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DETERMINATION OF THE EFFECTS ON MEAT QUALITY AND FATTY ACIDS OF DIFFERENT BORON SOURCES IN AKKARAMAN LAMBS

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Abstract: In this study, the effects of boron sources such as colemanite, ulexite and etibor-48 supplementation on meat quality and fatty acid composition of Akkaraman lambs weaned at 2.5 months of age were investigated. In the study, 50 single Akkaraman male lambs weaned at the age of 2.5 months were used as animal material. Concentrated containing (17.56% CP and 2600 Kcal/kg ME) and forage (meadow hay) were used as feed material. Colemanite (50.8% B_2O_2, $Ca_2B_6O11.5H_2O$), ulexite (43% B_2O_3, $NaCaB5O_9.8H_2O$) and etibor-48 (48%, $Na_2(OH)_2.8H_2O$) as boron sources were used. The highest protein content of Akkaraman lamb meat was obtained from C and S groups, and the lowest in L group (P<0.05), and there was no significant difference between the groups in terms of ether extract. The ash content of the meats was lowest in the L group (P<0.05). While the Ca level in meat was lowest in L and E groups (P<0.05), P and Water holding capacity (WHC) were found to be high in S and C groups (P<0.05). The Mg content was lowest (P<0.05) in the S group, the B content of the meat was the same in all groups. Among fatty acids, caproic acid in E group, stearic acid in L group, cis-8,11,14-eicosatrienoic acid in U, E and S groups was highest (P<0.05) and the lowest in L group, followed by C group (P<0.05). While oleic acid was numerically higher in C group than other groups, Linoleic acid was found to be low in the L group. Numerically increment was determined in terms of linoleic acid, Tricosanoic acid and Palmitoleic acid in boron groups. The highest a* value in Akkaraman lamb meat was determined in the U group, and there was no difference between the groups in terms of b*, c* and L* values. A numerical increase in b* and L* values in boron groups was determined compared to the S group. While hue value was highest in C, E and L groups and, was lowest in U group (P<0.05). The use of different boron sources in the ration did not have a significant effect on the flexibility, hardness and WBSF properties of meats. However, the addition of boron such as C, U and E to the ration caused a numerical decrease in WBSF.

Keywords: Akkaraman lamb, Meat quality, Fatty acids, Boron sources

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1. Introduction

Red meat has an important place in providing the need for animal protein, which is one of the cornerstones of a healthy diet. The increase in the world population also increases the demand for red meat. Meat and meat products have great importance in human nutrition because they contain protein, fat, essential amino acids, minerals, vitamins, and other nutrients (Olaoye, 2011), in addition, the bioavailability of some macronutrients found only in meat is much higher than those of plant sources (Wyness, 2015).

The main source of red meat production is cattle and small ruminant such as sheep, goats. Sheep and lambs are an important source of meat production among small ruminants. It's known that genetic structure plays an important role in meat quality. Furthermore, to biochemical, physical, histological factors, age, sex, species, race, muscle type, health, and especially nutrition play an important role in determining meat quality (Guerrero et al., 2013). Since the diet is easily manipulated, it significantly affects the nutrient composition of meat (Wyness, 2015).

Minerals are essential for normal animal health, growth, reproduction, and production, in structural, physiological, catalytic and regulatory functions, as components of proteins, enzymes or enzymatic cofactors for a number of biochemical processes (Lavinia et al., 2014). Minerals contribute even more than volatile fatty acids (VFA) to rumen osmolarity. High osmotic pressure may impair digestion in the rumen. Under normal nutritional conditions, the main buffering components in the rumen are Na, K, bicarbonate, and VFA. Therefore, an imbalance or low in mineral level is effective on microbial activity and rumen fermentation (Singh, 2021). In addition, minerals play a very important role in meat quality, as they affect some characteristics such as color and texture of red meat, (Schönfeldt and Hall, 2015, Domaradzki et al., 2016). Regarding energy production, besides the role in

muscle metabolism of minerals, mineral-dependent enzymes also play a role in the softening of meat after death (Bhat et al., 2018).

