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Effects of *Capsicum oleoresin* on the Growth Performance, Nutrient Digestibility and Meat Quality of Fattening Beef Cattle

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Simple Summary: Many studies have shown that adding capsicum extracts to livestock and poultry diets can improve animal immunity, enhance antioxidant capacity, regulate intestinal flora and reduce heat stress. However, so far, only few related studies are available on the use of capsicum extract in fattening beef cattle. In this study, the effects of different doses of *Capsicum oleoresin* on the growth performance, apparent digestibility of nutrients and meat quality of fattening beef cattle were studied. It was found that adding *Capsicum oleoresin* to the animals' diet can improve feed efficiency and meat quality to some extent. It is expected that these opinions will encourage the application of *Capsicum oleoresin* in the production of fattening beef cattle.

Abstract: This study investigated the effects of *Capsicum oleoresin* (CAP) on the growth performance, nutrient digestibility and meat quality of fattening beef cattle. A total of 48 Simmental crossbred cattle, selected based on body weight (484.7 ± 48.4 kg), were randomly assigned to four treatment groups (each with 12 animals) in a randomized complete block design. In each group, the basal diet was supplemented with 0 g/d CAP (control), 4 g/d, 8 g/d and 12 g/d. The results showed that adding CAP linearly increased the dry matter intake (DMI; $p = 0.023$), led to a quadratic increase in the average daily gain (ADG; $p = 0.035$) and linearly decreased the feed-to-gain ratio (F/G; $p = 0.018$). The apparent digestibility of CP also linearly increased with increasing CAP dosage ($p = 0.023$), while the apparent digestibility of ADF showed a decreasing trend ($p = 0.054$). Additionally, the slaughter performance index and nutritional composition of beef were not affected by the amount of CAP added ($p > 0.05$), while the pH value of beef decreased linearly with increasing CAP addition ($p = 0.016$). Among all groups, the 8 g/d one exhibited the highest DMI, ADG, F/G, apparent digestibility of CP and water-holding capacity, as well as the lowest cooking loss. In conclusion, CAP can be used as a potential novel feed additive in the diet of beef cattle to improve growth performance and nutrient digestibility. Under the conditions applied in this study, a CAP amount of 8 g/d per cattle was found to be optimum for fattening beef cattle.

Keywords: *Capsicum oleoresin*; growth performance; apparent digestibility of nutrients; meat quality; beef cattle

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1. Introduction

Growing awareness of food safety has significantly impacted the livestock and poultry industries, leading to more cautious use of feed additives. As a result, farms increasingly favor a more natural production system to ensure that livestock products are safe, green and healthy. Some of the natural feed additives that are commonly used in the market include capsaicin [1], anthocyanin [2], curcumin [3] and resveratrol [4], amongst others. These natural substances break down readily in animals after fulfilling their roles, leaving no toxic residues or traces that might contribute to drug resistance. Hence, capsicum extract is suitable as a natural feed additive in livestock and poultry production, with capsaicin (*8-methyl-N-vanillyl-trans-6-nonenamide*) and its analogs, the main active and pungent components extracted from capsicum fruit, being key for this application [5]. With advancements in the capsicum industry, the use of capsicum oleoresin (CAP), which is produced by extracting and concentrating the active components of capsicum, namely capsaicin and its analogs, has gained increasing attention [6]. Indeed, capsicum extract has many other functions besides being used as a spice. Because of the presence of capsaicin, which can be involved in the activation of the TRPV1 (transient receptor potential vanilloid-1) [7], it has a role in influencing the release of signals from neurons or promoting the secretion of neurotransmitters, and is therefore heavily used in medical research. It turns out that it offers various health benefits, such as providing relief from pain and itching [8,9], lowering blood sugar and lipid levels [10], carrying anticancer properties [11], and offering antibacterial [12], anti-inflammatory [13] and antioxidant effects [14], as well as protecting the gastrointestinal tract [15]. Nevertheless, as reported by Morittu et al. [16] the properties of capsicum could be affected by several factors (light intensity and temperature at which the plant grows, etc.). Given these properties, capsicum extract has found widespread application in the pharmaceutical industry. In addition, it is used across other fields, including in pesticides, military applications, condiments, additives, and weight management and health care products.

