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Comparison of Meat Quality From Hanwoo Cattle Having Yellow and White Carcass Fat[a]

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Abstract: This study aimed to investigate the relationship between the normal and yellow-colored fat on carcass on carotenoid contents in fat and meat quality of Hanwoo beef. A total of 20 female cattle, comprising 10 with normal carcass fat color (normal group) and 10 with yellow carcass fat color (yellow group), were collected from slaughterhouses throughout the country in Korea from May to July 2022. The color, fatty acid composition, and carotenoid contents in carcass fat, as well as various parameters related to meat quality such as proximate composition, pH, color, cooking loss, shear force, and thiobarbituric acid reactive substances in the striploin were measured. The results indicated that the yellowness of carcass fat was primarily influenced by the carotenoid content in the fat ($r = 0.540$, $P < 0.05$) and was not affected by other carcass properties such as quality grade, maturity, and age. The yellow group showed distinct differences in yellowness and fatty acid composition of the carcass fat compared to the normal group, with lower levels of saturated fatty acids and higher levels of monounsaturated fatty acids ($P < 0.05$). However, no significant differences were observed in the meat quality parameters between the normal and yellow groups, suggesting that the yellowness of carcass fat did not significantly correlate with the inferior physicochemical properties of Hanwoo beef. Although further research is needed to better understand the complex factors contributing to the appearance of yellow carcass fat in Korea, this study highlights that beef having yellow carcass fat does not necessarily have a negative effect on meat quality.

Key words: yellow fat, carotenoid, quality grade, fat color, fatty acids
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Introduction

Meat serves as a great source of protein and essential nutrients, and as a result, the consumption of beef has been steadily increasing. When consumers make the decision to purchase beef in the market, they primarily consider the quality of the beef, including factors such as color, marbling, texture, and freshness. Hanwoo, a native Korean breed, has been nurtured, transported, and even utilized in religious ceremonies within Korean culture for over 5,000 years (Chung et al., 2018). Korean consumers have consistently exhibited a preference for Hanwoo beef over imported beef, because of its juiciness and flavor. To control the quality of Hanwoo beef in Korea, the Korea Institute for Animal Products Quality Evaluation (KAPE) plays a crucial role in grading the quality and yield of beef before it is distributed. According to KAPE's criteria, beef is classified into different quality grades (QG) and yield grades (YG) (Gajaweera et al., 2020). The QG of beef are determined based on the marbling score (ranging from 1 = devoid, to

9 = abundant), lean meat color (ranging from 1 = very bright red, to 7 = very dark red), fat color (ranging from 1 = creamy white, to 7 = yellow), firmness and texture of the lean meat (ranging from 1 = firm, to 5 = soft), and maturity (ranging from 1 = youthful, to 9 = mature) observed in the exposed *longissimus thoracis* muscle at the 13th rib interface. The lowest grade from each parameter is determined for final QG, and if the maturity score is 8 or 9, the final grade is further downgraded by one grade (Figure S1; KAPE, 2023).

Fat color, specifically the color of bovine subcutaneous adipose tissue (carcass fat), holds significant importance in beef carcass grading, not only in Korea but also in countries such as Japan, Canada, Australia, and the United States (UNECE, 2004). When purchasing beef, many consumers consider the fat color and tend to have a lower preference for beef with yellow carcass fat (Piao et al., 2015). In the grading system, carcasses with a yellowish color of carcass fat are classified as lower QG (QG 1 or 2) compared to those with creamy white fat (QG 1++ or 1+). Consequently, the lower quality grade attributed to beef with yellow carcass fat has a significant economic impact, affecting the income of beef producers in Korea and globally.

The yellow color of carcass fat can be influenced by various extrinsic and intrinsic factors, including breed, gender, age, fatness, growth rate, diet, carotene content, and supplementation (Dunne et al., 2009). In terms of intrinsic factors, older cattle tend to exhibit more yellow carcass fat, while females tend to have a yellower carcass fat color compared to steers (Dunne et al., 2009). Among the extrinsic factors, a higher concentration of carotenoids in feedstuffs such as forages and certain concentrates has been correlated with the presence of yellow carcass fat. Zhou et al. (1993) reported a positive relationship between the yellowness of carcass fat and the total carotenoid concentration in beef ($r = 0.79$; $P < 0.01$), with carotenoid concentrations ranging from 0.2 to 1.4 μg/g in beef corresponding to Commission Internationale de l´Eclairage (CIE) b^* values of 6 to 18. Furthermore, beef produced from forage-based diets tends to have yellower-colored fat and contains higher proportions of beneficial nutrients such as omega-3 fatty acids and carotenoids (Umberger et al., 2002). Consequently, in the study, 23% of the participants expressed a willingness to pay a premium for beef with yellow fat due to their preference for it (Umberger et al., 2002). Nevertheless, the majority of consumers still believe that yellow fat may be an indicator of inferior meat quality. Therefore, there still exists a question regarding whether beef with yellow carcass fat truly exhibits lower meat quality and is considered negatively for consumption.

In this study, 20 cattle with either white or yellow carcass fat were collected in Korea. The objective was to identify the parameters that influence the yellowness of carcass fat and examine the relationship between meat quality and the color of carcass fat. This research was intended to be presented as a specific case study involving cattle from a distinct breed (Hanwoo) and market under a specific grading system in Korea.