Boron, a trace mineral, is an essential trace element for plants, humans, and animals. It is known that boron has functions in mineral metabolism, immune and endocrine systems, and low boron intake impairs bone health, brain function and immune response (Nielsen, 2008). Wang et al. (2014) reported that the addition of 160 mg/L boron to water of ostriches improved growth performance and meat quality; determined that high boron concentration decreased both performance and meat quality. The maximum tolerable level in sheep has been determined as 150 mg B/kg diet (NRC, 2007). It is reported that when 0, 35, 52.5 and 70 mg kg^{-1} levels of boron are used in the rams' ration, it does not affect the boron concentration in the rumen fluid, but improves rumen fermentation due to increasing the population and activation of microorganisms, especially protozoa and cellulolytic bacteria (Sızmaz et al, 2017). In studies related to boron, it has been determined that this trace element is used in both human foods and animal feeds in the form of boric acid and/or its salts (Lavinia et al., 2014).

It is stated that boron reserves in Türkiye constitute 73% of the world's total reserves. There is Ca in the structure of (50.8% B_2O_2, $Ca_2B_6O_{11}.5H_2O$) colemanite, Ca and Na in the structure of (43% B_2O_3, $NaCaB_5O_9.8H_2O$) ulexite, and Na in the structure of (48%, $Na_2(OH)_2.8H_2O$) etibor-48 from the boron sources (Anonymous, 2022).

There are no studies on the use of boron on meat quality and fatty acid properties in ruminant feeding. Boron sources especially such as colemanite, ulexite and etibor-48 mostly found in Türkiye have never been used in animal nutrition. Based on the idea that supplementation of boron sources may be a factor affecting the expression of trace elements in the body, it is thought that these B sources can be used as a mineral additive in ruminant feeding, and may affect meat quality and fatty acids, and may be a mineral additive in ruminant nutrition.

For this purpose; in this study was investigated the effect on meat quality and fatty acid composition of adding some boron sources (colemanite, ulexite and etibor-48) to the low Ca and P-containing diets of Akkaraman lambs weaned at the age of 2.5 months.

2. Materials and Methods

2.1. Materials

Fifty Akkaraman single, male lambs weaned at the 2.5 months-old were used as animal material in the study. Concentrated feed containing 17.56% HP and 2600 Kcal/kg ME and meadow hay were used as feed material. Boron sources; colemanite (50.8% B_2O_2, $Ca_2B_6O_{11}.5H_2O$), ulexite (43% B_2O_3, $NaCaB_5O_9.8H_2O$) and etibor-48 (48%, $Na_2(OH)_2.8H_2O$) were obtained from Eti Maden Operations in Türkiye.

2.2. Methods

A standard and low-level Ca and P-containing basal diet was prepared in the first phase of the experiment. Each of the boron sources (colemanite, ulexite and etibor-48) was added 90 ppm/kg (NRC, 2007) to the low Ca and P containing lamb diet, taking into account their purity, and 5 treatments groups 1- with standard Ca and P content, 2- with low Ca content and P content, 3- low Ca and P content +colemanite, 4- low Ca and P content +ulexite, 5- low Ca and P content + etibor-48) were formed. The concentrated feed was prepared as Crude protein (CP) content of 17.12% and metabolisable energy (ME) 2720 kcal/ Dry matter (DM) (Sarıçiçek and Yıldırım, 2021). The roughage was kept free in front of the animal, and concentrated feed was given in two meals. The roughage/concentrated feed ratio was 60/40. The daily need was determined taking into account the level specified in NRC (1985).

50 male Akkaraman single lambs weaned at 2.5 months-old were divided into 5 groups with equal weight (approximately 22 kg) and 10 lambs in each group, and the lambs were fattened in individual cages for 90 days. At the end of 90 days, a total of 30 animals, randomly 6 heads from each group, were slaughtered. LT muscle (longissimus thoracis) was separated between 12-13 ribs to determine meat quality, the separated meat was vacuum packed and kept for 5 days at 4ºC in a refrigerator. Then, nutrient analysis (dry matter, protein, fat, ash, Ca, P, Mg, boron in ash), pH, meat juiciness (water holding capacity: WHC and cooking loss: CL), fatty acids (saturated and unsaturated), color determination (brightness, redness, yellowness), and texture (flexibility, hardness, warner blatzer shear force; WBSF) in meats were examined.