Various animal studies have shown that adding capsaicin to livestock and poultry diets can enhance feed intake, daily weight gain and production performance, as well as the quality of meat, eggs and milk. For instance, research indicates that supplementing the diet of finishing pigs with 0.02% capsaicin does not increase feed intake, but significantly improves feed conversion efficiency, thereby boosting the return on investment [17]. Rosa-Medina et al. [18] also reported similar effects, noting that adding capsaicin to the diet of nursing sows and weaned offspring enhanced weight gain efficiency in the first week post-weaning. Furthermore, in the case of broiler production, several studies have shown that adding capsicum extract to diets can improve the average daily gain of broilers [19–21], while Liu et al. [22] found that increasing capsaicin intake in the diet of older laying ducks significantly enhanced both their laying rate and egg weight, thus indicating capsaicin's positive effects on the growth performance of these animals. Additional research in dairy farming has consistently shown that capsicum extracts can not only boost milk yield, but also improve the quality of milk by increasing the content of protein in milk [23–25]. In this context, after supplementing the diet of Holstein cows with 1.5 g/d of microencapsulated capsicum extract, Vittorazzi et al. [26] noted a significant increase in milk protein content, as well as in the yields of fat-corrected milk, lactose, fat and protein. However, despite the widespread use of capsicum extract in livestock and poultry, its application in beef cattle production remains underexplored. In fact, during the fattening process, beef cattle tend to consume higher levels of concentrate, which can lead to ruminal food accumulation or acidosis that may further affect digestion while reducing production performance. Therefore, this study investigates the effects of varying doses of CAP on the growth performance, apparent nutrient digestibility and meat quality of fattening beef cattle, thus providing a theoretical foundation for the application of CAP in beef cattle production.

2. Materials and Methods

2.1. Ethics Statement

The procedures for animal handling were approved by the Committee of Experimental Animal Management (approval code IIASVM-2023-013) at the Institute of Animal Science and Veterinary Medicine, Shandong Academy of Agricultural Sciences, China. Moreover, regarding the ethical use of experimental animals, all the applicable rules and regulation of the organization and government were followed.

2.2. Animals and Experimental Design

In this experiment, 48 Simmental crossbred male cattle, with a mean age of 16 months and an average weight of (484.73 ± 48.42) kg, were selected. A randomized block design was then used to divide the animals into four treatment groups, each containing 12 animals, and for each group, the basal diet was supplemented with 0 (control group), 4, 8 or 12 g/d of CAP. The adaptation period was 7 days and the trial period was 90 days. During this period, the beef cattle were contained in pens in a barn, with two cattle in each pen; all the cows could drink freely all day, and feed was provided twice daily, at 06:00 and 18:00. In addition, the amount of leftover feed was controlled to within 10% of the fresh weight. After breakfast was served, CAP was sprinkled on the surface of the feed and licked by the cattle for ingestion. The CAP (*Capsicum oleoresin*) used in this study was obtained from a company in Guangdong, China; it consisted of edible hydrogenated oil, and had a minimum capsaicin content of ≥2%. The composition and nutrient levels of the basal diet (on a dry matter basis) are shown in Table 1.

Table 1. Composition and nutritional level of the basal diet (dry matter basis).

Ingredients, % of DM	Contents	Nutrient Levels, % of DM	Contents
Corn kernels	46.00	CP	11.91
Soybean meal	8.50	NDF	32.01
Soybean hulls	2.00	ADF	21.46
Palm kernel meal	6.00	Ash	5.06
Date waste	4.00	Ca (%)	0.61
Corn straw yellow silage	30.00	P (%)	0.46
NaCl	0.70	ME [2] (MJ/kg)	10.06
$CaHPO_4$	0.70	Nem [2] (MJ/kg)	6.45
$CaCO_3$	0.70	Neg [2] (MJ/kg)	4.04
$NaHCO_3$	0.70		
Premix [1]	0.70		

[1] One kilogram of premix contained the following: VA—2,000,000 IU, VD_3—800,000 IU, VE—2000 mg, Cu—3 g, Fe—30 g, Mn—25 g, Zn—24 g, I—500 mg, Se—100 mg and Co—50 mg. [2] The ME, NEm and NEg values were calculated based on the NRC (2016), while the others were measured in the field.