Materials and Methods

Sampling and experimental design

A total of 20 carcasses from Hanwoo females were collected from slaughterhouses in Korea from May to July 2022. After carcasses were graded by KAPE, those with yellow carcass fat (fat color grade 6 or 7; yellow group, $n = 10$) were selected, along with normal carcasses (fat color grade 3; normal group, $n = 10$) having similar carcass properties as the yellow group. The average QG, carcass weight, and age of collected carcasses were similar between two groups showing 2.15 ± 0.59, 324.25 ± 48.51 kg, and 60.30 ± 24.68 mo, respectively. Samples of both carcass fat and beef striploin (M. *longissimus lumborum*) were obtained at the level of the 1st to 3rd lumbar vertebrae of carcass within 24 h postmortem. After obtaining samples, they were directly frozen at −20°C with vacuum packaging until used for analysis due to variations in sample collection time caused by the limited availability of carcasses with yellow fat color (grade 6 or 7). Detailed growth conditions and quality information of each cattle are reported in Table S1 and Table S2, respectively. All samples were uniformly thawed in a refrigerator for 14 h and used for analysis. Overall experimental design is shown in Figure 1.

Color of carcass fat and meat

The carcass fat and meat samples were cut into 1.5 cm thick, and the color was measured using colorimeter with illuminant C (CR-310, Konica Minolta Sensing Inc., Japan). Prior to analysis, the samples were allowed to bloom for 30 min at room temperature, and then at least 6 scans were obtained from each sample. The colorimeter was equipped with an 8-mm-diameter of aperture size and a 2° standard observer. The standards for lightness (CIE L^*), redness (CIE a^*), and yellowness (CIE b^*) were calibrated using the whiteboard (Y = 94.3, x = 0.3131, and y = 0.3194).

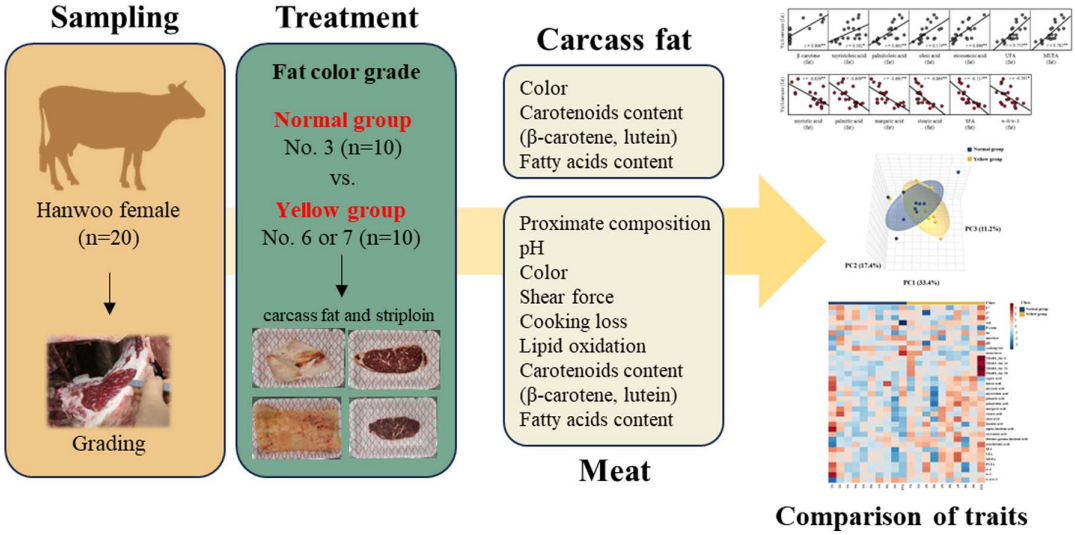

Figure 1. Experimental design for this study.

Hue angle (h^0) and whiteness index, chroma (C^*), and yellowness index were calculated using the methodology outlined by King et al. (2023).

Carotenoid contents in carcass fat and meat

The determination of β-carotene and lutein concentrations in carcass fat was carried out using a modified version of the methods described by Muramoto et al. (2005). A 7 g sample was saponified by adding 10 mL of 10% pyrogallol-ethanol and 2 mL of 60% KOH, followed by incubation in a 70°C water bath for 30 min. After cooling the saponified sample, an internal standard (1 µg of trans-β-Apo-8′-carotenal), 10 mL of 1% sodium chloride, and a hexane:ethyl acetate mixture (9:1) were added. The mixture was then shaken in a shaker incubator at room temperature for 20 min, and the supernatant was collected through centrifugation (1000 × *g*, 5 min). This process was repeated 4 times in total. The collected aliquot was dried under nitrogen gas at 40°C. The dried samples were re-dissolved in 1 mL of ethyl acetate and injected into a lipid chromatography system (Ultimate 3000, Dionex, Sunnyvale, CA) equipped with a YMC carotenoid column (4.6 mm × 250 mm, 5 µm; YMC, Kyoto, Japan). The mobile phases A and B consisted of water:ethyl acetate:methanol (10:10:80) and ethyl acetate:methanol (90:10), respectively. They were used in a linear gradient flow at a rate of 1.0 mL/min. The detection of β-carotene and lutein was performed at 450 nm, and quantification was conducted using the ratio of the internal standard to standard substances purchased from Sigma-Aldrich (St Louis, MO).