2.3. Analysis

Dry matter, protein, fat, and ash analysis of meat were made according to AOAC (1990), mineral substance contents (Ca, P, Mg, and B) in the ash were determined by plasma emission spectroscopy (CAP) method (ICP/6500 system sequential analysis Perkin-Elmer, Norwork, CT) in ICP.

The first pH value was determined in the meat taken from the right LT muscle as soon as the animals were slaughtered, and the final pH value was determined in the same meat that was rested for 24 hours. pH values were measured with a digital, portable pH meter (Orion 210A pH-meter and Orion 9106 glass electrode). The glass probe of the pH meter was placed directly in the center of the samples after calibrating with standard buffers pH 4.00 and pH 7.00.

The juiciness of the meat was estimated by two methods: water holding capacity (WHC) and cooking loss (CL). Meat samples for WHC were sliced into 1 cm thick, 4 cm^2 diameter steak, wrapped in gauze and placed between pre-weighed Wattman 18 papers, then a 2-2.5 kg weight was placed on it for 5 minutes and calculated according to the formula below (equation 1).

WHC= first weight of meat - final weight of meat/first weight of meat) x 100 (Grau and Hamm, 1953) (1)

The samples for CL, were cut into 65 g blocks and placed in polyethylene bags and kept in a thermostatically controlled water bath set for 1 hour at 75°C, then the samples were cooled in cold water for 30 minutes, the meats removed from the bag were dried with a dry towel and weighed. CL was calculated according to the formula below (equation 2).

CL= (weight of raw meat - weight of cooked meat) / weight of raw meat x 100 (Franko et al., 2011) (2)

Analysis of fatty acid methyl esters from the extracted lipid was made according to Anonymous (1987). Composition of fatty acids determined using Shimadzu brand gas chromatography (Model GC-2010, Japan) with flame ionization detector (FID) and with a DB-23 column (60 m x 0.25 mm I.D, 0.25 µm). Fatty acids were identified by comparing based on their arrival time of the standard 37-component FAME mixture (Supelco 37 Components FAME Mixture, Cat. No. 18919-1AMP, Bellefonte PA, USA).

Determination of color in meat; Lightness (L*), redness (a*) and yellowness coordinate (b*) Chroma (C*), and hue angle (H°) values were determined by Konica Minolta CR400 instrument. The chromameter was calibrated on a white calibration plate (Y = 87.1, x = 0.3158, y = 0.3225) before measuring color. The measuring head was adjusted to illumination C with 2° standard observer and 8 mm aperture.

The texture analysis of the meats (TA-HD Plus Texture Analyzer, UK) was determined by the compression test using a 5 N load cell. Hardness, flexibility and WBSF values were determined in the compression test. 3 sub-samples of 1x1 cm parallel to the direction of the muscle fibers were prepared from each cooked meat sample and WBSF was measured.

2.4. Statistical Analysis

The data obtained according to the criteria discussed at the end of the whole study were analyzed using SPSS 25.0 (IBM, Chicago, IL, USA) and Origin 2021b software (OriginLab, Northampton, MA, USA). Analysis of variance was performed to evaluate the differences between the means and then analyzed with the Duncan multiple comparison test (SAS, 2008). The least significant differences were determined as $P < 0.05$.

3. Results

3.1. Nutrient Content of Meats

The nutrient contents of the meat samples taken from the LT muscle are given in Table 1.

Table 1. Nutrient content of meats

Groups and Parameters	S	L	C	U	E
DM, %	26.88±0.478	25.42±0.576	26.98±0.483	26.73±0.247	25.67±0.269
Protein, %	20.56±0.001a	1.08±0.006a	20.96±0.001a	19.88±0.003ab	19.79±0.002ab
Fat, %	3.96±0.313	3.72±0.239	3.95±0.200	4.38±0.278	4.38±0.232
Ash, %	1.61±0.144a	0.94±0.017c	1.60±0.160a	1.58±0.132a	1.22±0.073b
Ca, mg/100g	5.94±0.238a	3.58±0.264b	5.71±0,249a	5.56±0,236a	3.53±0,228b
P, mg/100g	17.99±0.086a	15.48±0,035b	17.37±0.027a	15.55±0.038b	15.42±0.081b
Mg, mg/100g	19.78±0.057b	22.84±0.040a	22.27±0.042a	23.92±0.010a	23.11±0.092a
B, mg/100g	0.01±0.001	0.01±0.002	0.01±0.001	0.01±0.001	0.01±0.002

S= standart (Ca, P), L= low (Ca, P), C= low (Ca, P) + colemanite, U= low (Ca, P) + ulexite, E= low (Ca, P) + etibor-48, DM= dry Matter, Ca= calcium, P= phosphorus, Mg= magnesium, B= boron.

