributes and scoring procedure before testing, consistent with general sensory-assessor and test-room principles (ISO, 2007; ISO, 2023). Samples were served in labeled Petri dishes using random three-digit codes in a clean, well-lit, odor-controlled laboratory. Water was supplied for palate cleansing between samples. Color, texture, flavor, juiciness, and overall acceptability were scored on a 5-point quality scale (1=very poor, 5=excellent). Because the panel was trained and small, these scores were interpreted as trained-panel product-quality responses rather than population-level consumer preference.

Statistical analysis

The individual hide sample was the experimental unit. The uploaded raw dataset contained 24 sample-level observations (12 per dentition group). Final analyses were independently rechecked from these raw observations in Python 3.13 using SciPy 1.17. One-way analysis of variance (ANOVA) tested the fixed effect of dentition group. Results are presented as Mean ± standard error (SE), consistent with the reporting convention commonly used in Meat Research tables, and P<0.05 was considered statistically significant. Because only two treatment groups were compared, no post-hoc multiple-comparison test was necessary.

Pearson's product-moment correlation was used as a secondary analysis to evaluate four pre-specified instrumental-sensory relationships: shear force with texture score, cooking loss with juiciness, cooking loss with overall acceptability, and pH with sensory color score. Two-tailed P values were calculated. To reduce the risk of overinterpreting correlations created mainly by separation between the two dentition groups, coefficients were reported separately for T_1 and T_2 as well as for the pooled dataset.

Results and Discussion

Physicochemical properties

Table 1: Effect of dentition-based age on physicochemical properties of cooked Sahiwal crossbred cattle hide (Mean ± SE)

Variables	T^1 (Mean ± SE)	T^2 (Mean ± SE)	Level of Significance
pH	$6.768±0.013^b$	$7.646±0.057^a$	<0.0001
L*	$54.006±1.026^b$	$62.399±1.477^a$	0.0001
a*	$2.558±0.191^a$	$2.067±0.266^a$	0.149
b*	$13.033±0.176^a$	$11.936±0.716^a$	0.151
Drip loss (%)	$8.354±0.155^b$	$12.162±0.562^a$	<0.0001
Cooking loss (%)	$4.589±0.221^b$	$15.992±1.150^a$	<0.0001
Shear force (N)	$154.63±2.31^b$	$258.48±2.63^a$	<0.0001

Mean values in the same row with different superscripts differ significantly at P<0.05; identical superscripts indicate no significant difference. T^1=2-tooth (one pair of permanent incisors); T^2=4-tooth (two pairs); n=12 per group; SE=standard error. L*, a*, b*=CIE lightness, redness, and yellowness, respectively.

pH and instrumental color

Dentition group strongly affected hide pH. T_2 had a mean pH of 7.646 compared with 6.768 in T_1 ($P<0.0001$; Table 1). Dental-age effects on pH have also been reported in cattle muscle, although the magnitude and direction vary with tissue and postmortem conditions (Islam et al., 2023a; Bristy et al., 2025). The relatively alkaline values measured here should not be interpreted as conventional ultimate muscle pH because hide was subjected to washing, dehairing, freezing, thawing, and direct-probe measurement. Thus, pH is most appropriately interpreted as a physicochemical property of the processed hide matrix in this experiment rather than as evidence of a specific biochemical mechanism.

Lightness was higher in T_2 than T_1 (62.399 vs 54.006; $P=0.0001$), whereas redness and yellowness were not significantly different ($P=0.149$ and $P=0.151$). The selective effect on L* suggests that maturity altered surface reflectance more than chromatic intensity. Color in animal tissues is influenced by structure, water distribution, surface condition, and optical scattering (Hughes et al., 2014; King et al., 2023). Because hide contains far less myoglobin-rich muscle than conventional meat, explanations based solely on muscle pigment chemistry would be inappropriate.

Water loss and shear force

Water retention deteriorated markedly in the older dentition group. Drip loss increased from 8.354% in T^1 to 12.163% in T_2 ($P<0.0001$), while cooking loss increased from 4.589% to 15.992% ($P<0.0001$). Water-holding behavior depends on the structural organization and hydration of proteins; collagen-derived systems are particularly responsive to pH, hydrolysis, and thermal processing (Nunez et al., 2020). The present pattern therefore indicates that T_2 hide retained less water during both refrigerated holding and boiling. Comparable age-associated changes in water loss have been described in cattle meat, although muscle and hide matrices are not directly equivalent (Liza et al., 2024; Noh et al., 2025).