Proximate composition of meat

The moisture, fat, protein, and ash percentages were determined using a near-infrared spectrophotometer (FOSS FoodScan 78,800; Dedicated Analytical Solutions, Hillerod, Denmark). Prior to analysis, visible connective tissue and fat were removed from the samples, and they were subsequently ground. Approximately 200 g of each sample was used to measure the proximate composition, with independent readings taken from each sample.

pH of meat

The meat samples (3 g) were homogenized with 27 mL of distilled water and then filtered using filter paper No.4 (Whatman) according to previous study (Lee et al., 2023). The pH of the filtrate was measured using a pH meter (FEP20, Mettler Toledo, Switzerland).

Warner-Bratzler shear force and cooking loss of meat

The sliced meat of 1.5 cm thick were cooked in a water bath at 75°C until the internal temperature reached 72°C and then cooled at room temperature. Cooking loss was calculated as the percentage weight loss during cooking for the Warner-Bratzler shear force (WBSF) measurement. Five cylindrical samples (core diameter 1.27 cm) were prepared for each sample, which was taken parallel to fiber direction. The WBSF was defined as the peak force using the V-blade of a texture analyzer (Universal testing machine, Instron Crop., USA) with a cross-head speed of 200 mm/min (Lee et al., 2023).

Lipid oxidation of meat

To assess the extent of lipid oxidation of meat, the samples were vacuum-packed and stored at a temperature of 4°C ± 2°C for the period of 28 d. The measurement of 2-thiobarbituric acid reactive substances (TBARS) was conducted at day 0, 7, and 28, following the procedure described by Kim et al. (2022). The result was expressed as mg of malondialdehyde (MDA) per kilogram of the meat sample.

Fatty acid contents in carcass fat and meat

The fatty acid contents in both the carcass fat and meat samples were determined using the method described by Garcés and Mancha (1993). The carcass fat and meat samples were lyophilized using a freeze dryer (Shin PVTFD10R, Shinil Lab, Korea). The dried samples were then reacted with a methylation mixture consisting of 2 mL of methanol, benzene, 2,2-dimethoxy-propane, and H_2SO_4 in a ratio of 39:20:5:2 (v/v/v/v), along with 1 mL of heptane containing the internal standard (pentadecanoic acid). The reaction took place at a temperature of 80°C for 2 h. After the heating period, the reactant was cooled to room temperature and vigorously shaken. The upper layer, which contained the fatty acid methyl esters, was collected and utilized for gas chromatography analysis. Gas chromatography was performed using an Agilent 7890A instrument equipped with a DB 23 capillary column (Agilent Technology, Santa Clara, CA) with dimensions of 120 m × 0.25 mm i.d. Helium was used as the carrier gas at a flow rate of 1 mL/min. A 1 μL sample was injected in split mode (split ratio of 10:1) at an injector temperature of 220°C. The samples were detected by a flame ionization detector at 250°C. Fatty acids were identified using a fatty acid standard (Supelco 37 component FAME mix, Supelco, PA) and quantified using the internal standard method (mg/g).

Statistical analysis

To assess the relationship between carcass fat color grade and the factors under investigation, Pearson's and Spearman correlation analysis was conducted using SPSS software (IBM SPSS Statistics 21, IBM, NY). The quantification data were analyzed using a general linear mixed model in SPSS. The model included the main effects of carcass fat color, with random effects of QG and age according to the result of relationship analysis between carcass fat color grade and the factors. To determine the significance of differences between the normal and yellow groups, Student's *t*-test was performed at a significance level of $P < 0.05$. All data were presented as mean values with standard error of the mean (SEM) and accompanying *P* values. Multivariable analysis for meat quality data between normal and yellow groups was conducted using mean-normalization by log-transformed and auto-scaled data through Metaboanalyst 5.0 (https://www.metaboanalyst.ca/). In particular, principal component analysis (PCA), dendrogram, and heatmaps were employed to explore the associations of meat quality between the normal and yellow groups.

Results

Color traits and carotenoid contents in carcass fat

The color traits and carotenoid contents in carcass fat are shown in Figure 2. The yellow group exhibited significantly higher levels of yellowness (b^* value) and yellowness index compared to the normal group ($P < 0.05$). Additionally, the yellow group demonstrated higher values of hue angle (h^0) and chroma (C^*) in fat compared to the normal group. However, no significant differences were observed in lightness (L^* value), whiteness index, and redness (a^* value). Among the carotenoid compounds analyzed, β-carotene was detected in only 5 fat samples from the yellow group, with an average concentration of 0.43 μg/g (ranging from 0.44 to 1.11 μg/g), while lutein was not detected.

Correlation of various factors with carcass fat color grade

The correlation between carcass fat color grade and various factors, including QG and YG, marbling, age, maturity, carcass weight, and β-carotene content in carcass fat, was examined (Table 1). The results showed that carcass fat color grade by KAPE did not have a significant relationship with QG, marbling, age, maturity, and carcass weight ($P > 0.05$). However, there was a positive and significant correlation observed between β-carotene content in carcass fat and carcass fat color grade ($r = 0.540$; $P < 0.05$).

