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Quality characteristics and fatty acid profiles of Bafra, Akkaraman, and Bafra × Akkaraman F_1 lamb meat

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Abstract: The meat quality of Akkaraman, Bafra, and Bafra × Akkaraman F_1 (BAF_1) lamb genotypes was determined and then compared at slaughter weights of 34 and 42 kg. At the beginning of the study, 36 male lambs were fed intensively after weaning at approximately 3 months of age. Six animals of each genotype were slaughtered at each slaughter weight and certain meat quality characteristics, namely meat color, pH, cooking loss, tenderness, water holding capacity, and fatty acid profile, were investigated. The pH values of the *M. longissimus dorsi* (MLD) for the Bafra, Akkaraman, and BAF_1 genotypes at 24 h after slaughter were 5.67, 5.53, and 5.54 for 34 kg slaughter weight, respectively, and 5.50, 5.56, and 5.53 for 42 kg slaughter weight, respectively. As the slaughter weight increased, the redness value (a*) of MLD at 24 h and *M. semimembranosus* at 0 and 24 h were increased for all the genotypes. The studied genotypes had similar values for tenderness and water holding capacity for both slaughter weight groups, but the Bafra genotype had the lowest cooking loss value at 42 kg slaughter weight. Polyunsaturated fatty acids and monounsaturated fatty acids levels of BAF_1 were different between Akkaraman and Bafa genotypes for 34 kg slaughter weight, but the differences disappeared at 42 kg slaughter weight. In conclusion, the BAF_1 genotype had similar meat quality values compared to Akkaraman and Bafra genotypes. It would be beneficial to do a sensory evaluation for determining if there were any flavor differences between BAF_1 and the other genotypes.

Key words: Cooking loss, fatty acid composition, meat quality, tenderness, water holding capacity

1. Introduction

Meat is a valuable part of human nutrition and a key factor in a balanced diet owing to its components. It provides high quality protein and fat also essential micronutrients that include iron, zinc, B vitamins, selenium, and phosphorus for optimal human health. Lamb is one of the red meat production sources, along with beef and pork. Lamb meat production is profitable if high quality pastures and suitable genotypes are available. The saleable yield type from sheep varies according to the geographic structure of country and sociocultural level of people. Nowadays lamb meat production has largely switched from extensive to intensive production systems across the world (1).

In Turkey, sheep breeding is conducted with native breeds on pastures and grasslands. According to the 2017 data from FAO, nearly 24.2% of Turkish red meat production comes from sheep. For increasing the share of lamb meat production, more lambs could be slaughtered, or the carcass weight or the slaughter weight per lamb might be increased through fattening (2).

Rapid growth of the human population, economic development, and the awareness of consumers of the dietary requirements for a healthy life have increased the demand for red meat. An adult person needs to consume 70–80 g of protein per day and half of the protein should come from animals because of the essential amino acids present. As their level of education increases, consumers are not only concerned with the quantity of meat but also with its quality and therefore consider the quality characteristics before buying (3,4).

Meat pH and color are the most important traits for determining meat quality. pH decline of about 1 unit should occur in the first 24 h after slaughter for high-quality meats. Consumers understand the freshness of meat from its color, which affects their purchasing decisions. Water holding capacity (WHC) and cooking loss (CL) are related to meat flavor. WHC can be detected using several methods such as CL, drip loss, and expressed juice (EJ). Tenderness is an important indicator of the palatability of meat. Fatty acid profile of the meat influence nutritive value and plays an important role about definition of meat quality.

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It has become a more important consideration nowadays because of the increased awareness of cardiovascular diseases associated with the excessive consumption of fat, especially saturated fatty acids. The ratio between polyunsaturated and saturated fatty acids and the ratio between omega 6 and omega 3 fatty acids are considered two important indexes for nutritional evaluation of the meat (1-5).

Slaughter weight is an important parameter for the fatness level of the carcass. As the slaughter weights increase, the fatness degrees of the carcasses also increase. Consequently, meat quality parameters and fatty acid composition of the carcasses might change as a result of fatness level. Different growth rates of the lambs can also effect the fatness score (6). In Turkey, lambs are generally slaughtered nearly at 4–5 months of age and approximately at 35–45 kg live weight. Therefore, in the present study the selected slaughter weights are similar to the mentioned live weights.

Akkaraman breed forms the majority of the sheep population in Turkey and because of its high adaption ability, the breed can be bred any places in the country. Akkaraman breed is also used in certain crossbreeding studies. Bafra breed is a crossbreed genotype from Chios and Karayaka. This genotype has high fertility rates and milk production. Because of the Karayaka breed's effect on the Bafra, the meat quality of the breed is good. A crossbreeding trial was done with Bafra and Akkaraman breeds for increasing the yield quality and also determining the data of the crossbreed lambs (6–8).

The aim of this research is to determine the meat quality parameters and fatty acid composition of Akkaraman, Bafra, and BAF_1 genotypes at different slaughter weights.

2. Materials and methods

The research protocol for this study was approved by the Ethics Committee of Ankara University (Approval Number: 2006/173).