Shear force provided the clearest instrumental separation between groups, rising from 154.63 N in T_1 to 258.48 N in T_2 ($P<0.0001$). Greater cutting force is consistent with a mechanically tougher matrix. In connective tissues, age-related stabilization of collagen can reduce thermal solubility and increase resistance to deformation (Purslow, 2005; Shoulders and Raines, 2009; Ahmad et al., 2024). Because collagen concentration and cross-link chemistry were not measured in this experiment, the observed age effect supports - but does not directly prove - collagen maturation as the underlying mechanism.

Table 2: Effect of dentition-based age on proximate composition and calculated energy value of cooked Sahiwal crossbred cattle hide (Mean ± SE)

Variables	T^1 (Mean ± SE)	T^2 (Mean ± SE)	Level of Significance
Dry matter (%)	36.193 ± 0.176^a	34.184 ± 0.122^b	<0.0001
Moisture (%)	63.807 ± 0.176^b	65.816 ± 0.122^a	<0.0001
Crude protein (%)	33.465 ± 0.299^a	29.527 ± 0.144^b	<0.0001
Ether extract (%)	1.565 ± 0.039^b	2.749 ± 0.027^a	<0.0001
Ash (%)	0.686 ± 0.039^b	1.158 ± 0.047^a	<0.0001
Carbohydrate (%)	0.639 ± 0.063^b	1.009 ± 0.092^a	0.0031
Calculated energy (kcal/100 g)	150.50 ± 0.80^a	146.89 ± 0.42^b	0.0006

Mean values in the same row with different superscripts differ significantly at $P<0.05$. T1=2-tooth; T2=4-tooth; n=12 per group; SE=standard error. Proximate composition is expressed on a wet-weight basis. Carbohydrate was calculated by difference. Energy was calculated with Atwater factors and was not measured by bomb calorimetry.

Moisture, dry matter and crude protein

T_1 contained more dry matter than T^2 (36.193 vs 34.184%), while T_2 contained more moisture (65.816 vs 63.808%; $P<0.0001$). These paired results are mathematically consistent because moisture was derived as the complement of dry matter. Published edible-hide compositions vary widely with scalding, singeing, drying, and other processing operations, reinforcing the need to state analytical basis and preparation history when comparing studies (Akwetey et al., 2013; Ademola et al., 2022; Ogunlade-Anibasa and Ogwuiche, 2023).

Crude protein was 33.465% in T_1 and 29.528% in T_2 ($P<0.0001$). This confirms that cooked hide contained a substantial nitrogenous fraction on a wet-weight basis, with higher concentration in the younger group. Bovine skin and hide are collagen-rich raw materials (Ockerman and Hansen, 2000; Matinong et al., 2022), and recent characterization of bovine-hide gelatin further demonstrates its high protein content and collagen-associated amino-acid profile (Li et al., 2025). However, crude protein percentage alone does not establish amino-acid adequacy, digestibility, or equivalence to conventional muscle protein; dedicated amino-acid profiling and digestibility studies would be required before making protein-quality claims.

Ether extract, ash, carbohydrate and calculated energy

Ether extract increased from 1.565% in T_1 to 2.749% in T_2, and ash increased from 0.686% to 1.158% ($P<0.0001$). The absolute lipid content remained low, while the greater ash fraction in T_2 indicates a modest age-related change in inorganic residue. Both age and processing can alter the apparent composition of animal tissues through changes in water, fat, and solids concentration (Islam et al., 2023b; Ahmed et al., 2025).

Carbohydrate calculated by difference was low in both groups but higher in T_2 (1.009 vs 0.639%; $P=0.0031$). Because this value is residual rather than directly assayed, small between-group differences should be interpreted cautiously. Calculated energy was slightly higher in T_1 (150.50 vs 146.89 kcal/100 g; $P=0.0006$), largely reflecting the greater protein concentration. The term calculated energy is used deliberately because Atwater factors estimate energy from macronutrient composition rather than directly measuring gross heat of combustion (Capuano et al., 2018).