Effect of carcass fat color grade on physicochemical properties of meat

The effect of carcass fat color grade on the physicochemical properties of beef is presented in Table 2. The beef samples analyzed in this study exhibited approximately 20% protein content and 13% fat content, with no significant difference observed between

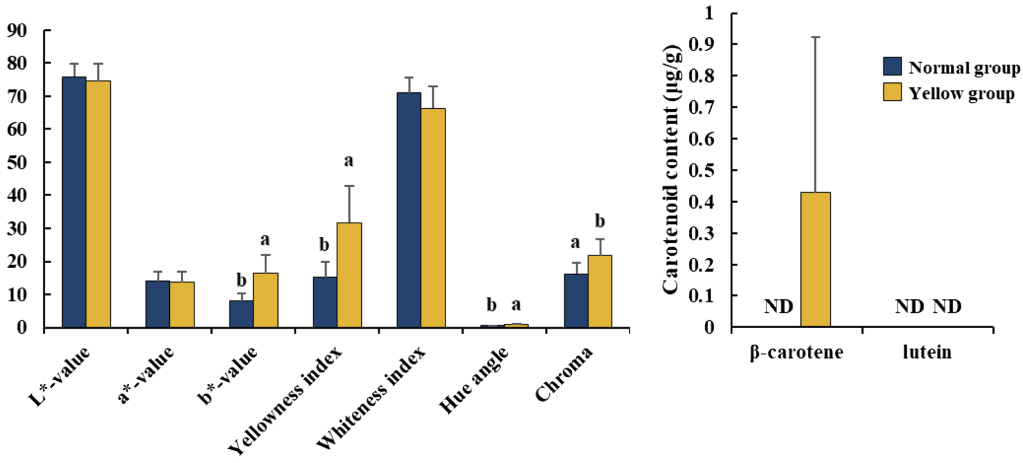

Figure 2. The color traits and carotenoid contents of carcass fat. Normal group having white carcass fat and yellow group having yellow carcass fat. ND, not detected. [a–b]Means within different superscripts differ significantly at $P < 0.05$.

Table 1. The correlation between carcass fat color grade and factors

Traits	Pearson's coefficient (r)	Spearman coefficient (ρ)
Quality grade (QG)	−0.036	0.018
Marbling	0.265	0.281
Age	0.103	0.160
Maturity	0.121	0.083
Carcass weight	−0.071	−0.059
β-carotene content in carcass fat	0.540*	0.591**

$N = 20$. *$P < 0.05$; **$P < 0.01$; ***$P < 0.001$.

Table 2. Effect of carcass fat color grade on physicochemical properties of meat

Item	Normal ($n = 10$)	Yellow ($n = 10$)	SEM	P value
Proximate composition (%)				
Ash	3.70	3.82	0.060	0.338
Crude protein	21.63	20.84	0.232	0.090
Crude fat	13.23	14.75	0.664	0.281
Moisture	64.76	63.45	0.580	0.285
pH	5.50	5.52	0.015	0.655
Cooking loss (%)	22.75	22.01	0.505	0.477
Shear force (N)	42.39	41.85	3.606	0.418
Meat color				
CIE L^*	38.32	38.55	0.542	0.831
CIE a^*	21.02	20.57	0.552	0.705
CIE b^*	8.89	9.02	0.237	0.769
Hue angle	0.40	0.42	0.014	0.327
Chroma	22.82	22.49	0.821	0.954
TBARS (mg malondialdehyde/kg meat)				
Day 0	0.19	0.26	0.048	0.320
Day 7	0.25	0.35	0.044	0.125
Day 21	0.30	0.45	0.063	0.125
Day 28	0.29	0.48	0.068	0.073

Normal, normal group having white carcass fat; Yellow, yellow group having yellow carcass fat.

the groups. The pH value of the beef samples was around 5.5, which matches within the normal pH range (5.40–5.79) as reported by Zhang et al. (2005). Similarly, normal and yellow groups showed similar cooking loss (22.01%–22.75%) and shear force values (41.85 N–42.39 N), with no significant difference observed. The meat color of the beef samples was also found to be similar between the two groups ($P > 0.05$). Moreover, during the storage period, there was no significant difference observed between the two groups. These findings suggest that the yellowness of carcass fat did not have a significant impact on changes in physicochemical properties of beef in this study.