2.3. Growth Performance

The cattle were weighed before the morning feed on days 0 and 90, with these values recorded as the animals' initial and end body weights, respectively, and they were fasted for 12 h before the final weight was determined. The feed intake and amount of leftovers were also continuously recorded during the last seven days of the trial. In this case, the initial weights of the feed and leftover samples were recorded as M and N, respectively, and after drying at 105 °C, the corresponding new weights, M1 and N1, were taken. From the readings, the average daily gain (ADG), dry matter intake (DMI) and feed-to-gain ratio (F/G) were calculated using the following formulas:

$$ADG = \frac{(\text{Final body weight} - \text{Initial body weight})}{\text{days of feeding}}$$

$$DMI = \frac{\mathrm{M_1}}{\mathrm{M}} - \frac{\mathrm{N_1}}{\mathrm{N}}$$

$$F/G = \frac{\mathrm{DMI}}{\mathrm{ADG}}$$

2.4. Apparent Digestibility of Nutrients

A week before the end of the trial period, fecal samples were collected before the morning feed for seven consecutive days [27]. The collected fecal samples were thoroughly mixed for individual beef cattle to obtain representative samples, and dried at 65 °C to determine the initial moisture. The samples were dried at 65 °C to determine the initial moisture, and then ground for further analyses. Proximate analyses were performed according to the Official Methods of Analysis (AOAC) [28]. Briefly, the DM (Dry Matter) was measured according to standard procedures (934.01), while the CP (Crude Protein) was determined using an automatic Kieldahl apparatus (KjeltecTM 8400, FOSS, Denmark). Additionally, the NDF (Neutral Detergent Fiber) and ADF (Acid Detergent Fiber) were measured, based on the Filter Bag method [29], using a fiber analyzer (R-100, UK RINGBIO INSTRUMENT GROUP Co., Ltd, Macedon, London, UK). Finally, the feed and feces were analyzed using 4N-HCl technology to determine their acid-insoluble ash (AIA) content [30]. From these measurements, the apparent digestibility of nutrients was then calculated as follows:

$$AD(\%) = (1 - \frac{\text{Nutrient content in feces} \times \text{AIA content in feed}}{\text{Nutrient content in feed} \times \text{AIA content in feces}}) \times 100$$

2.5. Slaughtering Performance

The live weight of the fattening beef cattle was recorded after 24 h of fasting, prior to slaughter. Following slaughter, the animals were bled and skinned before removing the head, viscera, forelimbs below the knee joints and hind limbs below the toe joints. The carcasses were then rested for 30 min before determining the hot carcass weight, net meat weight and bone weight to calculate the dressing percentage, net meat percentage and meat-to-bone ratio.

$$Dressing\ percentage(\%) = (\text{hot carcass weight}/\text{live weight}) \times 100$$

$$Net\ meat\ percentage(\%) = (\text{net meat weight}/\text{hot carcass weight}) \times 100$$

$$Meat : bone = \text{net meat weight}/\text{bone weight}$$

2.6. Meat Quality Assessment

At the time of slaughter, 1.5 kg of sirloin was sampled. After 24 h, the muscle pH was determined with a pH meter (Hanna Instruments, Italy), while meat color was detected using a color difference meter (3nh, Guangdong), based on specific parameters: L* (lightness), a* (redness) and b* (yellowness). In addition, approximately 300 g of the Longissimus dorsi was freeze-dried at ultra-low temperature, and after being ground, the nutrients were analyzed according to AOAC [28] standard procedures. Specifically, the DM (934.01) and ash content (942.05) were determined according to standard procedures, while the CP and EE were analyzed using the Kjeldahl nitrogen determination device and Soxhlet extraction, respectively [31]. Similarly, the cooking loss and drip loss of beef were assessed according to the method of Zhang et al. [32], while a combination of methods from Li et al. [33] and Ozdemir et al. [34] allowed texture characteristics, such as the shear force, water-holding capacity, hardness, adhesiveness, resilience, cohesiveness, springiness, gumminess and chewiness, to be determined using a texture analyzer (Stable Micro Systems, UK). For the shear force, meat blocks were trimmed to 3 × 1 × 1 cm in the direction of muscle fibers, and the maximum shear force was recorded with an HDP/BSW probe under 50 g trigger force. For the other texture parameters, boiled meat was trimmed into a cube with a side length of 1 cm and compressed twice, under 30% deformation, using a P/0.5S probe, to determine the hardness, adhesiveness, resilience, cohesiveness, springiness, gumminess and chewiness. In addition, a fresh meat sample cube with a side length of 2 cm was weighed, placed between eight sheets of qualitative filter paper and compressed with a P/100 probe at 350 N for 5 min. After the compression, the weight was recorded again and the water-holding capacity was calculated.