2.1. Lambs, feeds and experimental procedures

The study was performed at Gözlü farm in Konya Province, Turkey. The genotypes of the lambs were Akkaraman (A), Bafra (B), and Bafra × Akkaraman F_1 (BAF_1). Twelve lambs were randomly allocated to each study group from the main lamb flock. The main lamb flock had nearly 100 head of lambs at the same age in all of the genotypes. Thirty-six male lambs in total were selected and fed intensively after weaning at approximately 3 months of age. The mean live weights of the lambs were 20 kg at the beginning of the fattening period. Concentrated feed was provided ad libitum and an additional 300 g of alfalfa hay was provided per lamb per day. The nutritional composition of the diet is shown in Table 1. When the first slaughter weight of 34 kg was reached, 6 of the animals in each genotype group were slaughtered and chilled for 24 h at +4 °C for the determination of the quality of the meat via the assessment of various characteristics and the fatty acid profiles. When the rest of the 18 lambs reached the live weight of 42 kg, they were slaughtered. The carcasses of the lambs were chilled for 24 h at +4 °C and after that, meat quality characteristics and the fatty acid profiles were determined the same way as 34 kg slaughter weight.

Table 1. Nutritional composition of concentrate feed.

Nutritional composition	Concentrate feed
Dry matter (%)	89.70
Crude protein (%)	15.10
Crude cellulose (%)	6.10
Crude fat (%)	5.40
Crude ash (%)	6.70
Ca (%)	1.20
P (%)	0.54
Na (%)	0.32
Metabolic energy (kcal/kg)	2800

2.2. Sampling and analytical methods

Analyses of color and pH were performed on the full carcass from *M. longissimus thoracis* at the 12th and 13th thoracic vertebra and *M. semimembranosus* (MSM) from the left leg. For the other quality analyses as EJ, CL, tenderness and fatty acid composition, the meat samples were taken from *M. longissimus dorsi* (MLD) at the left side of carcasses at 24 h post mortem and frozen at –18 °C after chilling. For the analyses of EJ and CL the meat samples were taken from *M. longissimus thoracis* between the 6th and 13th ribs. *M. Longissimus lumborum* samples between the 1st and 5th lumbar vertebrae were used for tenderness assessments and determination of fatty acid profile analyses. The meat samples were defrosted at + 4°C one night before testing.

The pH of the carcasses was determined with a digital pH meter (Mettler Toledo) both on the MLD and MSM at 0 h (pH_0), 45 min (pH_{45}), and 24 h (pH_{24h}) after slaughter.

Meat color was measured on MLD and MSM at 0, 1, and 24 h after slaughter on cut surface from the full carcasses. Color of the carcasses was determined with a chromameter (Konica Minolta, CR 400) using the CIELAB color scale (L*, a*, b*) system.

CL (%) was determined according to the method of Honikel (9). Samples of meat nearly 50 g of piece were weighted, placed in plastic bags, and cooked with the Benmari method for 1 h at 80 °C. The meat samples were removed from the bags, cooled, dried, and weighted again. The CL percentage was determined as follows: (initial

sample weight – final sample weight / Initial sample weight) × 100 (9). CL analyses were made two times with frozen samples. For 24 h analyses, defrosted meat samples were used immediately and for 48 h analyses defrosted meat samples were stored at +4 °C for one day and after that used in the study.

Tenderness was evaluated with a Warner Bratzer shear force device (WBSF) as described by Hoffman et al. (2003). Defrosted meat samples approximately 50 g of pieces were placed in plastic bags and cooked with the Benmari method for 1 h at 75 °C. Six test pieces with dimensions of 1 × 1 cm were cut parallel to the muscle fibers from each cooked sample. The WBSF value was the average of the values for the six samples (10).

For determining WHC, the EJ method was used as described by Barton-Gade et al. (11). The meat sample (5 g) was placed between two filter papers and then exposed to 2250 g of pressure for 5 min. The EJ percentage was determined as follows: (final filter paper weight – initial filter paper weight / Initial sample weight) × 100 (9–11). Expressed juice analyses were made three times as 24, 48, and 72 h after defrosting. For 24 h analyses defrosted meat samples were used immediately, for 48 h analyses defrosted meat samples were stored at +4 °C for 1 day, and for 72 h analyses defrosted meat samples were stored at +4 °C for 2 days.

The extraction of intramuscular lipid as fatty acid methyl esters (FAMEs) from the examined muscle segments was conducted according to the method of Blight and Dyer (12). The FAMEs were kept in vials at –20 °C until analysis. The profile of the fatty acid content was determined with Gas chromatography–mass spectrometry (HP Agilent 6890 / 5972) equipment with a HP - 88 capillary column (100 m × 0.25 mm × 0.20 μm). The carrier gas was helium. The temperatures of the injector and detector ports were set at 250 and 270 °C, respectively. The temperature of the oven was set at 150 °C for the first 3 min and raised to 240 °C with a 3 °C per minute ramp rate. The separation was completed in 40 min (12). The fatty acid profile was determined by comparing the retention times of peaks and the standard fatty acids' peaks (Supelco, F.A.M.E. Mix and C4 - C24).

2.3. Statistical Analysis

One way analysis of variance (ANOVA) was performed in SPSS 18.0 to compare the quality of meat and profile of fatty acids for the Akkaraman, Bafra, and BAF_1 genotypes at different slaughter weights. For determining the effect of genotype, slaughter weight and genotype × slaughter weight interaction General lineer model analysis was performed. For comparing the differences between the means of the groups Duncan's multiple range test was performed. P-values less than 0.05 were considered significant.