Effect of carcass fat color grade on fatty acid composition of carcass fat and meat

The composition of major fatty acids in both carcass fat (Table 3) and meat (Table 4) primarily consisted of oleic acid, palmitic acid, stearic acid, palmitoleic acid, and myristic acid. In the yellow group, the carcass fat exhibited significantly lower levels of myristic acid and saturated fatty acids (SFA) compared to the normal group ($P < 0.05$). Oleic acid was found to be the most abundant monounsaturated fatty acid (MUFA) in carcass fat, with the yellow group showing a higher content of 309.10 mg/g (49.13% of total fatty acids) compared to the normal group (43.78% of total fatty acids) ($P < 0.05$). Additionally, eicosenoic acid, another MUFA, was higher in the carcass fat of the yellow group compared

Table 3. Effect of carcass fat color grade on fatty acid contents of carcass fat

Fatty acid (mg/g)		Normal ($n = 10$)	Yellow ($n = 10$)	SEM	P value
Capric acid	**C10:0**	0.20	0.21	0.014	0.691
Lauric acid	**C12:0**	0.63	0.68	0.041	0.493
Myristic acid	**C14:0**	24.60[a]	20.89[b]	0.976	0.022
Myristoleic acid	**C14:1**	12.13	12.96	1.574	0.720
Palmitic acid	**C16:0**	175.56	165.49	3.961	0.086
Palmitoleic acid	**C16:1**	45.61	55.05	6.414	0.340
Margaric acid	**C17:0**	4.31	3.79	0.439	0.440
Stearic acid	**C18:0**	78.76	49.54	11.793	0.111
Oleic acid	**C18:1n9c**	274.78[b]	309.10[a]	6.035	0.001
Linoleic acid	**C18:2n6c**	8.81	6.90	0.744	0.064
Alpha-linolenic acid	**C18:3n3**	0.64	0.70	0.064	0.547
Eicosenoic acid	**C20:1**	1.59[b]	2.93[a]	0.220	0.001
Dihomo-gamma-linolenic acid	**C20:3n6**	0.58	0.73	0.061	0.104
Arachidonic acid	**C20:4n6**	0.28	0.40	0.054	0.149
SFA		284.07	240.60	15.064	0.064
UFA		344.43[b]	388.77[a]	10.844	0.012
MUFA		334.12[b]	380.05[a]	10.971	0.011
PUFA		10.31	8.73	0.840	0.168
w6		9.67	8.03	0.796	0.129
w3		0.64	0.70	0.064	0.547
w6/w3		15.56	12.25	1.139	0.053

Normal, normal group having white carcass fat; Yellow, yellow group having yellow carcass fat; SFA, saturated fatty acids; UFA, unsaturated fatty acids; MUFA, monounsaturated fatty acids; PUFA, polyunsaturated fatty acids.

[a,b]Means within a row with different superscripts differ significantly at $P < 0.05$.

Table 4. Effect of carcass fat color grade on fatty acid contents of meat

Fatty acid (mg/g)		Normal ($n = 10$)	Yellow ($n = 10$)	SEM	P value
Capric acid	**C10:0**	0.13	0.14	0.012	0.725
Lauric acid	**C12:0**	0.28	0.25	0.035	0.611
Myristic acid	**C14:0**	9.78	9.21	0.777	0.610
Myristoleic acid	**C14:1**	2.88	2.83	0.404	0.931
Palmitic acid	**C16:0**	88.92	92.97	3.687	0.466
Palmitoleic acid	**C16:1**	13.17	15.44	1.131	0.196
Margaric acid	**C17:0**	1.99	2.11	0.128	0.510
Stearic acid	**C18:0**	35.69	36.33	2.342	0.839
Oleic acid	**C18:1n9c**	129.63	151.88	7.297	0.053
Linoleic acid	**C18:2n6c**	5.01	5.47	0.475	0.483
Alpha-linolenic acid	**C18:3n3**	0.39	0.35	0.100	0.775
Eicosenoic acid	**C20:1**	0.70[b]	0.97[a]	0.083	0.042
Dihomo-gamma-linolenic acid	**C20:3n6**	0.48	0.56	0.029	0.109
Arachidonic acid	**C20:4n6**	0.89	1.00	0.057	0.153
SFA		136.79	141.02	5.627	0.604
UFA		153.16	178.51	8.540	0.060
MUFA		146.38	171.13	8.383	0.062
PUFA		6.77	7.38	0.543	0.420
w6		6.38	7.03	0.475	0.331
w3		0.39	0.35	0.100	0.775
w6/w3		24.11	21.42	2.721	0.470

Normal, normal group having white carcass fat; Yellow, yellow group having yellow carcass fat; SFA, saturated fatty acids; UFA, unsaturated fatty acids; MUFA, monounsaturated fatty acids; PUFA, polyunsaturated fatty acids.

[a,b]Means within a row with different superscripts differ significantly at $P < 0.05$.

to the normal group ($P < 0.05$). Consequently, unsaturated fatty acids (UFA) and MUFA were higher in the carcass fat of the yellow group compared to the normal group ($P < 0.05$). In the meat samples, eicosenoic acid was found to be significantly higher in the yellow group with a content of 0.97 mg/g (0.3% of total fatty acids) compared to the normal group (0.24% of total fatty acids) ($P < 0.05$; Table 4). And no significant differences were observed in the total content of SFA, UFA, and MUFA in the meat samples.

The results suggest that the yellowness of carcass fat in this study showed different fatty acid composition in the carcass fat, particularly leading to an increase in MUFA. However, these changes in the fatty acid composition of the carcass fat did not have a strong presence in the fatty acid composition of the meat samples.