[a, b, c]There is a significant difference between the means shown with different letters on the same line, (P<0.05).

There was no statistically significant difference between the groups for dry matter (DM) and fat content of meat. The protein content was highest in C and S groups, and the lowest in L group, and the difference between them and the L group was significant ($P < 0.05$), however, the difference between E and U and L was not statistically significant. The lowest ash content of the meats was determined in L group, followed by E group. The difference between these two groups and the other groups was significant ($P < 0.05$), there was no significant difference between S and C and U groups. When the mineral contents of the meats were examined, the lowest Ca were determined L and E groups. Significant differences were found between these and other groups ($P < 0.05$). No significant difference was determined between S control group and boron groups. The highest P content was determined in S and C groups. While there was no significant difference between these groups, the difference between these groups and the others was significant ($P < 0.05$). While S group had lowest Mg content ($P < 0.05$) compared to all other groups, no significant difference was found between the other groups. B content of meat was the same in all groups. No significant differences were found between the treatment groups.

3.2. Meat pH Water Holding Capacity and Cooking Loss Value,

The pH at 0 h and 24 h after slaughtering, water holding capacity (WHC) and cooking loss (CL) values of the meats after the first and 24 hours are given in Table 2. As seen in Table 2, the initial pH_0 value of the meats varied between 6.60 and 7.04, and the pH_{24} value varied between 5.61-5.83. There was no significant difference between the groups in terms of pH_0 and pH_{24}. Addition of boron to the ration had no effect on the pH values of the meat compared to the S control group.

The WHC varied between 16.67-21.67%. In terms of WHC, S and C groups were significantly higher ($P < 0.05$) compared to the other groups. There were no significant differences between both S with C and L with U, E. CL values in Akkaraman lamb's meat varied from 27.38 to 32.96%. There was no significant difference between the groups in terms of CL. But C and U were numerically lower.

Table 2. pH, water holding capacity and cooking loss values of meats

Groups and Parameters	S	L	C	U	E
pH_0	6.77±0.223	7.04±0.164	6.76±0.108	6.60±0.111	6.77±0.053
pH_{24}	5.67±0.032	5.83±0.023	5.65±0.023	5.61±0.033	5.67±0.025
WHC, %	21.67±0.103[a]	16.67±0.133[b]	20.54±0.169[a]	16.74±0.131[b]	17.12±0.141[b]
CL, %	32.96±2.434	31.06±1.776	27.38±1.963	30.16±2.468	31.05±2.638

S= standart (Ca, P), L= low (Ca, P), C= low (Ca, P) + colemanite, U= low (Ca, P) + ulexite, E= low (Ca, P) + etibor-48, WHC= water holding capacity (%), CL= cooking loss (%).

[a, b, c]There is a significant difference between the means shown with different letters on the same line, ($P<0.05$).

3.3. Color Characteristics of Meat

Color analysis were made with a color measuring device in the meat taken from the LT muscle and results are shown in Table.3. The a* value, which is an indicator of redness in the meat of Akkaraman lambs, ranged from 8.77 to 10.47. The highest a* value compared to the other groups was determined in the U group, and the numerical difference between the other groups was not significant. There was no difference between the groups in terms of the yellow color indicator "b*", chroma "c*" and lightness expression "L" values in meats. The b* and L* values in the boron groups were numerically higher than S group. However, while Hue angle value, which indicates the color intensity, was highest in C, E and L groups, there was no significant difference between these groups. H° was lowest in U group. While the difference between U and S groups was not significant, a significant difference was found between the other groups ($P < 0.05$).