3. Results

3.1. pH and color

Meat color and pH data for the groups were shown in Table 2. In terms of LD muscle, Akkaraman had the lowest pH value immediately after slaughter for 34 kg and BAF_1 had the highest pH value for 42 kg ($P < 0.05$). There were no significant differences between Bafra and BAF_1 for 34 kg slaughter weight also Akkaraman and Bafra for 42 kg slaughter weight ($P > 0.05$). In terms of pH values measured from MSM at 24 h after slaughter, Bafra had the highest value for 34 kg slaughter weight, while Akkaraman had the highest value for 42 kg slaughter weight ($P < 0.05$). There were no significant differences between Akkaraman and BAF_1 for 34 kg slaughter weight and also between Bafra and BAF_1 for 42 kg slaughter weight ($P > 0.05$). In both slaughter weight groups, the pH_0 value decreased nearly 1 unit compared to the pH_{24} value. Regardless of genotype effect, there is no slaughter weight effect on analyzed pH values. Interactions between genotype × slaughter weight effects were significant for MLD at 45 min and 24 h after slaughter ($P < 0.05$) and for MSM at 24 h after slaughter ($P < 0.001$) .

Meat color parameters (L*, a*, b*) of the genotypes were shown in Table 2. At 34 kg slaughter weight, significant differences between genotypes were determined 24 h after slaughter for a* value from MSM ($P < 0.05$). At 42 kg slaughter weight there were significant differences between genotypes for L* and b* parameters at 0 h for MLD and b* for MSM ($P < 0.05$). One hour after slaughter, a* ($P < 0.05$) and b* ($P < 0.01$) values measured from MSM at 42 kg slaughter weight changed significantly between genotypes. Regardless of genotype effect, differences between slaughter weight groups were significant for MLD b* and MSM a* at 0 h ($P < 0.05$); MLD a* and MSM a* at 24 h after slaughter ($P < 0.05$). The genotype × slaughter weight interactions for the analyzed color parameters were not significant.

3.2. EJ, CL, and WBSF

EJ, CL, and WBSF values of the genotypes were presented in Table 3. EJ ranged between 9.29% and 9.64%. Regardless of the slaughter weight differences, the genotype effects between groups were significant ($P < 0.05$). At 34 kg slaughter weight, the CL differences between genotypes and analysis times were not significant ($P > 0.05$). At 42 kg slaughter weight, the Bafra genotype had a lower CL value than the Akkaraman genotype for both analysis times ($P < 0.05$). The differences among the genotypes were not significant ($P > 0.05$) in terms of WBSF. Regardless of genotype for EJ analyzed at 24 and 72 h after defrosting differences between slaughter weights were significant. As the slaughter weight increased, the EJ values were increased.

Table 2. pH and color values of Akkaraman, Bafra, Bafra × Akkaraman F_1 lamb meat at 34 and 42 kg slaughter weights (n = 6 for each group).

Slaughter weight			34 kg				42 kg						
Meat quality parameters			A	B	BAF_1	P	A	B	BAF_1	P	G	SW	G*SW
pH	0 h	MLD	6.45 ± 0.03[b]	6.65 ± 0.05[a]	6.59 ± 0.06[a]	*	6.47 ± 0.04[b]	6.50 ± 0.03[b]	6.61 ± 0.02[a]	*	**	-	-
		MSM	6.40 ± 0.02	6.70 ± 0.05	6.53 ± 0.09	-	6.51 ± 0.04	6.53 ± 0.03	6.57 ± 0.03	-	-	-	-
	45 min	MLD	6.10 ± 0.04	6.21 ± 0.04	6.21 ± 0.03	-	6.18 ± 0.04	6.14 ± 0.02	6.14 ± 0.02	-	-	-	*
		MSM	6.15 ± 0.02	6.19 ± 0.07	6.15 ± 0.05	-	6.17 ± 0.04	6.12 ± 0.03	6.17 ± 0.02	-	-	-	-
	24 h	MLD	5.53 ± 0.04	5.67 ± 0.05	5.54 ± 0.03	-	5.56 ± 0.03	5.50 ± 0.04	5.53 ± 0.04	-	-	-	*
		MSM	5.52 ± 0.01[b]	5.77 ± 0.04[a]	5.61 ± 0.05[b]	*	5.68 ± 0.03[a]	5.57 ± 0.04[b]	5.54 ± 0.01[b]	*	*	-	***
Color	0 h	MLD L*	35.76 ± 0.84	34.88 ± 0.92	34.54 ± 1.71	-	37.23 ± 0.77[a]	33.98 ± 0.81[b]	36.00 ± 0.93[ab]	*	-	-	-
		MLD a*	12.87 ± 0.61	14.09 ± 0.56	13.50 ± 0.82	-	14.09 ± 0.23	14.25 ± 0.90	12.62 ± 0.84	-	-	-	-
		MLD b*	4.32 ± 0.16	4.33 ± 0.24	5.17 ± 0.62	-	4.48 ± 0.08[a]	3.56 ± 0.15[b]	4.06 ± 0.30[ab]	*	-	*	-
		MSM L*	38.63 ± 1.75	36.60 ± 1.37	32.43 ± 2.14	-	36.62 ± 0.74	34.11 ± 0.79	36.07 ± 0.94	-	-	-	-
		MSM a*	13.98 ± 1.33	15.24 ± 0.95	13.04 ± 0.99	-	17.31 ± 0.80	15.39 ± 0.51	14.97 ± 0.79	-	-	*	-
		MSM b*	4.89 ± 0.37	4.66 ± 0.26	4.68 ± 0.54	-	5.12 ± 0.17[a]	4.32 ± 0.12[b]	4.37 ± 0.24[b]	*	-	-	-
Color	1 h	MLD L*	35.01 ± 2.17	35.58 ± 1.10	32.30 ± 1.42	-	36.15 ± 0.86	33.28 ± 0.82	35.34 ± 0.98	-	-	-	-
		MLD a*	13.23 ± 1.07	14.10 ± 0.73	11.64 ± 0.82	-	13.48 ± 0.30	12.49 ± 0.53	12.60 ± 0.29	-	-	-	-
		MLD b*	4.60 ± 0.39	4.66 ± 0.42	3.86 ± 0.38	-	4.41 ± 0.12	3.51 ± 0.30	3.98 ± 0.27	-	-	-	-
		MSM L*	37.07 ± 1.44	34.37 ± 1.53	32.94 ± 2.15	-	35.84 ± 0.46	33.29 ± 0.67	33.66 ± 1.42	-	-	-	-
		MSM a*	13.04 ± 0.40	14.18 ± 1.02	13.12 ± 1.25	-	15.79 ± 0.68[a]	14.17 ± 0.60[ab]	13.28 ± 0.31[b]	*	-	-	-
		MSM b*	4.19 ± 0.34	4.34 ± 0.48	4.33 ± 0.44	-	4.87 ± 0.12[a]	3.98 ± 0.25[b]	3.83 ± 0.25[b]	**	-	-	-
Color	24 h	MLD L*	41.75 ± 1.22	43.36 ± 0.73	41.60 ± 1.34	-	44.80 ± 0.61	44.01 ± 1.65	43.12 ± 0.82	-	-	-	-
		MLD a*	16.26 ± 1.31	16.46 ± 0.83	14.50 ± 1.01	-	16.76 ± 1.10	19.01 ± 0.66	17.01 ± 0.57	-	-	*	-
		MLD b*	8.34 ± 0.94	7.63 ± 0.57	6.48 ± 0.63	-	7.65 ± 0.80	8.68 ± 0.61	8.37 ± 0.32	-	-	-	-
		MSM L*	41.57 ± 1.56	44.90 ± 2.12	42.99 ± 1.42	-	46.84 ± 1.38	44.87 ± 1.05	44.58 ± 1.69	-	-	-	-
		MSM a*	14.36 ± 0.31[a]	11.36 ± 0.14[b]	14.33 ± 1.48[a]	*	14.71 ± 1.32	15.83 ± 0.78	16.13 ± 0.58	-	**	*	-
		MSM b*	6.42 ± 0.40	5.36 ± 0.33	6.59 ± 0.44	-	6.77 ± 0.74	6.99 ± 0.21	7.63 ± 0.28	-	-	-	-

