

# EFFECTS OF DIFFERENT PRODUCTION SYSTEMS ON CARCASS AND MEAT QUALITY OF SHEEP AND LAMB FROM WESTERN BALKAN AND NORWAY

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**Abstract:** The identification of meat quality characteristics from selected breeds grazing in specific regions is particularly relevant to achieve a marketing advantage. *Longissimus thoracis at lumborum* (LTL) from the indigenous Western Balkan (WB) sheep - VlašićkaPramenka (VP) sheep and lambs, and Pivska Pramenka (PP) sheep grazing in Bosnia & Herzegovina (B&H) and Montenegro (MN), respectively, was compared regarding carcass and meat qualities to the crossbred Norwegian white sheep (NWS) - sheep and lambs, grazing in wide Hardangervidda and Jotunheimen regions where the lamb meat is marketed as gourmet meat. The WB sheep had lower average carcass weights and antioxidant capacity, higher ultimate pH, intramuscular fat and *n-6/n-3* ratio, but better tenderness and color stability compared to NWS. The WB lambs were lighter, had higher *n-6/n-3* ratio, lower antioxidant capacity and became more easily rancid despite a higher fat  $\alpha$ -tocopherol content. The marketing advantage of WB meat is its tenderness properties while NO's NWS lambs displayed a better nutritional profile.

**Key words:** production system, sheep meat quality, physical and chemical traits, meat color, fatty acid composition.

## Introduction

The consumers' have an increasing interest in more healthy meat products and lower production costs. EU's Common Agricultural Policy stimulates

at the same time pasture-based production systems resulting in meat with higher content of omega 3 polyunsaturated fatty acids (PUFA) (Enser et al., 1998; Carrasco et al., 2009). The consumers in Western Balkan (WB) are becoming more aware of claimed organic meat advantages, but prefer domestic meat from non-conventional production systems. The purchase motives for such meat are safety, "natural" content, health, good meat quality and a distinctive taste (Vukasović, 2013). The Norwegian consumers also prefer domestic meat from mountain pastures with perceived elements of naturalness, healthiness and environmental friendly production combined with good meat quality (Hersleth et al., 2012).

Meat quality differ among animal species (Guerrero et al., 2013), and can be used to promote sheep and lamb sale, such as done for the Texel sheep (Cockett et al., 2004) and lamb from Aragosa (Martinez-Royo et al., 2008). The producers in EU were encouraged to continue producing lamb meat according to the traditional methods (Texiera, 2005) in agreement with consumers' requirements and acceptance. In Europe the Spanish scientists have carried out a substantial amount of research on their autochthonous breed Aragonese in order to obtain the PGI (Protected Geographical Indication) label (Martínez-Cerezo et al., 2005).

The predominant sheep breed in the WB is the Pramenka sheep (PS). It makes up 80 to 90% of the sheep population and belongs to indigenous primitive sheep type (Robić, Liker, and Rupić, 1992). In the 20<sup>th</sup> century, most PS types were crossed with different exotic breeds, mostly Merino, but the last indigenous PS types remain in the high mountain regions of the Balkan Peninsula, where the environmental conditions and quality of pastures are less favorable for conventional sheep grazing (Cinkulov et al., 2008).

In B&H, the dominant sheep is Vlašićka Pramenka (VP) (synonym Dubska) with female adults weighing 60-70 kg (Porcu and Marković, 2006), while PP (synonym Jezeropivska) is the predominant sheep in MN, with female adults weighing 51-54 kg (Marković, Marković, and Adžić, 2007). Farming in WB is done semi extensively, oriented towards utilization of grassland and pasture areas.

A predominant sheep breed in Norway is the Norwegian White Sheep (NWS). It constitutes 76.2% of all sheep flocks in Norway (Domke et al., 2011). NWS is a crossbreed composed of Dala, Rygja, Steigal and Texel breeds selected for fast growing lambs, good reproduction and high meat yield (Boman, et al., 2010). NWS rearing is intensive, but lamb and sheep graze outdoors during the summer. An adult sheep can reach up to 100 kg live weight. Norwegian lambs grazing in specific regions are marketed by origin (e.g. Gourmet lamb from the mountains in Central Norway; Lofot-lamb from the mountainous islands of North Norway).