2.7. Statistical Analysis

All the data were analyzed by one-way analysis of variance (ANOVA) using the GLM procedure of the SPSS 26.0 software (IBM, Armonk, NY, USA), with treatment as the fixed effect, and the beef cattle undergoing treatment as the random effect. Differences among treatments were determined using the Duncan's multiple range test. All the data were presented as least squares means with pooled standard errors. In addition, the linear and quadratic effects of increasing the levels of CAP were assessed using orthogonal polynomial contrasts. Differences were considered to be statistically significant at $p < 0.05$, and trends were noted for $0.05 \leq p \leq 0.10$.

3. Results

3.1. Growth Performance

The initial weights and final weights of the cattle were not different between treatment groups ($p > 0.05$; Table 2), hence indicating a uniform weight distribution across the groups. However, in the 8 g/d group, the DMI and ADG were significantly higher compared with the control group ($p < 0.05$), while the F/G was significantly lower ($p < 0.05$). Furthermore, in the case of the 12 g/d group, the ADG increased significantly ($p < 0.05$) compared with the control, with no significant changes noted for the DMI and F/G. Finally, at the 4 g/d dose, there were no significant changes in DMI, ADG and F/G ($p > 0.05$). Moreover, the DMI and ADG were found to increase linearly with higher doses of CAP ($p < 0.05$), while the F/G decreased linearly ($p < 0.05$).

Table 2. Effects of CAP on the DMI, ADG and F/G of fattening beef cattle.

Items	CAP Addition Amount (g/d)				SEM	*p*-Value		
	0	4	8	12		P	L	Q
Initial weight/kg	484.58	482.33	485.50	486.50	7.063	0.997	0.892	0.912
End weight/kg	584.83	588.92	600.08	596.83	7.396	0.886	0.491	0.810
DMI/(kg/d)	11.12 ^{b}	11.46 ^{ab}	11.82 ^{a}	11.59 ^{ab}	0.089	0.040	0.023	0.101
ADG/(kg/d)	1.11 ^{c}	1.19 ^{bc}	1.27 ^{a}	1.23 ^{ab}	0.016	0.001	0.001	0.035
F/G	10.05 ^{a}	9.74 ^{ab}	9.30 ^{b}	9.47 ^{ab}	0.104	0.052	0.018	0.219

NOTE: P: CAP addition amount; L: linear effect; Q: quadratic effect; Means in the same row with different superscripts (a, b, c) are significantly different ($p < 0.05$).

3.2. Apparent Digestibility of Nutrients

The results presented in Table 3 indicate an apparent linear increase in the digestibility of CP with increasing CAP supplementation ($p < 0.05$). Specifically, in the 8 g/d group, the apparent digestibility of both DM and CP increased significantly compared with the control ($p < 0.05$). However, no significant changes in the apparent digestibility of DM and CP were observed between the 4 g/d and 12 g/d groups ($p > 0.05$). Similarly, the addition of CAP had no significant effects on the apparent digestibility of ADF and NDF in fattening beef cattle ($p > 0.05$).

Table 3. Effects of CAP on the apparent digestibility of nutrients in fattening beef cattle (%).

Items	CAP Addition Amount (g/d)				SEM	*p*-Value		
	0	4	8	12		P	L	Q
DM	66.27 [b]	65.80 [b]	68.31 [a]	67.41 [b]	0.405	0.115	0.098	0.782
NDF	54.69	54.69	56.40	54.38	0.535	0.540	0.872	0.352
ADF	46.23	48.77	50.68	50.44	0.835	0.212	0.054	0.401
CP	60.67 [b]	62.44 [ab]	65.26 [a]	64.85 [ab]	0.756	0.104	0.023	0.458

NOTE: P: CAP addition amount; L: linear effect; Q: quadratic effect; Means in the same row with different superscripts (a, b) are significantly different ($p < 0.05$).