- : P > 0.05 ; * : P < 0.05 ; ** : P < 0.01 ; *** : P < 0.001

a, b : Values with different letters in the same slaughter weight groups of the row differ significantly.

Table 3. EJ, CL, and WBSF values in Akkaraman, Bafra, Bafra × Akkaraman F_1 genotypes at 34 and 42 kg slaughter weights (n = 6 for each group).

Slaughter weight		34 kg				42 kg						
Meat quality parameters		A	B	BAF_1	P	A	B	BAF_1	P	G	SW	G*SW
EJ %	24 h	9.40 ± 0.02	9.38 ± 0.05	9.29 ± 0.07	-	9.55 ± 0.04	9.48 ± 0.05	9.39 ± 0.06	-	*	**	-
	48 h	9.49 ± 0.06	9.40 ± 0.02	9.54 ± 0.05	-	9.58 ± 0.08	9.53 ± 0.05	9.53 ± 0.03	-	-	-	-
	72 h	9.40 ± 0.06	9.55 ± 0.04	9.55 ± 0.05	-	9.64 ± 0.04	9.58 ± 0.02	9.61 ± 0.06	-	-	**	-
CL %	24 h	31.89 ± 0.62	31.42 ± 0.56	32.20 ± 1.16	-	33.31 ± 0.75[a]	29.25 ± 0.63[b]	31.00 ± 0.58[a]	*	*	-	-
	48 h	31.55 ± 0.73	32.30 ± 0.35	31.95 ± 1.18	-	31.98 ± 0.78[a]	29.11 ± 0.57[b]	32.43 ± 1.17[a]	*	-	-	-
WBSF kg/cm^2		5.48 ± 0.32	5.30 ± 0.32	5.33 ± 0.69	-	6.33 ± 0.22	5.97 ± 0.46	5.60 ± 0.51	-	-	-	-

EJ: Expressed juice
WBSF: Warner–Bratzler shear force
CL: Cooking loss
- : P > 0.05 ; * : P < 0.05 ; ** : P < 0.01
a, b : Values with different letters in the same slaughter weight groups of the row differ significantly.

3.3. Fatty acid profiles

The fatty acid profiles were shown in Table 4. The basic fatty acids were C16:0, C18:0, and C18:1 with regard to the amounts of fatty acids in the meat samples. Significant differences were detected among the genotype groups.

The differences between genotypes for certain saturated fatty acids (C10:0 ($P < 0.01$), C12:0 ($P < 0.001$), C14:0 ($P < 0.001$), C16:0 ($P < 0.05$), C18:0 ($P < 0.05$), C24:0 ($P < 0.01$)) and for some unsaturated fatty acids (C18:1 ($P < 0.01$), C18:2 ($P < 0.05$), C20:5 ($P < 0.01$), C24:1 ($P < 0.05$)) were significant at 34 kg slaughter weight. All of the fatty acid differences disappeared, except for C10:0 ($P < 0.05$) and C18:3 ($P < 0.05$), at 42 kg slaughter weight.