The research on NWS meat quality began in 1990, but is still not extensive. Meat quality characteristics such as typical EU grade scores, fat content, fatty acid composition (only adipose tissue), color, flavor and sensory traits have

been reported to depend on grazing regions (*Ådnøy et al., 2005; Lind et al., 2009*). The fattening of lambs on nutrition rich pastures lowered n-6/n-3 FA ratio, while fattening on a concentrate-based diet lowered the content of C18:3 (n-3) fatty acids and intensity of acid taste (*Lind et al., 2009*).

The aim of this study was to: 1) describe the meat quality characteristics of Western Balkan PP and VP breeds grazing in typical regions; 2) compare sheep and lamb meat quality from WB regions with a crossbreed NWS from Norwegian mountains developed for intensive meat production; 3) describe the meat quality variations within each meat production group.

## Materials and Methods

### *Grazing regions*

All three grazing regions are characterized by a complex, but different floristic composition.

**WB:** PP animals were collected in 2012 from the grazing region Ljubišnja, at an altitude of 900-1300m. The MN pastures are unique areas of fragmented mountain grasslands with trees and bushes. *Poetum violaceae*, *Festucetum ovinae*, *Festucetum rubra-falax*, *Festucetumvalesiaca*, *Nardetum strictae*, *Brometum erectistrictae* predominate the floristic composition of the grasslands up to 1200 m (*Dubljevic, 2009*). VP animals were collected in 2012 from the Vlašić grazing region, at an altitude of about 1500 m. The grazing region of VP is characterized by fragmented mountain grasslands, separated by trees and bushes. *Poa pratensis*, *Bromus racemosus*, *Dactylis glomerata*, *Briza media*, *Lotus corniculatus*, *Trifolium pratense*, *Trifolium repens*, *Vicia sativa* and *Pteridium aquilinum* dominate floristic composition (*Alibegovic-Grbic, 2009*).

**Norway:** NWS animals were collected in 2012 from grazing regions in central and southeast Norway at an altitude 500-1700 m. The region is about 40 000 km<sup>2</sup>, and covers the production of Gourmet lamb. At an elevation of 500-900 m, the grazing area is characterized by spruce and pine forests, while at an elevation of 900-1700 m by scarce birch forests with little grass. *Avenella flexuosa*, *Luzula pilosa*, *Festuca ovina*, *Anthoxanthum odoratum*, *Agrostisca pillaris*, *Deschampsia cespitosassp.cespitosa*, *Carex spp.* are floristically predominant (*Lunnan and Todnem, 2011*).

Only the 4 years old NWS were fed indoor their last 3 months after the outdoor grazing period on the concentrate and local grass silage.

### *Slaughtering*

Totally 92 *Longissimus thoracis at lumborum* (*LTL*) sheep/lamb samples were collected from 3 countries.

**B&H:** *LTL* was collected at “BB” Kotor Varoš, a traditional slaughterhouse, from 15 female sheep (age 4-5 years) and 15 lambs (age 5-6 months). Traditional slaughtering without stunning was used. The handling of *post mortem* (*pm*) was set up to reduce the effect of cold shortening, i.e. by a controlled temperature drop. **MN:** *LTL* was collected from 15 female sheep (age 4-5 years) at the meat production company Franca, Bijelo Polje. We were not able to collect the lambs from MN, because there was not a sufficient number of female lambs ageing 5-6 months from the same herd in a small production area. In addition, lambs are not commonly raised to age 5-6 months to be slaughtered for meat consumption. **Norway:** *LTL* from 14 female sheep (age 4-5 years) and 15 female sheep (age 2 years) as well as from 18 lambs in an early fattening phase (9 ecologically fed) were collected at the Nortura Gol slaughter plant. The only difference between ecological and conventional production was the lower level of the fatty acid C22:6 (*n*-3) in ecological lamb, and therefore these two groups were merged into a single group in all analysis.