3.3. Slaughtering Performance

As shown in Table 4, the addition of different amounts of CAP did not significantly influence the live weight, hot carcass weight, bone weight, net meat weight, carcass rate, net meat rate and meat-to-bone ratio of the fattening beef cattle ($p > 0.05$).

Table 4. Effects of CAP on the slaughtering performance of fattening beef cattle.

Items	CAP Addition Amount/(g/d)				SEM	*p*-Value		
	0	4	8	12		P	L	Q
Live weight/kg	599.00	610.75	615.25	610.88	8.458	0.925	0.615	0.651
Hot carcass weight/kg	342.21	349.78	360.16	350.68	5.504	0.739	0.486	0.458
Bone weight/kg	63.51	64.43	63.89	64.81	1.027	0.975	0.731	0.999
Net meat weight/kg	278.70	285.35	296.27	285.88	4.930	0.675	0.478	0.406
Dressing percentage, %	57.02	57.23	58.61	57.43	0.364	0.429	0.429	0.348
Net meat ratio, %	46.37	46.72	48.21	46.79	0.382	0.349	0.428	0.255
Meat:bone ratio	4.38	4.47	4.66	4.43	0.076	0.620	0.657	0.312

NOTE: P: CAP addition amount; L: Linear effect; Q: Quadratic effect.

3.4. Meat Quality Determination

As the amount of added CAP increased, the ash content showed a quadratic trend ($p < 0.05$), reaching its lowest level at a CAP supplementation of 8 g/d. However, the DM, CP and EE were not significantly affected by the amount of CAP added ($p > 0.05$). These results are presented in Table 5.

As CAP supplementation increased, the pH value of the cattle meat, 24 h post-slaughter, decreased significantly ($p < 0.05$). At the same time, the water-holding capacity of the meat initially increased and then decreased ($p < 0.05$), with the highest water-holding capacity observed when 8 g/d of CAP was added. Additionally, compared with the control group, the cooking loss in the 8 g/d group was significantly reduced ($p < 0.05$), while the water-holding capacity was significantly enhanced ($p < 0.05$). However, no significant differences in cooking loss and water retention were observed between the 4 g/d and 12 g/d groups ($p > 0.05$). Similarly, CAP addition did not affect the L*, a*, b*, drip loss and shear force of the beef. Finally, in the case of TPA texture analysis, resilience in the

4 g/d group was significantly lower than in the control group ($p < 0.05$), while other texture parameters, namely hardness, adhesiveness, cohesiveness, springiness, gumminess and chewiness, were not significantly influenced by CAP addition. These results are shown in Table 6.

Table 5. Effects of CAP on the conventional nutritional components of beef (%).

Items	CAP Addition Amount/(g/d)				SEM	*p*-Value		
	0	4	8	12		P	L	Q
DM	24.85	25.11	25.31	24.84	0.181	0.777	0.919	0.339
CP	86.05	84.78	86.56	86.46	0.530	0.640	0.541	0.593
EE	8.03	9.64	7.91	7.78	0.491	0.522	0.583	0.391
Ash	4.76^{ab}	4.68^{ab}	4.62^{b}	4.84^{a}	0.036	0.152	0.557	0.040

NOTE: P: CAP addition amount; L: linear effect; Q: quadratic effect; Means in the same row with different superscripts (a, b) are significantly different ($p < 0.05$).

Table 6. Effects of CAP on the beef quality index of fattening beef cattle.