Regardless of genotype some of the detected fatty acids as C12:0 ($P < 0.01$), C14:0 ($P < 0.001$), C14:1 ($P < 0.05$) , C15:1 ($P < 0.05$), C16:1 ($P < 0.05$), C18:1 ($P < 0.05$) , C18:2 ($P < 0.05$), C20:5 ($P < 0.01$) and C24:1 ($P < 0.05$) were affected by the change of slaughter weight. As the slaughter weight increased, for BAF_1 genotype the mentioned fatty acids decreased; for Akkaraman genotype the mentioned fatty acids decreased except C18:1 and for Bafra genotype C14:0, C15:1, C16:1 decreased, C14:1, C18:1, C18.2, and C20:5 increased, C12:0 and C24:1 did not change. Interactions for genotype and slaughter weight were found significant in C18:1 ($P < 0.05$), C18:2 ($P < 0.01$), C20:2 ($P < 0.05$), C20:5 ($P < 0.01$) and C24:0 ($P < 0.05$).

The sums, ratios, and calculated values for fatty acids were presented in Table 5. Significant differences were detected for monounsaturated fatty acids (MUFA) ($P < 0.001$), polyunsaturated fatty acids (PUFA) ($P < 0.01$), polyunsaturated fatty acids / saturated fatty acids (PUFA / SFA) ($P < 0.05$) and MUFA / SFA ($P < 0.05$) at 34 kg slaughter weight and the omega 6 / omega 3 ratio (ω6 / ω3) ($P < 0.01$) at 42 kg slaughter weight between genotypes groups. At 34 kg slaughter weight the Akkaraman genotype had the lowest level of MUFA ($P < 0.001$) and the Bafra genotype had the lowest PUFA value ($P < 0.05$). In accordance with these results Bafra genotype had the lowest PUFA / SFA ratio ($P < 0.05$) and Akkaraman genotype had the lowest MUFA / SFA ratio ($P < 0.05$).

Regardless of genotype, PUFA value and PUFA / SFA ratio were significant between slaughter weight groups ($P < 0.05$). For the Akkaraman and BAF_1 genotype as the slaughter weight increased, the PUFA value decreased and for Bafra genotype it increased. As the slaughter weight increased, Akkaraman and BAF_1 genotypes' PUFA / SFA ratio decreased. Interactions for genotype and slaughter weight parameters were found significant for the PUFA value ($P < 0.05$).

4. Discussion

4.1. Color and pH

pH has a considerable influence on meat tenderness, color, taste, and juiciness. After slaughtering, muscle glycogen is degraded to lactic acid and as a consequence the pH level of the muscle decreases. Meat quality is affected by this pH decline. The desirable pH value at 24 h after slaughter is between 5.50 and 5.80. It is known as the acceptable quality range (13). Several factors (preslaughter conditions, stress and muscle physiology) may affect the ultimate pH. Final pH values (pH_{24}) recorded in the current study for genotype groups were within the optimal range that would not negatively affect meat quality. Moreover, the final pH values were in strong concordance with the reported values for different breeds (Table 2) (13–15).

The color of meat is an important indicator of meat freshness and quality before purchasing by consumers. Animal age, sex, feeding regime, type of muscle fiber, glycogen content of the muscle, speed of cooling, and pH affect meat color. In Turkey, pink lamb meat is preferred to dark color lamb meat (2,4,16).

At different times of measurement for 34 kg slaughter weight, there were no significant color differences between genotypes, except for the Bafra genotype 24 h after slaughter. Bafra had the lowest a* value at 24 h after slaughter, that is, the lowest redness level and the highest pink color level among the genotypes at 34 kg slaughter weight for MSM. At 42 kg slaughter weight, Akkaraman and BAF_1 genotypes had the highest L* and b* values for the MLD and Akkaraman group had the highest b* value for the MSM at 0 h. At 1 h after slaughter, the Akkaraman group had the highest b* values for the MSM, so the redness and yellowness degree of the Akkaraman's meat was higher at these times but at 24 h after slaughter there were no significant differences between genotypes (Table 2).

As the slaughter weight increased a* value of MLD at 24 h and MSM at 0 and 24 h after slaughter increased among all of the genotype groups. This can be due to higher myoglobin content of the lambs slaughtered at 42 kg slaughter weight. Myoglobin is reported to increase with age besides an impact on meat pigmentation (17).

The lightness (L*) is associated with the structural features of the muscle whereas redness (a*) and yellowness (b*) are related to the content of myoglobin pigment. In the current study, the three genotypes were similar in terms of color profiles. This may be explained by the same feed mixture and fattening program for all the experimental groups. Several researchers have reported that pasture-fed lambs have higher L* and b* values than lambs fed indoors; the b* value is affected by the amount of intermuscular fat. Higher b* values indicate higher intermuscular fat levels (18,19). Numerous authors have reported significant differences in meat color between different genotypes and at different slaughter weights. Differences in feeding programs can also affect meat color (13, 15, 20).

4.2. EJ, CL, and WBSF

Water constitutes 75% of meat weight. EJ is a measure of the ability of meat to retain its constituent water during the

Table 4. Fatty acid profile of Akkaraman, Bafra, Bafra × Akkaraman F_1 genotypes at 34 and 42 kg slaughter weights (%) (n = 6 for each group).