The carcasses in Norway and MN were exposed to low electrical stimulation, and then returned to the chiller (4°C). All *LTL* samples were cut along the carcass length and vacuum-packed in the cutting room  $\leq 5$  h at 10°C, before being returned to the chiller. The vacuum packaged samples were transported on ice to the laboratories 24 h *pm*.

One *LTL* from each animal was stored at 4°C for 7 days and then sliced, vacuum-packed and frozen. The second *LTL* was cut in pieces suitable for the intended measurements, vacuum-packaged and stored at -80°C, for tenderness measurements at -40°C.

### **Meat quality assessments**

**pH:** In Norway and MN, the pH value was measured 24 h *pm* (pH<sub>24</sub>) using the Knick Portamess Model 913 (Knick, Berlin Germany), while in B&H using the HANNA Model 99161 (Cluj-Napoca, Romania). Both instruments were calibrated with commercial standard solutions.

**Color stability:** Fresh meat samples (24 h *pm*) were sliced into 2 cm thick cuts, and placed on trays (Polystyrene Weigh Boats 85x85x24mm, VWR International, Darmstadt, Germany) over-wrapped with oxygen-permeable polyvinyl chloride film (PVC) and stored at 4°C. One hour after slicing was denoted as time zero. The meat color was determined in triplicates on slices after 4, 72 and 144 h chill storage. The meat surfaces were turned up, towards the cling wrap, during measurements at a temperature of 19°C. **Norway:** Konica Minolta Spectrophotometer CM 700d (Konica Minolta Sensing Inc., Osaka, Japan)

calibrated by a white ceramic calibration cap (CM-A177) was used. The light source was a pulsed xenon lamp. Illuminant D65 (Daylight, color temperature 6504 K) with a 10° observer (CIE Konica-Minolta 1964) was used. **B&H**: Konica Minolta Spectrophotometer CM 2600d (Konica Minolta Sensing Inc., Osaka, Japan) calibrated by a white ceramic calibration plate (CM-A145). The light source, standard illuminant and observer was the same as in Norway. **MN**: Color-Tec PCM+ (ColorTec, Clinton-New Jersey, USA) 20 mm reflectance colorimeter was used. The light source was a light emitting diode (LED) array.

To secure that the measurements were comparable in the 3 countries, seven paint codes (black, white and 5 shades of red) from "JOTUN" A/S (Sandefjord) were measured in Norway, B&H and MN and used to calculate and correct for instrumental differences.

**Warner Bratzler tenderness measurements:** Slices (4 cm), thawed overnight and heated at 72°C in the core of the samples, were cooled on ice up to approximately 20°C. Sensors inserted in dummy samples recorded internal temperatures. Muscle samples (1×1×4 cm) were cut in parallel to the fiber direction, and sheared across the fiber direction. **Norway**: shear cell HDP/BSK Warner Bratzler, load cell 25 kg, TA-HDi Texture Analyser, Stable Micro Systems, Godalming, UK. **MN/B&H**: Shear cell HDP/BS Warner Bratzler, load cell 25 kg, TA.XT, PLUS, Texture Analyser, Stable Micro Systems, Godalming, UK. The number of replicates was 6-8. In order to transfer data between labs, a rubber was split in two and each half was measured in each country, and a factor was calculated to transfer data from one instrument to another one.

**Cooking loss (% weight loss):** Cooking loss (%) was calculated as a percent difference between the fresh and heated samples weights.

### **Chemical composition**

**Protein Content:** Nitrogen content was determined using the Kjeldahl method as described by ISO 937:1992 (ISO, 1992). Total Kjeldahl nitrogen was converted to protein by conversion factor 6.25.

**Water content:** Water content in meat samples was determined, according to the AOAC Official Method (AOAC 950.46, 1950) in three replicates.

**Fat content and fatty acid composition:** Fat content was determined according to the AOAC Official Method (AOAC 991.36, 1996), and fatty acid composition according to the O'Fallon method (2012).

**Vitamin E content:** The measurements were carried out by applying the procedure of *Triumpf et al. (2012)*, with modification of the centrifugation time.