Relationship between carcass fat color and meat quality

Figure 3 illustrates the relationship between the yellowness of carcass fat and various quality traits, including physicochemical properties and fatty acid composition in both carcass fat and meat. A total of 13 traits were found to be significantly correlated with the yellowness of carcass fat. Out of these, 7 traits exhibited a positive correlation with carcass fat yellowness, while 6 traits showed a negative correlation. These correlations provide insights into the relationship between carcass fat yellowness and other characteristics, shedding light on the difference in parameters between samples from normal and yellow groups. Importantly, all the correlated traits were related to carcass fat, as already expected. The highest positive correlation was observed between β-carotene content and carcass fat yellowness ($r = 0.806$, $P < 0.01$), while the highest negative correlation was found with SFA ($r = -0.737$, $P < 0.01$). These findings indicate that the yellowness of carcass fat strongly had a relationship with fat-related traits rather than meat quality.

To assess the relationship between carcass fat color grade and meat quality (physicochemical properties and fatty acid), PCA plots, dendrogram, and heatmaps

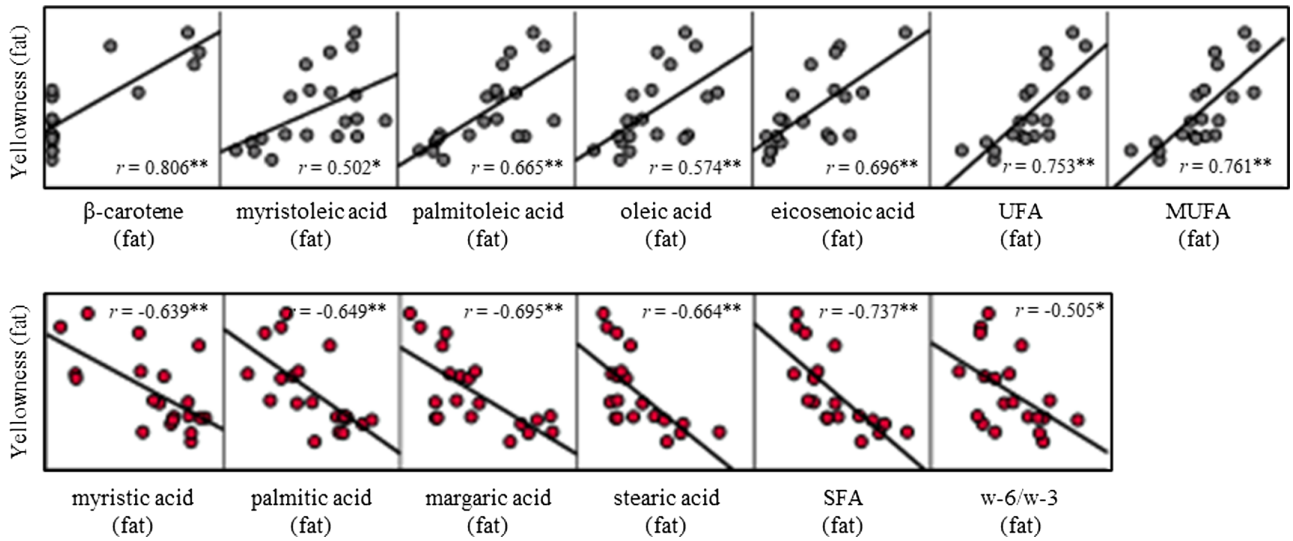

Figure 3. Significant relationship between yellowness (b^*) of carcass fat and meat quality traits. SFA, saturated fatty acids; UFA, unsaturated fatty acids; MUFA, monounsaturated fatty acids. $N = 20$; $^*P < 0.05$; $^{**}P < 0.01$.

were generated (Figure 4). The PCA plots accounted for 62% of the variation in meat quality data but did not show a significant distinction between the normal and yellow groups (Figure 4a). Similarly, the dendrogram and heatmap did not reveal any specific grouping or pattern between the two groups (Figure 4b and 4c). Therefore, the meat quality of both normal and yellow groups appeared to be similar and not distinctly separated based on carcass fat color grade.

Discussion

Carcass fat refers to the layer of fat situated between the skin and the meat, on the outside of the muscle. It is typically removed from beef prior to sale due to its perceived inferiority compared to other types of fat. Nonetheless, the color of carcass fat remains a crucial factor in determining the high-quality grade of beef in Korea. According to KEPA, carcass fat color grade is assessed on a scale ranging from white (No. 1) to yellow (No. 7). It has been observed that when the carcass receives a fat color grade over No. 6, it negatively impacts the final QG However, as carcass fat is typically removed during the processing of fresh beef cuts or meat products in Korea, it is hard to influence consumer perception directly. Consequently, at the point of the producer, there may be questions regarding the significance of carcass fat color as a determining factor for the QG.