Items	CAP Addition Amount/(g/d)				SEM	*p*-Value		
	0	4	8	12		P	L	Q
pH	6.87	6.85	6.24	6.14	0.132	0.078	0.016	0.874
Drip loss, %	3.52	3.27	2.69	2.45	0.213	0.253	0.087	0.555
Cooking loss, %	31.50^{a}	31.10^{ab}	28.47^{b}	30.79^{ab}	0.505	0.137	0.278	0.168
Water holding capacity, %	39.73^{b}	41.04^{ab}	42.47^{a}	40.55^{ab}	0.437	0.156	0.310	0.064
Shear force/N	159.59	173.07	154.35	187.16	6.848	0.338	0.301	0.483
Meat color								
L*	32.68	31.09	32.43	30.76	0.406	0.251	0.224	0.956
a*	16.89	18.54	17.67	17.75	0.295	0.279	0.516	0.187
b*	7.27	7.87	7.65	7.47	0.230	0.837	0.857	0.423
Texture profile analysis (TPA)								
Hardness/N	9.84	10.69	8.42	8.92	0.500	0.399	0.268	0.861
Adhesiveness/(g.sec)	0.89	1.26	1.18	0.84	0.089	0.252	0.780	0.050
Resilence, %	31.73^{a}	28.34^{b}	32.18^{a}	29.74^{ab}	0.539	0.032	0.630	0.629
Cohesiveness, %	70.81^{ab}	67.57^{b}	73.07^{a}	68.81^{b}	0.698	0.022	0.929	0.009
Springiness, %	69.47	66.81	69.62	69.62	0.572	0.227	0.521	0.242
Gumminess/N	7.00	7.20	6.14	6.16	0.348	0.614	0.270	0.895
Chewiness/N	7.00	7.20	6.14	6.16	0.348	0.614	0.270	0.895

NOTE: P: CAP addition amount; L: linear effect; Q: quadratic effect; Means in the same row with different superscripts (a, b) are significantly different ($p < 0.05$).

4. Discussion

4.1. Growth Performance

In a study by Oh et al. [35], feeding multiparous Holstein cows with 0, 250, 500 and 1000 mg/d of rumen-bypass CAP did not affect DMI, but as the dosage increased, the milk yield showed a quadratic increase, with the yield of milk fat also significantly improving. Similarly, another study showed that the supplementation of cows with 0.75 g/D or 1.5 g/d of encapsulated pepper significantly increased their DMI and increased the yield of fat-corrected milk and milk solids under heat stress conditions [26]. These findings suggest that rumen-bypass CAP can have a positive impact on the growth performance of dairy cows. In a different study, Westphalen et al. [36] found that adding rumen-protected CAP to the diet of calves significantly increased their ADG by day 50, but the results of DMI and F/G were not affected by the addition of CAP. In contrast, Yi et al. [1] found no difference in DMI when adding 1.5 g/d capsaicin to beef cattle diets. Similarly, Eidsvik et al. [37]

found no significant difference in the DMI, ADG and FCR of fattening beef cattle fed with 77 mg/d or 250 mg/d of rumen capsaicin. Our results are different from theirs. Studies have shown a linear increase in the DMI and ADG of cattle with increased CAP supplementation, hence highlighting the positive impact of CAP addition on the animals' growth performance. In the meantime, in the case of the F/G, its value decreases linearly with higher CAP doses. Specifically, the DMI and ADG increased significantly, while the F/G decreased significantly, with optimal results obtained at a dose of 8 g/d. The cause of this difference is not known, but we suspect that it may be due to different dosing and processing of the product. Increased water intake [25,38,39], as well as increases in digestive enzymes [40], bile acids [41] and endogenous Cholecystokinin [42] in the gut, caused by capsaicin stimulation, are likely to be responsible for the increased DMI and feed efficiency. However, when the dosage was increased to 12 g/d, the DMI and ADG showed a downward trend, while the F/G began to rise. It is speculated that the decrease in performance at the 12 g/d level could have been due to the strong spicy taste of capsaicin, which could have stimulated the taste receptors on the cattle's tongues, causing a burning and tingling sensation that impacted feed intake [43].

4.2. Apparent Digestibility of Nutrients

The apparent digestibility of nutrients reflects an animal's ability to digest and absorb nutrients in feed [22]. In this context, studies by Vittorazzi et al. [26], Oh et al. [35] and Martins et al. [44] have shown that adding capsaicin to the diet of dairy cows had no significant effects on the apparent digestibility of nutrients. Additionally, Westphalen et al. [36] found that supplementing cattle diet with 5, 10 or 15 mg/kg of rumen-bypass CAP did not influence the apparent total tract digestibility of nutrients. Similarly, in this study, CAP supplementation did not significantly affect the apparent digestibility of DM, ADF and NDF in fattening beef cattle. However, unlike the above studies, the apparent digestibility of CP increased linearly with increased CAP doses. Specifically, the addition of 8 g/d of CAP resulted in a significantly higher CP digestibility compared with the control. Similarly to our results, a study by Oh et al. [45] showed a linear increase in the apparent digestibility of CP with the addition of rumen chili oleoresin to cow diets. Capsaicin can promote the synthesis of microbial proteins by rumen microorganisms [39], and increase the activities of trypsin in the small intestine [46] and protease in the jejunum mucosa [47], which may increase the apparent digestibility of CP; in addition, the amount of feed intake can also affect this. Therefore, we cannot be sure that the increase in the apparent digestibility of CP in this experiment was caused by the addition of CAP. Nevertheless, what we can be sure of is that CAP supplementation does not negatively impact the digestibility of nutrients.