**2,2-diphenyl-1-picrylhydrazyl (DPPH), total antioxidant capacity:** The antioxidant capacity was determined by using DPPH, according to the procedure

described by *Brand-Williams et al. (1995)*, with some modifications. Meat pieces (0.5 g) were added to 4 ml of DPPH in ethanol (0.050mg/ml). The homogenates were incubated (50 min) in the dark at room temperature. Trolox solutions were used as a standard. The samples were shortly vortexed and centrifuged at 2534 x g for 5 min. The reduction of DPPH was measured by Synergy H4, Hybrid Multi-Mode Microplate Reader from BioTek Instruments Inc., P.O. Box 998 (Highland Park, Winooski, Vermont 05404-0998 USA) at 515 nm after 60 min incubation (until stable absorptions values were obtained). The percentage of DPPH-scavenging activity was calculated as  $(A_o - A_t) / (A_o) \times 100$ , where  $A_o$  was the absorbance of the control and  $A_t$  was the absorbance in the presence of the sample after 1 h of incubation.

***Cathepsin B analysis:*** The assay was based on the procedure of *Barret and Kirschke (1981)*, with some modifications. The frozen meat was pulverized (IKA 11 basic Analytical mill, Germany). Meat (1 gram) was mixed with 10 ml extraction buffer (containing 0.25 M of sucrose and 1 mM EDTA in 0.2 M KCL; pH 6.0, adjusted with NaOH). After adjusting the pH of the extraction buffer 0.2 (w/v) Triton X100 was added. The meat homogenates were vigorously shaken and centrifuged (VWR by Hitachi Koki, CT 15E, Japan) at 1946 x g for 20 min at 4°C. The supernatant was mixed with 100 µl buffer, 50 µl Milli-Q water and 100 µl stock solution (15mM Z-Arg-Arg-AMC in 100% DMSO). The blank sample contained 150 µl Milli-Q water, 100 µl assay buffer (containing 0.2 sodium acetate, 4mM EDTA and 8 mM DTT, the final pH 6.0 was adjusted with NaOH) and 50 µl supernatant.

The stock solution of the standard contained Milli-Q water, 7-methylcoumarin amide MCA (1mM MCA in 100% DMSO) and assay buffer. The assay buffer and the diluted extract were incubated in Synergy H4 Hybrid Multi - Mode Microplate Reader (BioTek Instruments. Inc. USA) at 40°C for 30 min. The excitation wavelength was 340 nm, and the emission was monitored at 460 nm.

***Heme pigment /hemin analysis:*** The method was based on the procedure described by *Lombardi-Boccia et al. (2002)*, adapted to Eppendorf tubes.

***Total peroxide value using the ferric-xyleneol orange method:*** The frozen and aged samples were prepared according to the procedure described by *Yi et al. (2013)*.

***TBARS:*** Lipid oxidation was assessed by the TBARS (thiobarbituric acid reactive substances) assay on the aged samples. Two g frozen meat was pulverized (IKA 11 basic Analytical mill, Germany) and mixed with 10 ml stock solution (0.375 % TBA and 15% TCA in 0.25 N HCl). All samples were treated in a water bath at 98 °C for 10 min and cooled on ice for the next 30 min. Solutions under the upper fat layer (1.5 ml) were carefully removed and centrifuged for 25 min at

25 186 x g and 4°C. The absorption (at 532 nm) of the supernatant was measured immediately after centrifugation using Shimadzu UV-1800 (Shimadzu corp. Kyoto, Japan).

**Statistical analysis:** All statistical analyses were performed using one way ANOVA or a general linear model (Minitab version 16 or 17, Minitab Ltd., Coventry) in combination with Tukey's test for individual comparisons. Significant differences were reported for  $P \leq 0.05$ .

## Results and Discussion

### Physical characteristics of sheep/lamb LTL

**Carcass characteristics:** Carcass weight, fat and conformation grading, tenderness, cooking loss and pH<sub>24</sub> for the six different age and breed categories are shown in Table 1. NO carcasses had nominally higher slaughter weights when compared to carcasses from WB. The carcasses from NO and B&H lambs had similar slaughter weights. The B&H sheep were small, had more fat, but good conformation score (Table 1), while the B&H lamb had the lowest fat and conformation score. The conformation score was highest for NO lambs. Due to unusual WB weather conditions in 2012 with pasture in surplus, the WB sheep and lamb were slaughtered one month later than usual; consequently the animals were also fatter (Bjelanovic et al., 2013). A significant difference ( $P < 0.001$ ) in fatness and conformation score was found between groups.