Slaughter weight	34 kg				42 kg						
Fatty acids	A	B	BAF_1	P	A	B	BAF_1	P	G	SW	G*SW
C10:0	0.15 ± 0.01^{a}	0.12 ± 0.01^{b}	0.12 ± 0.01^{b}	**	0.16 ± 0.02^{a}	0.11 ± 0.01^{b}	0.14 ± 0.01^{ab}	*	**	-	-
C12:0	0.23 ± 0.01^{a}	0.13 ± 0.02^{b}	0.25 ± 0.03^{a}	***	0.15 ± 0.02	0.13 ± 0.01	0.18 ± 0.02	-	***	**	-
C14:0	2.95 ± 0.07^{b}	2.54 ± 0.07^{c}	3.55 ± 0.18^{a}	***	2.50 ± 0.09	2.37 ± 0.13	2.82 ± 0.20	-	***	***	-
C14:1	0.11 ± 0.02	0.08 ± 0.01	0.13 ± 0.02	-	0.06 ± 0.00	0.09 ± 0.02	0.08 ± 0.01	-	-	*	-
C15:0	0.38 ± 0.02	0.40 ± 0.06	0.39 ± 0.03	-	0.37 ± 0.04	0.32 ± 0.04	0.31 ± 0.02	-	-	-	-
C15:1	0.12 ± 0.01	0.08 ± 0.02	0.12 ± 0.00	-	0.08 ± 0.01	0.07 ± 0.01	0.11 ± 0.01	-	**	*	-
C16:0	22.36 ± 0.72^{b}	24.44 ± 0.50^{a}	23.06 ± 0.26^{ab}	*	23.94 ± 0.49	24.54 ± 1.04	24.44 ± 0.60	-	-	-	-
C16:1	2.19 ± 0.07	2.30 ± 0.16	2.54 ± 0.08	-	2.25 ± 0.07	2.09 ± 0.10	2.18 ± 0.10	-	-	*	-
C17:0	1.33 ± 0.11	1.51 ± 0.25	1.17 ± 0.10	-	1.57 ± 0.21	1.30 ± 0.18	1.03 ± 0.04	-	-	-	-
C17:1	0.80 ± 0.07	0.98 ± 0.14	0.90 ± 0.08	-	1.05 ± 0.12	0.84 ± 0.10	0.71 ± 0.05	-	-	-	-
C18:0	16.02 ± 0.80^{a}	14.37 ± 0.72^{ab}	13.45 ± 0.38^{b}	*	14.27 ± 0.62	14.43 ± 0.77	14.90 ± 0.62	-	-	-	-
C18:1	43.52 ± 0.49^{b}	46.30 ± 0.55^{a}	46.02 ± 0.45^{a}	**	46.90 ± 0.82	46.77 ± 1.00	45.84 ± 0.32	-	-	*	*
C18:2 (ω6)	5.36 ± 0.41^{a}	3.85 ± 0.41^{b}	4.34 ± 0.20^{ab}	*	3.52 ± 0.23	4.08 ± 0.32	4.12 ± 0.24	-	-	*	**
C18:3 (ω6)	0.79 ± 0.14	0.63 ± 0.07	0.91 ± 0.16	-	0.75 ± 0.11	0.76 ± 0.18	0.68 ± 0.08	-	-	-	-
C18:3 (ω3)	1.37 ± 0.16	1.20 ± 0.09	1.51 ± 0.08	-	1.26 ± 0.13^{ab}	1.03 ± 0.17^{b}	1.47 ± 0.07^{a}	*	*	-	-
C20:0	0.22 ± 0.05	0.14 ± 0.02	0.26 ± 0.05	-	0.16 ± 0.04	0.11 ± 0.03	0.15 ± 0.03	-	-	-	-
C20:1	0.22 ± 0.05	0.15 ± 0.03	0.14 ± 0.01	-	0.16 ± 0.03	0.12 ± 0.02	0.17 ± 0.04	-	-	-	-
C20:2 (ω6)	0.12 ± 0.02	0.17 ± 0.01	0.21 ± 0.03	-	0.14 ± 0.04	0.14 ± 0.02	0.09 ± 0.01	-	-	-	*
C20:3 (ω6)	0.19 ± 0.04	0.09 ± 0.02	0.12 ± 0.03	-	0.10 ± 0.02	0.10 ± 0.03	0.08 ± 0.02	-	-	-	-
C20:5 (ω3)	1.16 ± 0.23^{a}	0.37 ± 0.05^{b}	0.56 ± 0.03^{b}	**	0.43 ± 0.10	0.42 ± 0.03	0.33 ± 0.05	-	***	**	**
C22:0	0.08 ± 0.03	0.06 ± 0.02	0.08 ± 0.02	-	0.07 ± 0.02	0.05 ± 0.01	0.04 ± 0.01	-	-	-	-
C24:0	0.20 ± 0.04^{a}	0.07 ± 0.01^{b}	0.10 ± 0.02^{b}	**	0.10 ± 0.02	0.09 ± 0.01	0.11 ± 0.01	-	**	-	*
C24:1	0.15 ± 0.04^{a}	0.05 ± 0.01^{b}	0.10 ± 0.02^{ab}	*	0.07 ± 0.01	0.05 ± 0.01	0.04 ± 0.01	-	*	*	-

- : P > 0.05; * : P < 0.05; ** : P < 0.01; *** : P < 0.001

a, b, c : Values with different letters in the same slaughter weight groups of the row differ significantly.

Table 5. Means and standard errors for sums and ratio based on fatty acids in Akkaraman, Bafra, Bafra × Akkaraman F_1 genotypes at 34 and 42 kg slaughter weights (%) (n = 6 for each group).