Table. 3. Color characteristics of meat

Groups and Parameters	S	L	C	U	E
L*	30.78±1.383	33.61±1.069	33.45±1.350	31.94±1.049	35.02±0.816
a*	9.45±0.398[b]	9.37±0.318[b]	8.77±0.206[b]	10.47±0.181[a]	9.42±0.213[b]
b*	7.36±0.369	7.84±0.232	7.66±0.341	7.65±0.257	7.95±0.241
C*	11.99±0.472	12.22±0.314	11.66±0.314	12.98±0.151	12.33±0.216
H°	7.81±0.035[ab]	8.43±0.033[a]	8.74±0.036[a]	7.37±0.031[b]	8.52±0.037[a]

S= standart (Ca, P), L= low (Ca, P), C= low (Ca, P) + colemanite, U= low (Ca, P) + ulexite, E= low (Ca, P) + etibor-48, L*= lightness, a*= redness, b*= yellowness, C*= chroma, H°= hue angle.

[a, b, c]There is a significant difference between the means shown with different letters on the same line, ($P<0.05$).

3.4. Textural Characteristics of Meat

After the cooking loss was determined in the meat samples taken from the LT muscle, the texture analysis of the meat was performed. Data on flexibility, hardness and WBS cutting force of meats are given in Table 4. The flexibility of the meat of the trial lambs are between 54.91-79.02 N, the hardness measured with a 1 mm probe is between 6.36-10.91 N; WBSF varied between 27.92-35.91.

The use of different boron sources in the ration did not have a significant effect on the flexibility, hardness and cutting force properties of the meats. However, while the addition of C increased the flexibility, the addition of C and U increased the hardness numerically, the addition of C, U and E caused a decrease in WBSF compared to the control groups.

3.5. Fatty acid content of meats

In the material extracted from meat samples taken from LT muscle, 37 fatty acids were examined in gas chromatography, and fatty acids found at very low levels were not taken into consideration. Data on fatty acids of meats are given in Table 5. Caproic acid ranged between 0.11-0.39 g/100g, caproic acid was found to be significantly higher than the others in group E ($P < 0.05$), but there was no significant difference between the other groups. Stearic acid was found to be significantly higher

in L group compared to all groups ($P < 0.05$), no significant difference was found between boron groups and S group. Cis-8,11,14-eicosatrienoic acid was high in U, E and S groups, and the lowest in L group, followed by C group. While the difference between these two groups was significant ($P < 0.05$), the difference between these groups and other groups was also significant ($P < 0.05$). While oleic acid was higher in C group (41.56 g/100g), Linoleic acid was lower in L group (3.57 g/100g) compared to all groups.

Table 4. Texture characteristics of meat

Groups and Parameters		S	L	C	U	E
Flexibility, N		58.53±81.541	78.32±30.378	79.02±34.860	54.91±28.303	72.96±70.475
Hardness, N (1mm)		6.36±23.806	7.58±21.277	10.17±17.858	10.91±17.014	7.45±17.746
Warner	Shear Force, N	19.84±64.388	20.90±76.179	19.58±33,122	18.06±23.352	17.69±36,686
Blatzer	Work shear, N	35.91±89.538	31.97±77.138	29.73±68.184	28.19±60.583	27.92±108.539

S= standart (Ca, P), L= low (Ca, P), C= low (Ca, P) + colemanite, U= low (Ca, P) + ulexite, E= low (Ca, P) + etibor-48, N= Newton.

Table 5. Fatty acids content of meat (g/100g)