**Table 1. Carcass and meat physical quality assessments (mean and standard error square).**

	Norwegian white sheep			WB Pramenka sheep		
	NO old	NO young	NO lamb	MN sheep	B&H sheep	B&H lamb
Age (years)	4-5	2	0.5	4-5	4-5	0.5-0.6
Carcass w. (kg)	30.4(±5.2) <sup>ab</sup>	33.1(±3.2) <sup>a</sup>	17.1(±2.6) <sup>d</sup>	27.3(±3.6) <sup>bc</sup>	25.0(±3.1) <sup>c</sup>	16.0(±1.7) <sup>d</sup>
EU fatness s.*	8.0(±1.4) <sup>b</sup>	7.4(±0.8) <sup>b</sup>	5.6(±1.3) <sup>c</sup>	7.7(±1.3) <sup>b</sup>	9.8(±1.0) <sup>a</sup>	5.1(±1.2) <sup>c</sup>
EU conformation s.**	5.0(±0.0) <sup>b</sup>	7.6(±0.6) <sup>a</sup>	8.0(±0.0) <sup>a</sup>	5.3(±1.5) <sup>b</sup>	7.9(±1.6) <sup>a</sup>	3.4(±0.9) <sup>c</sup>
pH	5.55(±0.12) <sup>b</sup>	5.61(±0.07) <sup>ab</sup>	5.64(±0.07) <sup>ab</sup>	5.75(±0.08) <sup>a</sup>	5.75(±0.25) <sup>a</sup>	5.75(±0.15) <sup>a</sup>
>pH 5.8	0/14	0/15	0/18	4/15	2/15	0/15
SF (N/cm <sup>2</sup> )***	52.4(±10.4) <sup>a</sup>	54.6(±12.3) <sup>a</sup>	40.1(11.06) <sup>bc</sup>	47.4(±7.9) <sup>ab</sup>	38.9(±6.1) <sup>bc</sup>	31.8(±5.9) <sup>c</sup>
Range	38-70	37-77	25-60	28-83	25-66	25-42
>50 (N/cm <sup>2</sup> )	4/14	8/15	4/18	3/15	1/15	0/15
Cooking loss (%)	20.5(±5.1) <sup>ab</sup>	19.3(±4.2) <sup>b</sup>	21.8(±5.1) <sup>ab</sup>	25.4(±4.9) <sup>a</sup>	18.1(±1.7) <sup>b</sup>	21.5(±5.2) <sup>ab</sup>

\*Scale 1-15 points: 1=P-; 2=P (poor); 3=P+; 4=O-; 5=O(normal); 6=O+; 7=R-; 8=R (good); 9=R+; 10=U-; 11=U(very good); 12=U+, 13=E-; 14=E (excellent), and 15=E+

\*\*Scale 1-15 points: 1=1-; 2=1(very scarce); 3=1+; 4=2-; 5=2 (scarce); 6=2+; 7=3-; 8=3 (medium); 9=3+; 10=4-; 11=4 (important), 12=4+; 13=5-; 14=5 (excellent), and 15=5+

\*\*\*8 days p.m.

<sup>abcd</sup> Row means within factors with different letters indicate statistically significant differences at ( $P < 0.001$ ).

### ***Sheep and lamb meat quality related characteristics:***

Mean  $pH_{24}$  ranged from 5.55 to 5.75 (Table 1). A significant difference between groups in  $pH_{24}$  ( $P < 0.001$ ) was found. pH was higher in WB than in NO samples. This may indicate less stress in NO animals when slaughtered (Martínez-Cerezo et al., 2005), or less type I fibers (Park et al., 1987). PS is an indigenous breed, and may uphold its natural instincts (i.e. fear) and sensitivity to stress. Stress results in excretion of adrenaline causing a series of biochemical changes that indirectly catalyze the breakdown of glycogen ante mortem (*am*), leading to an elevated muscle  $pH_{24}$  (Voisinet et al., 1997). Priolo et al. (2002), also connected higher ultimate pH to physical activity of animals and extensive production system.