Trained-panel sensory quality

Table 3: Effect of dentition-based age on trained-panel sensory attributes of cooked Sahiwal crossbred cattle hide (Mean ± SE)

Variables	T^1 (Mean ± SE)	T^2 (Mean ± SE)	Level of Significance
Color score	4.133 ± 0.081^a	2.608 ± 0.122^b	<0.0001
Texture score	4.275 ± 0.091^a	2.542 ± 0.087^b	<0.0001
Flavor score	3.517 ± 0.074^a	2.775 ± 0.097^b	<0.0001
Juiciness score	4.467 ± 0.063^a	2.900 ± 0.170^b	<0.0001
Overall acceptability	4.042 ± 0.051^a	2.683 ± 0.065^b	<0.0001

Mean values in the same row with different superscripts differ significantly at P<0.05. T^1=2-tooth; T^2=4-tooth; n=12 per group; SE=standard error. Attributes were assessed by a five-member trained panel on a 5-point quality scale (1=very poor, 5=excellent).

All five sensory attributes favored T_1. Color score declined from 4.133 in T1 to 2.608 in T_2, despite the higher instrumental L* of T_2. This apparent contrast is plausible because trained visual quality integrates multiple features beyond lightness alone, including surface uniformity, translucency, discoloration, and overall appearance. Processing-dependent differences in hide color and acceptability have likewise been reported for edible cow skin (Ademola et al., 2022; Ojinnaka et al., 2023). Texture and juiciness showed especially large differences: T_1 scored 4.275 for texture and 4.467 for juiciness, compared with 2.542 and 2.900 in T2 (P<0.0001). These responses were directionally consistent with lower shear force and cooking loss in T_1. Instrumental tenderness and moisture retention are established determinants of eating quality in meat systems (Warner, 2017; Hashem et al., 2024), and the same conceptual relationship is relevant to cooked hide even though its collagen-dominant structure differs from muscle.

Flavor was also higher in T_1 (3.517 vs 2.775; P<0.0001), while overall acceptability was 4.042 in T_1 and 2.683 in T_2 (P<0.0001). Studies of cooked edible hide show that processing, seasoning, and structural softening can substantially alter sensory acceptance (Maguipa et al., 2022; Afuye and Ogunyemi, 2022). The present panel was trained and consisted of only five assessors; therefore, the results indicate comparative product quality under controlled evaluation and should not be generalized as population-wide consumer liking.

Associations between instrumental and sensory quality

Table 4: Selected Pearson correlations between instrumental and sensory quality attributes of cooked cattle hide

Relationship	T^1, r (P)	T^2, r (P)	Combined, r (P)
Shear force x texture	-0.921 (<0.0001)	-0.947 (<0.0001)	-0.982 (<0.0001)
Cooking loss x juiciness	-0.939 (<0.0001)	-0.988 (<0.0001)	-0.993 (<0.0001)
Cooking loss x overall acceptability	-0.806 (0.0015)	-0.892 (<0.0001)	-0.959 (<0.0001)
pH x color score	-0.860 (0.0003)	-0.882 (0.0001)	-0.971 (<0.0001)

T^1=2-tooth (n=12); T^2=4-tooth (n=12); combined n=24. P values are two-tailed. Combined coefficients are provided descriptively and may partly reflect separation between dentition groups; within-group coefficients are therefore emphasized for biological interpretation.

The raw-data correlation analysis strengthened the concordance between instrumental and sensory measurements. Shear force was inversely associated with texture score within both T_1 (r=-0.921, P<0.0001) and T_2 (r=-0.947, P<0.0001), indicating that samples requiring greater cutting force were consistently judged poorer in texture even within the same dentition class. Similarly, cooking loss was strongly and inversely associated with juiciness in both T_1 (r=-0.939, P<0.0001) and T_2 (r=-0.988, P<0.0001). These relationships are mechanistically coherent with established links among water retention, structural resistance, tenderness, and juiciness (Hughes et al., 2014; Warner, 2017).

Cooking loss also correlated negatively with overall acceptability within T_1 (r=-0.806, P=0.0015) and T_2 (r=-0.892, P<0.0001). In addition, pH was inversely associated with sensory color score in both dentition groups. Although pooled coefficients were even larger, they should not be treated as independent evidence because T_1 and T_2 occupy distinct regions of the quality space. Reporting the group-specific coefficients therefore provides the more conservative interpretation: instrumental toughness and thermal water loss tracked sensory texture and juiciness within each maturity class, not merely between them.