	S	L	C	U	E
Caproic acid	0.22±0.024^{b}	0.11±0.025^{b}	0.13±0.051^{b}	0.20±0.024^{b}	0.39±0.074^{a}
Capric acid	0.17±0.006	0.17±0.013	0.18±0.008	0.16±0.010	0.15±0.005
Lauric acid	0.18±0.020	0.15±0.013	0.18±0.021	0.16±0.017	0.20±0.037
Myristic acid	2.40±0.140	2.37±0.102	2.54±0.105	2.27±0.116	2.42±0.241
Myristoleic acid	0.16±0.093	0.05±0.005	0.07±0.003	0.06±0.004	0.06±0.007
Pentadecanoic acid	0.36±0.028	0.36±0.030	0.30±0.026	0.30±0.015	0.33±0.018
Palmitic acid	23.77±0.288	24.48±0.70	24.71±0.733	24.28±0.938	23.31±0.994
Palmitoleic acid	1.28±0.042	1.08±0.058	1.39±0.079	1.30±0.058	1.31±0.107
Heptadecanoic acid	1.52±0.091	1.55±0.132	1.18±0.094	1.20±0.106	1.33±0.099
cis-10 heptadecanoic acid	0.76±0.046	0.70±0.052	0.72±0.043	0.71±0.037	0.72±0.026
Stearic acid	18.57±1.084^{b}	22.53±1.327^{a}	18.45±0.747^{b}	18.31±0.925^{b}	19.42±1.346^{ab}
Elaidic acid	1.54±0.117	1.33±0.429	0.79±0.254	1.41±0.91	1.40±0.167
Oleic acid (C18:1n9t)	40.42±1.243	38.97±0.647	41.56±0.908	38.99±0.996	39.55±0.721
Linolelaidic acid	0.13±0.030	0.08±0.012	0.07±0.07	0.10±0.049	0.10±0.029
Linoleic acid	4.63±0.541	3.57±0.197	4.30±0.321	5.73±0.877	5.08±0.435
Arachidic acid	0.12±0.014	0.15±0.020	0.12±0.019	0.12±0.013	0.13±0.010
gama-linoleic acid	0.11±0.009	0.08±0.004	0.10±0.008	0.10±0.010	0.10±0.006
cis-11-eicosenoic acid	0.15±0.011	0.13±0.005	0.14±0.009	0.15±0.010	0.14±0.007
Heneicosanoic acid	0.46±0.027	0.42±0.029	0.44±0.031	0.51±0.063	0.48±0.033
cis-11,14-eicosadienoic acid	0.07±0.004	0.07±0.006	0.06±0.003	0.07±0.003	0.07±0.007
cis-8,11,14-eicosatrienoic acid	0.32±0.007^{a}	0.18±0.013^{c}	0.29±0.006^{b}	0.39±0.007^{a}	0.38±0.004^{a}
Tricosanoic acid	2.42±0.52	1.26±0.144	2.13±0.30	3.00±0.690	2.57±0.409
cis-5,8,11,14,17-eicosapentaenoic acid	0.21±0.033	0.11±0.007	0.16±0.033	0.24±0.049	0.21±0.024
cis-4,7,10,13,16,19-docosahexaenoic acid	0.11±0.020	0.05±0.005	0.09±0.018	0.12±0.024	0.10±0.014

S= standart (Ca, P), L= low (Ca, P), C= low (Ca, P) + colemanite, U= low (Ca, P) + ulexite, E= low (Ca, P) + etibor-48.

$^{a, b, c}$There is a significant difference between the means shown with different letters on the same line, ($P<0.05$).

4. Discussion

4.1. Nutrient Content of Meats

The DM, protein, fat, and ash content of Akkaraman lamb meat in study varied between 25.42-26.98%, 19.08-20.96%, 3.72-4.38% and 0.94-1.61%, respectively. Since there were no studies on boron sources in lambs, the findings were compared with the results of other studies on lamb meat quality. Jacques et al. (2016) determined the water, protein and fat values in Dorset male lambs meat fed with concentrated feed respectively was 75, 21.5 and 3.2%. These values were like the results of Akkaraman lamb meat in this study. Likewise, the information obtained in water, protein, and ash of Akkaraman lamb meat in our study was compatible with Camacho et al. (2015), who determined the water (72.70%), protein (21.86%) and ash (0.92%) contents of 25 kg Canarian lamb as meat. Similar results were obtained by Oliveira et al. (2019) for water (73.54%), protein (20.20%) and ash (0.99%) in Santa Ines lamb meat, but the result for fat (5.16%) was found to be higher than the current study. The reason of these differences may be due to the different breeds, ages, production systems and nutritional management of the animals.

In our study, Ca in meat varied between 3.53-5.94 mg/100g, the lowest Ca content was found in L and E groups, it was highest in S groups and C and U groups. The presence of Ca in structure of colemanite and ulexite may have caused an increase in the Ca content of the meat. Kaić et al. (2016) determined as 5.03 mg/100g Ca concentration in LT muscle of Lika Pramenka lambs. This result is similar to the results of the other groups in our study, except for L group. Phosphorus content ranged between 15.42-17.99 mg/100g and was highest in S and C groups, and was similar in L, E and U groups. Mg levels changed between 19.78-23.92 mg/100g and the lowest was determined in S control group. Similar findings were reported by Bellofet al. (2006), who determined as 16.06 mg/100g P content in German Merino lamb in the growing period, but Mg content was found to be higher than the results of our study. On the contrary, The Ca (7.05 mg/100g) content determined by Lima et al. (2013) for lamb meat was higher than our study, and Mg content (19.24 mg/100g) was similar to result of our study.