Generally, the samples from WB sheep and lamb were significantly tenderer when compared to NO sheep and lamb, and this may depend both on breed and production system in agreement with Guerrero et al., (2013). Meat samples from B&H sheep and lamb were tenderer compared to the other groups. The samples from young NO were the toughest, while the MN sheep varied the most (Table 1). Meat with shear force scores above 50 N/cm<sup>2</sup> is regarded as tough (Davey, Gilbert, and Carse, 1976) and will be discounted by consumers. The breeding aim for higher muscular mass is often at the expense of lower tenderness and lower IMF content (Więcek et al., 2008). Cooking losses were highest in the MN samples (Table 1). This may reflect these samples lower protein content (Table 2).

The average changes in surface meat color parameters ( $L^*a^*b^*$ ) during the aerobic storage were significantly different among groups (Figure 1 a,b). The first measurement (4 h) would reflect a bloomed sample with dominantly oxy-myoglobin (OMb) in the surface. A decline in  $L^*$  and  $a^*$  with time would be interpreted as conversion to meat-myoglobin (MMb). Surface  $L^*$  may increase due to microbial growth after prolonged storage in air.

$L^*$  (lightness) was always higher in WB animals (Figure 1a) with B&H lamb having the highest initial  $L^*$  value.  $L^*$  increased/remained the same for 72 h, except for the young NO and B&H sheep.  $L^*$  may dependent on production system. Some authors have reported darker meat from extensive production systems (Mancini and Hunt, 2005; Priolo et al., 2002), but Lorenzo et al. (2014), reported a higher  $L^*$  value in meat from a free extensive production system. This phenomenon may be explained by a higher IMF level in meat from extensive production systems (Priolo et al., 2002).



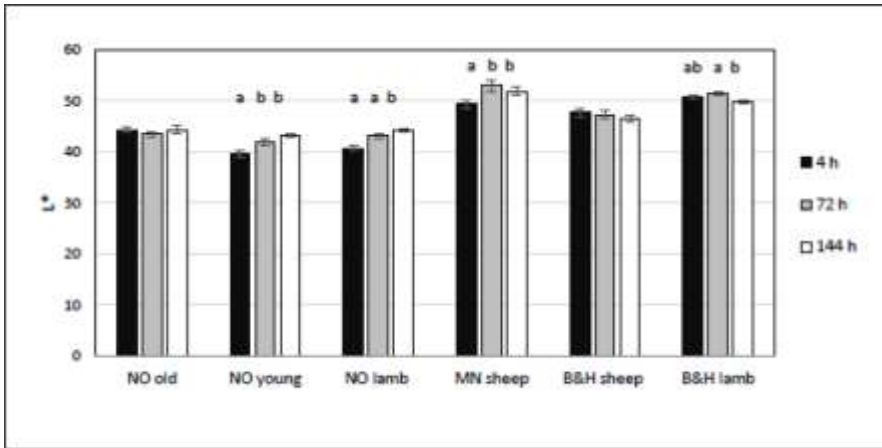


Figure 1a. The average changes in L\* during aerobic incubation for different sheep/lamb groups and times. Different letters indicate significant ( $P < 0.05$ ) differences.

The variable  $a^*$  was not dependent on production system. Four h post mortem, only the NO lamb and B&H sheep had low  $a^*$  values. This could be due to low color stability for the NO lamb or the higher fat level in B&H sheep (Table 1). The variable  $a^*$  of MN sheep declined after 72 h, but still retained a higher level than in the other groups.  $a^*$  of the B&H sheep declined only moderately from 4 to 72 h. The color stability of NO sheep, using  $a^*$  as an indicator, was lower than in MN sheep and B&H sheep (Figure 1b). For lamb,  $a^*$  declined the least for the NO lamb.