Slaughter weight	34 kg				42 kg						
Calculated fatty acid values	A	B	BAF_1	P	A	B	BAF_1	P	G	SW	G*SW
SFA	43.91 ± 0.96	43.76 ± 0.53	42.44 ± 0.27	-	43.25 ± 0.66	43.43 ± 1.45	44.11 ± 0.51	-	-	-	-
MUFA	47.10 ± 0.55^{b}	50.43 ± 0.48^{a}	49.56 ± 0.43^{a}	***	50.06 ± 0.97	47.42 ± 3.28	49.02 ± 0.37	-	-	-	-
PUFA	8.99 ± 0.78^{a}	6.30 ± 0.46^{b}	7.64 ± 0.42^{ab}	*	6.20 ± 0.52	6.53 ± 0.63	6.77 ± 0.34	-	-	*	*
TUFA	56.08 ± 0.12	56.73 ± 0.49	57.20 ± 0.57	-	56.27 ± 1.14	53.95 ± 3.33	55.78 ± 0.64	-	-	-	-
DFA	72.10 ± 1.39	71.11 ± 0.79	70.64 ± 0.60	-	70.54 ± 1.23	68.37 ± 3.94	70.69 ± 0.57	-	-	-	-
Nutritive value (%)	2.67 ± 0.09	2.49 ± 0.07	2.58 ± 0.05	-	2.56 ± 0.05	2.52 ± 0.12	2.49 ± 0.09	-	-	-	-
PUFA / SFA	0.20 ± 0.02^{a}	0.14 ± 0.01^{b}	0.18 ± 0.01^{ab}	*	0.14 ± 0.01	0.15 ± 0.02	0.15 ± 0.00	-	-	*	-
MUFA / SFA	1.07 ± 0.03^{b}	1.15 ± 0.02^{ab}	1.17 ± 0.02^{a}	*	1.16 ± 0.04	1.09 ± 0.07	1.11 ± 0.02	-	-	-	-
TUFA / SFA	1.28 ± 0.05	1.30 ± 0.02	1.35 ± 0.02	-	1.30 ± 0.04	1.24 ± 0.07	1.27 ± 0.03	-	-	-	-
Σω6 / Σω3	2.63 ± 0.21	3.04 ± 0.32	2.70 ± 0.10	-	2.72 ± 0.15^{b}	3.70 ± 0.32^{a}	2.77 ± 0.13^{b}	**	**	-	-
AI	0.53 ± 0.03	0.55 ± 0.01	0.58 ± 0.02	-	0.55 ± 0.02	0.58 ± 0.04	0.57 ± 0.02	-	-	-	-
TI	1.07 ± 0.06	1.16 ± 0.02	1.06 ± 0.02	-	1.14 ± 0.04	1.23 ± 0.08	1.17 ± 0.03	-	-	-	-

- : P > 0.05; * : P < 0.05; ** : P < 0.01; *** : P < 0.001
a, b: Values with different letters in the same slaughter weight groups of the row differ significantly.
SFA: Saturated fatty acids
MUFA: Monounsaturated fatty acids
PUFA: Polyunsaturated fatty acids
TUFA: Total unsaturated fatty acids
DFA: Desirable fatty acids, (C18:0 + TUFA)
Nutritive value: (C18:0 + C18:1) / C16:0
Σω6 / Σω3: (C18:2 + C18:3 + C20:2 + C20:3) / (C18:3 + C20:5)
AI: Atherogenic index, (C12:0 + 4 * C14:0 + C16:0) / (TUFA + Σω3 + Σω6)
TI: Thrombogenic index, (C14:0 + C16:0 + C18:0) / (0.5 * TUFA) + (0.5 * Σω6) + (3 * Σω3) + (Σω3 / Σω6)

application of force during processing. It is related to meat's ability to retain water within the myofibrillar system. When pressure is applied, intracellular water in meat is expelled to the extracellular space and consequently there will be moisture on the meat. EJ is closely related to pH and color. Myoglobin, the basic pigment giving the color of meat, is water-soluble. Thus, excessive water loss leads to meat color becoming paler and consumers generally discriminate against pale colored meat (21). Lower expressed juice could be associated with a faster pH decline (9,21). In the study there were no significant differences between genotypes for EJ and it could be related with no faster pH decline between genotypes (Table 3). In addition, EJ values recorded in the current study were lower than those of Bafra slaughtered at 35 and 45 kg (7), Karayaka (22), and İvesi (23) lamb genotypes. These differences might be due to the myofibrillar structure of the muscle.

Exposure to heat causes changes in the structural components of meat, particularly in the connective tissues. These changes cause cooking losses (11). In the current study, for 42 kg slaughter weight, the Bafra genotype had the lowest CL value which means that after cooking, Bafra had the highest internal water content and therefore should have higher meat weight than the other genotypes (Table 3) (24,25). On the other hand, losing internal water affects the juiciness and flavor of meat that are related with consumer preferences. Juiciness is the feeling of moisture in the mouth and CL has been observed to be negatively correlated to it (25–27). In this study the CL values were similar to the results for Bafra (7), Karayaka (22), and Chall and Zell (28); higher than Turkish Merino, Ramlıç, Kıvırcık, Chios and İmroz (2), Afshari (29), and Barbarine lambs (30). The differences might be attributable to the breed, cooking method or cooking temperature or a combination of these factors (24,27).