Mostert and Hoffman (2007) reported that the mineral content of meat can be affected by various factors such as mineral concentration in the diet, hormones, age, species, and region. According to Lin et al. (1988), it is possible that changes in lamb feeds affected mineral content in animal meat. The B level of meat was the same in all boron added treatment groups. Bharti et al. (2007) stated that boron is not stored in soft tissues but excreted in the urine. This view supports the results of the research. There is boron at the level of 0.015-0.6 (mg/kg fresh tissue) in the soft tissues and fluids of humans and animals (Nielsen, 1997). The B level determined in meat in this study is consistent with the literature report.

4.2. Meat pH, Water Holding Capacity and Cooking Loss Value,

In the present study, pH_0 of Akkaraman lamb meat was between 6.60-7.04, and after 24 hours the pH value changed between 5.61-5.83. Since there was no study on meat quality with the Boron sources studied, Akkaraman lamb meat quality criteria were compared with the results of different lamb meats. Similar findings were reported by McGeehin et al. (2001), who the pH values of male lambs meat taken from LT at 0 and 24 hours found as 6.37-6.91, 5.31-5.76, respectively. Likewise, Tejeda et al. (2008) similarly found pH 24 (5.83-5.60) for merino male lambs, while Díaz et al. (2002) also similarly found pH 24 values (5.51 and 5.71) of Talaverana lambs slaughtered at 24 and 28 kg carcass weight.

In the current study, WHC was determined the highest in S (21.67%) and C (20.54%) groups, while L and other B groups (16-17%) had lower WHC. Boron addition caused an increase in WHC compared to L group. List et al. (2011) determined 18.48% for WHC in Spanish Ternasco type lambs weaned at the 45 days-old and fed with feed containing 18% CP and 11.5 MJ ME, and this results is lower than the findings in this study. In the present study, the CL of meat varied between 27.38 and 32.96%. CL decreased numerically in all groups, especially in the C group compared to the S group. Since there was no study on CL with boron sources in lambs, the results were compared with studies on meat quality of lambs. This result was higher than the findings of Sheridan et al. (2003), who in Meat Merino lambs meat fattened for 28 and 56 days found as 33.93% and 39.62% of CL, respectively. Likewise, the CL values (35.90, 35.49, 36.37 and 35.23%) determined in the meat of growing crossbred male lambs (¾ chios. ¼ ossimi and ½ chios. ½ ossimi) by Abd El-aal and Suliman (2008) were higher than the results of this study. This difference may be due to the age of the animal, the cooking time of the meat, the temperature, and the feeding difference. As the age or physiological maturity of the lambs' progress, it is necessary to cook the meat longer, which leads to more cooking loss (Russo et al., 2003). During the cooking, meat greatly loses the water present in its structure, which leads to a decrease in the tenderness and flavor of the meat. Moreover, if the cooking temperature rises above 70 °C, cooking losses in meat increase (George-Evins et al., 2004).

4.3. Color Characteristics of Meat

The L* value, which is the indicator of lightness, is ranged 30.78-35.02 this study. This result was lower than the report of Akcay et al. (2014) in Bafra lambs (39.55), but the L value (31-40) determined by Şirin (2009) in Kıvırcık lambs was found to be similar to this study. The a* (11.5) and L* (41.3) values determined by Jacques et al. (2016) in Dorset male lambs were higher than the current study, the b* (5.3) value was lower than the study, and the C* value (12.7) was similar to the study. The values of a* (19.59), b* (6.08) L* (43.89), C* (20.61) and H° (20.61) determined in 25 kg Canarian lambs in

study of Camacho et al. (2015), are higher than results of study. L* value in this study was similar (33.2) to the report for Texel crossbred male lambs (5-8 months old) of Johnson et al. (2005) but the a* value was lower than report (13.8).