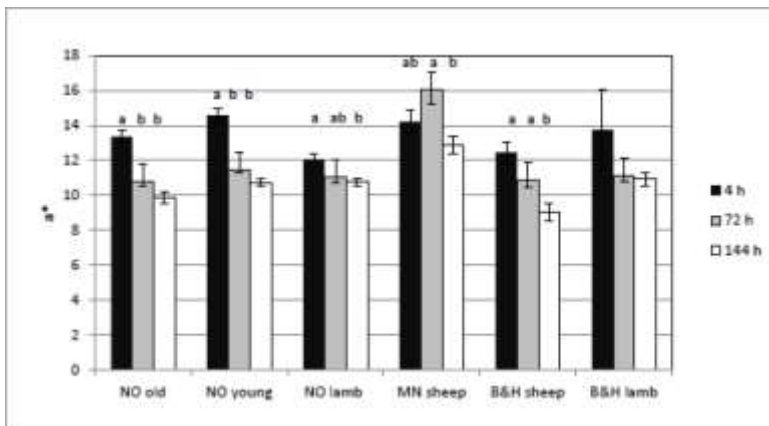


Figure 1b. The average changes in  $a^*$  during aerobic incubation for different sheep/lamb groups and times. Different letters indicate significant ( $P < 0.05$ ) differences.

NO young sheep and NO lamb had the lowest  $b^*$  and a much lower  $b^*$  than NO old (not presented). Interestingly,  $b^*$  was also high in B&H meat. Differences in muscle lightness and yellowness can be attributed to dietary effects on pre-slaughter glycogen and on marbling levels (*Mancini and Hunt, 2005*) while differences in  $a^*$  depend largely on heme amount, myoglobin states plus marbling.

### Composition of sheep/lamb LTL

The iron concentration in meat is highly dependent on breeding, age, sex and muscle type of the animal (*Lombardi-Boccia et al., 2002*). As expected, heme was highest in older sheep and lowest in lambs (Table 2). There was no difference in heme between NO and B&H lambs, but NO lambs had the nominally lowest heme concentration (0.15 mg/ml).

Water content depended on age and was higher in younger compared to older and more fatty animals. The low water content in B&H sheep meat was related to its higher fat content (supported by Table 1 and 2). Breed combined with production system had no significant impact on dry matter.

**Table 2. Meat chemical quality assessments (mean and standard error square).**

	Norwegian white sheep			WB Pramenka sheep		
	NO old	NO young	NO lamb	MN sheep	B&H sheep	B&H lamb
Heme (mg/ml)	0.23(±0.05) <sup>a</sup>	0.21(±0.04) <sup>ab</sup>	0.15(±0.03) <sup>c</sup>	0.24(±0.04) <sup>a</sup>	0.21(±0.05) <sup>ab</sup>	0.18(±0.03) <sup>bc</sup>
Water content*	73.13(±0.6) <sup>b</sup>	73.42(±1.0) <sup>b</sup>	75.30(±0.9) <sup>b</sup>	73.15(±0.4) <sup>b</sup>	70.93(±0.6) <sup>c</sup>	75.83(±0.4) <sup>a</sup>
Dry matter*	26.87(±0.6) <sup>b</sup>	26.58(±0.9) <sup>b</sup>	24.69(±0.6) <sup>b</sup>	26.85(±0.4) <sup>b</sup>	29.07(±0.6) <sup>a</sup>	24.17(±0.4) <sup>c</sup>
Protein content*	21.38(±0.9) <sup>a</sup>	21.61(±0.9) <sup>a</sup>	20.56(±0.6) <sup>b</sup>	17.12(±0.4) <sup>c</sup>	20.49(±0.6) <sup>b</sup>	20.63(±0.4) <sup>b</sup>
Fat content*	3.88(±0.5) <sup>b</sup>	3.38(±0.2) <sup>b</sup>	2.58(±0.6) <sup>c</sup>	7.46(±0.8) <sup>a</sup>	7.39(±0.4) <sup>a</sup>	2.35(±0.1) <sup>c</sup>
Vitamin E (mg/100g)	0.23(±0.04) <sup>ab</sup>	0.12(±0.05) <sup>c</sup>	0.09(±0.07) <sup>c</sup>	0.29(±0.15) <sup>a</sup>	0.22(±0.08) <sup>ab</sup>	0.16(±0.06) <sup>bc</sup>
Vitamin E/Fat (mg/100g)	0.07(±0.05) <sup>ab</sup>	0.03(±0.03) <sup>b</sup>	0.05(±0.04) <sup>b</sup>	0.04 (±0.02) <sup>b</sup>	0.04(±0.02) <sup>b</sup>	0.11(±0.05) <sup>a</sup>
DPPH (total antioxidant)*	66.2(±5.2) <sup>b</sup>	66.5(±3.3) <sup>b</sup>	66.3(±4.8) <sup>b</sup>	70.9(±2.6) <sup>a</sup>	68.7(±3.7) <sup>ab</sup>	72.7(±3.7) <sup>a</sup>
Cathepsin B**	0.33(±0.07) <sup>ns</sup>	0.33(±0.04) <sup>ns</sup>	0.30(±0.03) <sup>ns</sup>	0.32(±0.05) <sup>ns</sup>	0.31(±0.04) <sup>ns</sup>	0.32(±0.03) <sup>ns</sup>
TBARS***	0.33(±0.13) <sup>ab</sup>	0.33(±0.21) <sup>ab</sup>	0.22(±0.05) <sup>b</sup>	0.47(±0.25) <sup>a</sup>	0.23(±0.23) <sup>b</sup>	0.43(±0.03) <sup>a</sup>