Several factors influence the occurrence of yellow carcass fat, including species, age, diet, and sex (Mare et al., 2013). However, in this study, there was no significant correlation between carcass fat color grade and carcass properties such as QG, marbling, YG, age, maturity, and carcass weight (Table 1). Among the factors examined, only the β-carotene content in carcass fat exhibited a notable coefficient value, with a correlation of $r = 0.540$ ($P < 0.05$) and $\rho = 0.591$ ($P < 0.01$). The yellow group of carcass fat displayed carotenoid levels ranging from 0.44 to 1.11 μg/g (Figure 2). The content of carotenoids in carcass fat can be influenced by various factors. A diet rich in α-tocopherol and polyunsaturated fatty acids (PUFA) has been shown to improve the absorption of carotenoids (Yang et al., 2002). Conversely, supplementation of vitamin A has been found to decrease carotenoid concentrations in plasma, subsequently reducing the concentration in adipose tissues (Knight et al., 1996). Additionally, consistent dietary patterns have been identified as the primary influencer of color and carotenoid levels in carcass fat, suggesting that variations in tissue size may not be the sole contributing factor (Dunne et al., 2009). When adipogenesis is suppressed due to factors such as lactation or feed restriction, carotenoids consumed through feed tend to accumulate in adipose tissue (Swanson, 1989). Meanwhile, the production of fatter carcasses through grain-feeding, which results in increased fat deposition in major fat depots, may dilute the carotenoid content in tissues (Noziere et al., 2006). In particular, in Korea, Hanwoo cattle is commonly raised using a total mixed ration (TMR)-feeding strategy and rice straw to accumulate lipids in intramuscular fat and

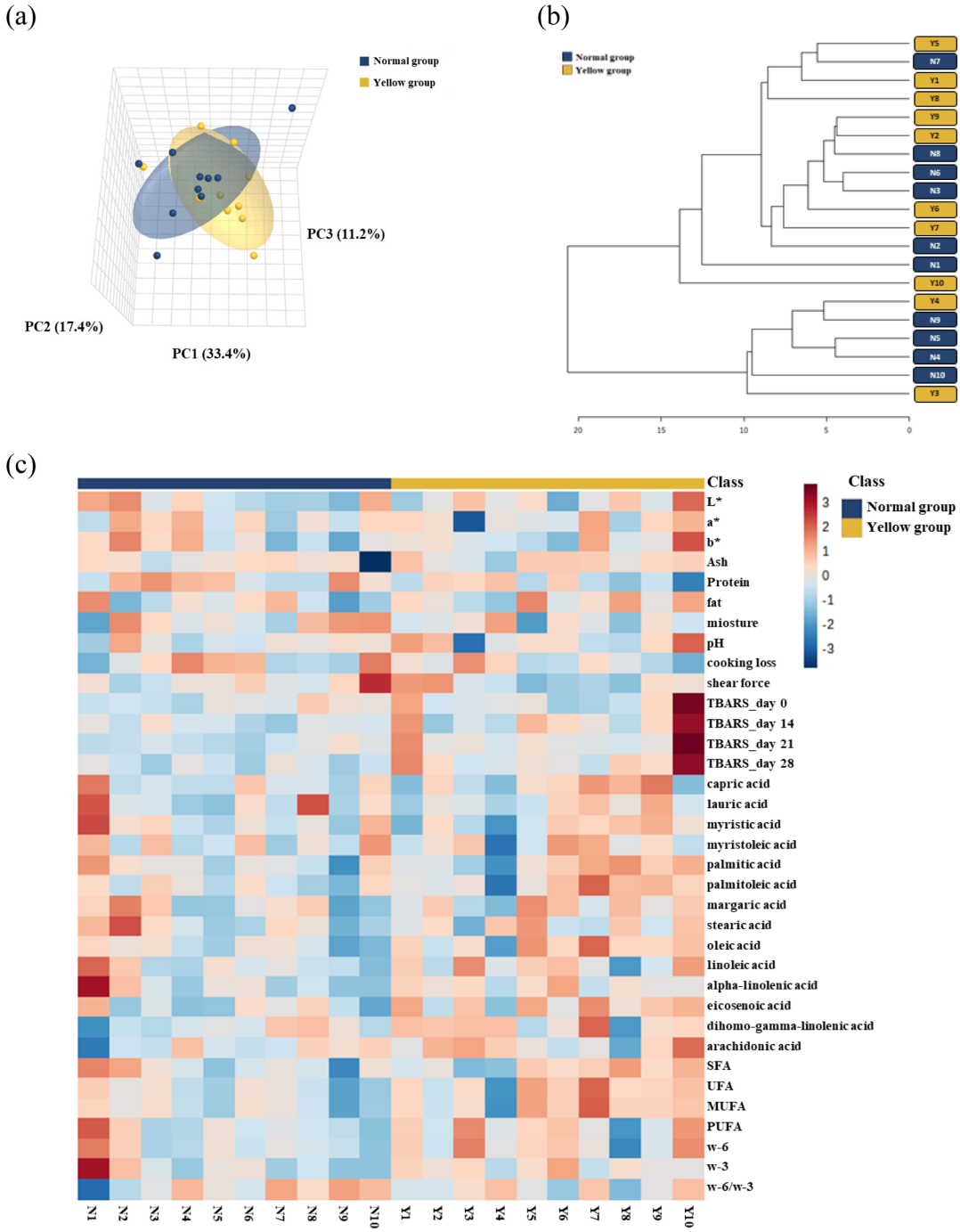

Figure 4. Principal component analysis (a), dendrogram (b), and heatmaps (c) for meat quality traits. $N = 20$. PC, principal component; N, normal group having white carcass fat; Y, yellow group having yellow carcass fat; SFA, saturated fatty acids; UFA, unsaturated fatty acids; MUFA, monounsaturated fatty acids; PUFA, polyunsaturated fatty acid.

address the issue of limited pasture resources (Kang et al., 2022).