4.3. Slaughtering Performance

Slaughtering performance is a key index for evaluating animal production, and it is largely influenced by diet quality. In particular, slaughter performance metrics provide insights into the economic benefits, management practices and living conditions of animals before slaughter. This study showed that varying levels of CAP supplementation did not significantly affect the live weight, hot carcass weight, bone weight, net meat weight, carcass rate, net meat ratio and meat-to-bone ratio of fattening beef cattle. Similarly, Eidsvik et al. [37] reported that adding rumen-protected capsaicin to the diet of fattening cattle did not influence their carcass rate, but might have affected the carcass yield grade, marbling score and quality grade. Additionally, supplementing quail diets with different levels of red pepper oil had no significant effects on their slaughter characteristics [48]. Altogether, these findings support the results of the current study, indicating that CAP supplementation in the diet does not negatively impact the slaughter performance of fattening beef cattle.

4.4. Meat Quality Assessment

The nutrient content in animal muscle is closely linked to meat quality, with the latter often assessed based on key indicators such as pH, color, drip loss, cooking loss, water-holding capacity and shear force. Beef is nutritionally valuable, being rich in protein, fats, carbohydrates, trace elements, vitamins and other nutrients. Hence, changes in these nutrient levels will undoubtedly impact beef quality [49]. This study showed that the DM, CP and EE content in the meat of fattening beef cattle were not influenced by the amount of CAP added, thus indicating that CAP supplementation does not negatively affect the nutritional composition of beef. However, as the CAP dosage increased, the pH values of the meat decreased linearly at 24 h post-slaughter. Additionally, at a CAP dosage of 8 g/d, the water-holding capacity significantly improved, while the cooking loss decreased. On the other hand, no significant changes in water-holding capacity and cooking loss were observed at CAP doses of 4 g/d and 12 g/d. In any case, as reported by Cutrignelli et al. [50] water retention also depends on the meat's pH, and this could hardly influence successive muscle proteolysis. In a study by Liu et al. [51], capsicum extract supplementation did not affect drip loss in broilers' breast muscle, but the L* value was significantly reduced. While the results vary, both studies suggest that capsicum extract can enhance meat quality. In particular, adding 8 g/d of CAP was shown to improve meat quality by enhancing water retention and cooking loss.

In TPA, indicators of meat quality include hardness, adhesiveness, resilience, cohesiveness, springiness, gumminess and chewiness. Of these, shear force measures meat tenderness, and can indirectly reflect the intramuscular fat content [52]. Typically, shear force is positively correlated with hardness, which may be influenced by the water content and level of protein denaturation in muscle [53]. Springiness reflects a meat's ability to resist external forces within the protein-based network structure and hydration layer, while cohesiveness reflects the meat's resistance to breakdown during chewing, thus indicating binding strength between muscle cells and tissues. Finally, chewiness is affected by hardness, cohesiveness and springiness [54]. The results of this experiment showed that the resilience of beef decreased significantly in the 4 g/d group, although the other texture parameters, namely hardness, adhesiveness, cohesiveness, springiness, gumminess and chewiness, remained unaffected by CAP supplementation. The results also suggest that adding CAP to the diet does not negatively impact beef's texture characteristics.

5. Conclusions

In summary, adding CAP to the diet of fattening beef cattle did not affect their nutrient digestibility or slaughter performance. However, it significantly increased their DMI and ADG, while decreasing the F/G, thereby promoting growth performance. Additionally, it reduced the cooking loss of beef samples and improved their water-holding capacity, as well as enhancing beef quality to a certain extent. Under the conditions of this experiment, the optimal growth performance and meat quality were achieved with a CAP supplementation level of 8 g/d.

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