Tenderness is associated with meat flavor, including the contribution of marbling. Greater deposition of marbling may contribute to weakening the connective tissue structure and improving the tenderness and flavor of meat. Tenderness is related to how much force is required to bite through a piece of meat and the optimal tenderness value of meat is 5.5 kg / cm^2 (31,32). As values of the meat rise above that value, it becomes tougher. Although differences between tenderness values for 34 and 42 kg slaughter weight groups were not significant in the present study (Table 3), at 34 kg slaughter weight the three genotypes had lower mean values than 5.5 kg/cm^2 so they can be rated tender. At 42 kg slaughter weight, the tenderness values for the three genotypes were higher than 5.5 kg/cm^2 so the meats had started to become tougher. Tenderness values for Merino Branco (15), Turkish Merino, Ramlıç, Kıvırcık, Chios and Imroz (2), Bafra (7), Afshari (29), Qula (33), and Rasa Aragenosa (34) lambs were lower than the findings of the current study. Different genotypes, slaughter weights, feeding programs, and analysis methods may have contributed to the differences.

4.3. Fatty acid profiles

In the present study C18:1, C16:0, and C18:0 comprised nearly 85% of the total fatty acid content of the MLD. The most abundant fatty acid was C18:1 for all the genotypes and slaughter weight groups (Table 4). The proportions of C16:0 and C18:0 followed it. These results were similar to those of previous studies conducted with lambs. The breed of the lamb had no influence to the mentioned fatty acids (15, 30). There were several differences between fatty acids between genotypes at 34 kg slaughter weight but the differences were disappeared for C12:0, C14:0, C16:0, C18:0, C18:1, C18:2, C20:5, C24:0, C24:1 at 42 kg slaughter weight ($P > 0.05$). This might be due to differences between the level of carcass fatness, different growth rates or the differences in reaching times to the desired slaughter weights among genotypes (35,36). The genotype and slaughter weight effects were significant together for C12:0, C14:0, C15:1, and C20:5 in the study (Table 4).

Various studies have demonstrated that for optimal health outcomes the quantities of PUFA and SFA in the diet should be in appropriate proportions (37). In order to minimize the risk of cardiovascular diseases, it is beneficial to minimize the SFA intake and enhance the PUFA intake. In the present study, Bafra and BAF_1 genotypes had the highest values of MUFA ($P < 0.001$) and Akkaraman and BAF_1 had the highest values of PUFA ($P < 0.05$) at 34 kg slaughter weight (Table 5). This can be a desired result for crossbreeding, but at 42 kg slaughter weight the differences disappeared. As the slaughter weight increased, PUFA ($P < 0.05$) and PUFA / SFA ($P < 0.05$) values decreased for Akkaraman and BAF_1; on the contrary, Bafra genotype's PUFA and PUFA / SFA values increased.

In the present study the ω6 / ω3 ratios for the three genotypes were similar to those determined for Fabrianese (20), Bafra (7), Norway white (38), and Iranian local lambs (39) and higher than those determined for Bergamasca lambs (40). Management of the dietary ω6 / ω3 ratio is very important for minimizing cardiovascular diseases. The recommended ratio of ω6 to ω3 in the human diet is less than 4 : 1 (35). In this study, the Bafra genotype had the highest mean value for the ratio of ω6 / ω3 at 42 kg slaughter weight ($P < 0.001$) and all the groups' ratios were less than 4 : 1 (Table 5). Therefore, all the lamb meats investigated in the current research would have acceptable effects on the human cardiovascular system and can therefore contribute to a healthy diet with regards to fatty acid profile.

In the current study, total unsaturated fatty acid values (TUFA) were higher than for Bafra (7), Chall and Zell (28), and Qula (33) lambs. SFA values were lower than for Bafra

(7), Karayaka (22), Chall and Zell (28), Qula (33) and Bergamasca (40) lambs. Furthermore, the SFA values in this study were lower and TUFA values were higher than those in several studies, so the meats of the three studied genotypes can be consumed for their desirable fatty acid composition (Table 5).

Consequently, in the current research, the meat quality characteristics of Akkaraman, Bafra, and BAF_1 lamb genotypes at different slaughter weights were evaluated and with this study providing the first data on the BAF_1 genotype. The recorded pH values were within the optimal range at the time of taking the measurements and the desired decrease occurred 24 h after slaughter. As the slaughter weight increased the redness value (a*) of MLD at 24 h and MSM at 0 h and 24 h increased for all the genotypes. For Bafra and BAF_1 genotype b* values detected from MSM at 42 kg slaughter weight were lower than Akkaraman for 0 and 1 h, so the yellowness degree of the Akkaraman's meat was higher at these times, but at 24 h after slaughter there were no significant differences between genotypes for MLD and MSM. There were no significant differences for EJ and WBSF between the genotypes. The Bafra genotype had the lowest CL value at both analysis times at 42 kg slaughter weight. Tenderness was in the desired range for the three genotypes at the lower slaughter weight but during the following period of fattening, the meats became tougher and consequently the tenderness value increased but it was not significant between the slaughter weight groups. PUFA and MUFA levels of BAF_1 were between those of Akkaraman and Bafra genotypes at 34 kg slaughter weight and there were no differences between genotypes at 42 kg slaughter weight. In the study there were no significant meat quality differences between BAF_1 and Bafra and Akkaraman. Besides the mentioned meat quality characteristics, sensory evaluation is one of the most essential selection parameters for consumers. In follow-up studies it would be beneficial to research the relationship between meat quality and human sensory perceptions among genotypes.

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