Furthermore, carotenoid pigments in tissues have been considered as biomarkers of grass-feeding (Prache et al., 2003). The fatty acid composition of muscle and carcass fat from grass-fed cattle exhibits decreased levels of SFA and increased levels of w-3 PUFA (Dannenberger et al., 2004). Similar to previous study (Dannenberger et al., 2004), our study also found a strong negative correlation between the yellowness of carcass fat and SFA ($r = -0.737$, $P < 0.01$) as well as the w-6 to w-3 fatty acid ratio ($r = -0.505$, $P < 0.05$) (Figure 3). However, there was no association observed between the yellowness of carcass fat and UFA in both carcass fat and meat (Figure 3). Also, it has been generally reported that the fatty acid composition of meat

and fat obtained from grass-fed cattle is characterized by low levels of oleic acid and MUFA (Nogoy et al., 2022). Surprisingly, in this study, the fat of the yellow group exhibited significantly higher levels of oleic acid and MUFA compared to the normal group (Table 3). It was found that grain-fed animals had higher proportions of MUFA (Moholisa et al., 2018). This finding contradicts the hypothesis that the yellow group, characterized by high carotenoid contents, is solely attributed to grass-feeding. According to Cooke et al. (2004), the exposure of animals to different levels of exercise can also influence the effects of grass- and grain-feeding on fat color changes. Previous studies have also reported that diet can impact meat color, particularly when animals are raised outdoors (Bidner et al., 1986; Morris et al., 1997; Muir et al., 1998). However, in another study in which all animals were housed indoors, the effect of diet on meat color was not observed (Cooke et al., 2004). Considering that most beef production systems involve varying proportions of grass and grain at different stages of production, it is difficult to attribute the carotenoid contents observed in the yellow group to a single specific factor. It is possible that an environment conducive to carotenoid absorption was established within these samples; however, further research is necessary to fully elucidate the underlying factors.

Interestingly, the diet of the yellow group showed a higher presence of probiotics (Table S1). Previous research by Mun et al. (2013) has demonstrated that supplementation of probiotics in the diet of Hanwoo steers can increase the content of oleic acid and decrease myristic acid levels in meat. Probiotics are live microorganisms believed to confer beneficial effects on the health of the host animal, including improved digestion and immune function (Uyeno et al., 2015). While limited research exists on the specific impact of probiotics on the color of carcass fat in beef, it is possible that they could indirectly influence fat color by enhancing nutrient absorption and metabolism in the animal. Studies have suggested that probiotics can improve the composition of the gut microbiota in animals, leading to enhanced nutrient utilization and absorption (Kowalski et al., 2009; Qiao et al., 2009). Consequently, this could potentially increase the deposition of carotenoids and other yellow pigments in adipose tissue. However, the current evidence supporting the effect of probiotics on carcass fat color in beef is limited and inconsistent. Further research is necessary to comprehensively understand the relationship between probiotics, gut microbiota, and carcass fat color in beef.

In previous studies, the relationship between meat quality and yellow carcass fat has been explored. For instance, it was reported that feeding pasture to cattle resulted in beef with yellow carcass fat, as well as higher eicosenoic acid and lower w-6 to w-3 fatty acid ratio in intramuscular fat. However, no significant difference in beef yellowness was observed (Varela et al., 2004), consistent with the findings of French et al. (2000). Shemeis et al. (1994) evaluated meat quality based on the age of cattle and found that meat from mature cattle exhibited higher yellowness in carcass fat and tended to have tougher tenderness. However, no significant differences were observed in meat color, dry matter, and intramuscular fat percentage. In contrast to these previous studies, the current study collected carcass fat and meat samples as the normal and yellow groups from 20 cattle with similar carcass performance, to evaluate the differences in meat quality. The results revealed no significant differences in proximate composition, shear force, even meat color between the normal and yellow groups. However, the yellow group only exhibited higher levels of eicosenoic acid in the meat ($P < 0.05$), which aligns with the findings of Varela et al. (2004). Eicosenoic acid, also known as 20:1, is a MUFA commonly found in beef and other animal fats. It contributes to the sensory qualities of beef by providing a mild, buttery taste and enhancing the overall richness of the meat (Song and Hwang, 2023). Additionally, dietary MUFA have been associated with reduced serum cholesterol levels and a lower risk of coronary heart disease (Nogoy et al., 2022). Therefore, the higher eicosenoic acid content in meat with yellow carcass fat could be considered an advantage.

Conclusions

The results suggest that the yellowness of carcass fat in beef is primarily influenced by carotenoid content in carcass fat than other factors. There were no significant differences in meat qualities, including physicochemical properties and intramuscular fatty acid composition, between beef in normal and yellow groups. On the contrary, beef in yellow groups showed higher MUFA, positively affecting human health and consumption. It means that beef with a yellow carcass fat can be considered normal beef in terms of meat quality. Also, these results can present a new perspective on the beef grading system in Korea and provide an alternative approach that could benefit the economic interests of Korean cattle producers. However, the study highlights the complexity of factors contributing to the color of carcass fat and calls for further research

to better understand the underlying mechanisms and potential effects of probiotics and other factors on carcass fat color in beef production.

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