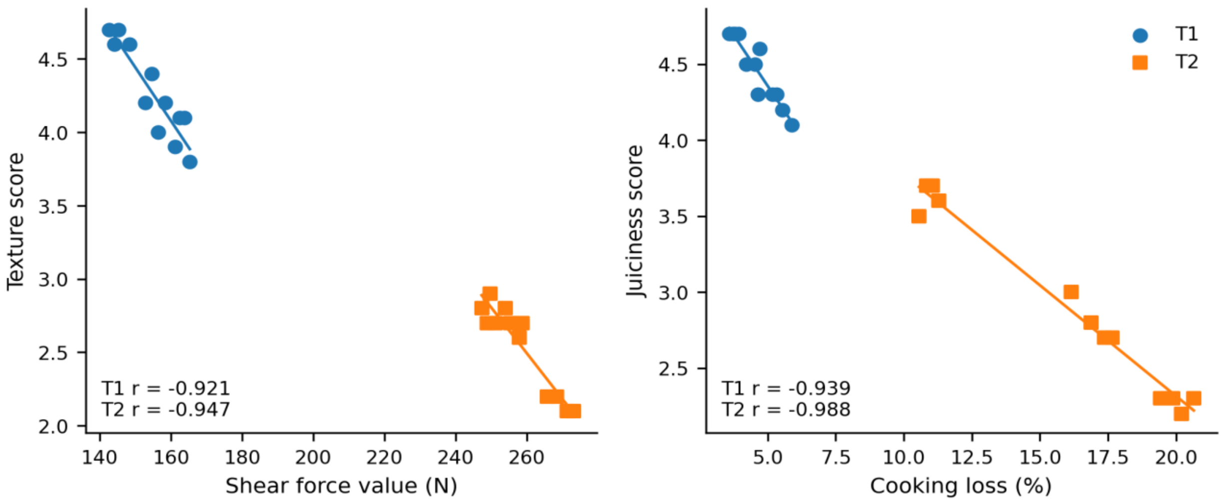

Figure 1: Relationships of (A) shear force value with trained-panel texture score and (B) cooking loss with juiciness in T_1 and T_2 cattle hide samples. Lines show group-specific least-squares fits; r values are Pearson correlation coefficients.

Overall interpretation and limitations

Across physicochemical, compositional, sensory, and correlation analyses, the 2-tooth group showed the more favorable profile for the boiling process used in this study. The major practical distinction was not simply nutrient concentration but processing behavior: younger hide lost less water, required substantially less cutting force, and received higher texture, juiciness, and overall-acceptability scores. This supports dentition as a potentially useful raw-material classification criterion when edible hide is intended for direct culinary processing.

Several limitations constrain the scope of inference. Dentition is a maturity proxy rather than an exact chronological age. Only male Sahiwal crossbred cattle and neck-region hide were studied, and collection occurred across two slaughter periods that were not modeled separately. Collagen concentration, cross-link type, collagen solubility, thermal shrinkage, amino-acid composition, and in vitro or in vivo digestibility were not measured. The study also did not include microbiological, chemical-contaminant, or shelf-life testing; therefore, it cannot establish food safety. Finally, the sensory panel was small and trained rather than representative of consumers. These limitations identify clear next steps: direct collagen characterization, amino-acid and digestibility analysis, validated safety assessment, processing optimization for older hide, and larger consumer studies.

Conclusions

Dentition-based maturity was strongly associated with the quality of cooked Sahiwal crossbred cattle hide. Compared with 4-tooth hide, 2-tooth hide had lower pH, drip loss, cooking loss, and shear force; higher dry matter and crude protein; and superior trained-panel scores for color, texture, flavor, juiciness, and overall acceptability. Raw-data Pearson analysis further showed that instrumental shear force tracked sensory texture and that cooking loss tracked juiciness within both dentition groups. These convergent results support younger hide as the better raw material for direct boiling under the conditions tested. Cattle hide can be described as a protein-rich slaughter co-product with potential for value addition, but claims regarding protein quality, digestibility, safety, and broad consumer acceptance require dedicated studies before commercial dietary recommendations are justified.

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Conflict of interest

The other authors declare no potential conflict of interest.

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