In this study, a* value, which is an indicator of redness in the meat of Akkaraman lambs, ranged between 8.77 - 10.47. Adding U to the ration caused an increase in a* value. Akcay et al. (2014) determined a* value as 18.37 in Bafra lambs and Şirin (2009) determined between 17-21 in Kıvırcık lambs, these results are considerably higher than the value determined for Akkaraman lambs.

b* value, which is an indicator of yellowness in meat, ranged between 7.36-7.95 in this study. These results, similar with the b* value (4-7) determined in Kıvırcık lambs by Şirin (2009), and b* (7) value determined in Bafra lambs by Akçay et al. (2014).

In a study conducted in Merinos, the L*, a* and b* values (respectively; 43.68-43.39, 13.27-12.73, 8.73-9.13) found in male lambs for slaughter weight of 24 kg and 29 kg were calculated higher than the current study (Tejeda et al., 2008). These differences between the results may be atributed to race and age differences, as well as the structure of the feed fed to the animal and the difference in feeding. According to Priola et al. (2001) the fattening method, slaughtering practices, carcass preservation, rigor mortis temperature, and meat pH may also affect these values. No study has been found on the effect of B sources on the color characteristics of lamb meat. But it is clear that boron sources provided a numerical increase in a*, L* and C* values in this study. The color of the meat is affected by the age, sex, muscle fiber, ration used, roughage-concentrated and roughage types, glycogen concentration in the muscle, cooling rate, oxidation rate, and pH level (Sarıçiçek, 2007; Suman et al., 2014).

4.4. Textural Features of Meat

In the present study, Flexibility ranged from 54.91 to 78.32 N. A numerical decrease was observed with the addition of Ulexide to diet. While the addition of boron sources caused an increase in hardness and a decrease in WBSF. However, no study was found on B sources to support the result in lambs' meat.

Many researchers have determined the WBSF value of different breeds of lamb higher than the results in this study (Liste et al., 2011; Camacho et al., 2015; Thorkelsson et al., 2019). In addition, boron was not used in the studies by researchers. According to Shorthose et al. (1986) ≤5 kg (~49 N) WBSF threshold can be interpreted as the meat obtained from slaughter systems is acceptably tender. In this study, the WBSF value remained below 49 N, therefore, it can be considered sensitive.

WBSF values were determined by researchers for lambs slightly older than 4 months (17.2 N and 18.3 N) and lambs over 7 months old (27.6 N) are similar to the study (Sañudo et al., 2003, Berge et al., 2003).

The difference between research results also depends on other factors such as race, processing before and during slaughter, age, breed, type of muscle used, pH, cooking temperature, and cooking time, as reported in previous studies (Behrends et al., 2009). It is seen that addition of B sources to the ration caused a decrease in WSBF compared to the control groups in this research.

5. Conclusion

When all findings of our study are evaluated again, the addition of colemanite, ulexite and etibor-48 to the diets of Akkaraman male lambs weaned at the age of 2.5 months, containing low Ca and P, resulted in an improvement in some parameters related to meat quality. While the addition of C to the ration causes an increase in protein, P and Ca and oleic acid content of the meat, the addition of C and U causes an increase in Ca content, but numerically lowered the WBS value.

Linoleic acid was high in all groups except L group. All boron sources increased the Mg content, the addition of U improved the a* value of the meat, while the addition of all the boron sources improved the b* and c* value of the meat. The addition of C and E increased the H° value of the meat. The addition of U and E showed an improvement in cis-8,11,14-eicosatrienoic acid content compared to the L group. Numerical increases in linoleic acid, tricosanoic acid and palmitoleic acid levels were determined in boron groups. Thus, the use of colemanite, ulexide and etibor-48 in the ration in this study caused an improvement in the quality of Akkaraman lamb meat, but it would be beneficial and need to conduct other studies in ruminants.

Author Contributions

B.Z.S (% 100) designed of study initiated the research. B.Z.S (% 50) and B.Y. (% 50) collected data, analyzed and interpreted the data. B.Z.S (% 100) wrote the manuscript. B.Z.S (% 100) supervised the research, suggested the research methods, structured the paper and edited the manuscript. All authors reviewed and approved final version of the manuscript.

Conflict of Interest

The authors declared that there is no conflict of interest

Ethical Consideration

This study was approved by Ankara University Animal Experiments Ethics Committee (Decision No. 2013-4-13) protocol, which complies with the international guidelines on the use of animals in scientific research procedures.

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