\* expressed in %

\*\* μM MCA/min/g meat

\*\*\* 8 days p.m. / mg malondialdehyde/kg

<sup>abcd</sup>Row means within factors with different letters indicate statistically significant differences at ( $P < 0.001$ ) except TBARS ( $P < 0.005$ ).

Protein content was significantly different among all animal groups (Table 2). Both old and young NO had higher protein content than B&H and MN sheep. MN sheep had the lowest protein content, but with no difference for lamb groups. *Hofman et al. (2003)* reported that the muscles with the highest protein content were characterized by lower fat content. NO sheep had a more favourable fat/protein ratio (Table 2) in agreement with general breeding goals. The results also indicated that old and young NO sheep, with the highest protein content, were

less tender (Table 1). This can again relate to types of muscular fibers. *Wood et al. (1999)* suggested that genetic selection for modern breeds with increased meat yield and lean content increases the proportion of white glycolytic fibers (type IIB), and consequently less tender meat (*Karlsson et al., 1993*).

Vitamin E ( $\alpha$ -Tocopherol) is a fat-soluble vitamin. Its content was significantly different among all six animal groups (Table 2). Green pasture or supplementation in feeds increase vitamin E in meat (*Jose et al., 2008*). Vitamin E can delay OMB oxidation via inhibition of lipid oxidation (*Faustman et al., 1998*). Color and lipid stability of fresh beef *longissimus muscle* can be improved if  $\alpha$ -tocopherol concentrations of tissues is between 3.0 to 3.3  $\mu\text{g}$   $\alpha$ -tocopherol/g meat (*Faustman et al., 1989*). MN sheep had a high concentration of vitamin E (0.29 mg/100g), close to this threshold. This can be a possible explanation of the delayed OMB conversion to MMB in MN sheep. Older sheep groups had a higher vitamin E concentration than younger groups. Unexpectedly, vitamin E/fat (mg/100g fat) was nominally highest in B&H lamb, and significantly different from the other groups (Table 2).

$\alpha$ -Tocopherol level is interesting from a nutritional perspective, assuming that its antioxidative power protects cells against the effects of free radicals which can contribute to the development of chronic diseases like cancer and cardiovascular diseases. This vitamin can enhance the immune function and block the formation of cancerogenous nitrosamines in the stomach from nitrates used as additive in food products. Vitamin E also prevents against cataracts (*Daley et al., 2010*).

Cathepsin B is a relevant enzyme for dry cured sheep production since its level is closely related to textural defects during the ripening phase of pig hams (*Priolo et al., 2002*). The activity of cathepsin B in *LTL* (Table 2) did not differentiate between groups, only within groups; the highest variation was for old NO and MN sheep. The variation was lowest for NO lamb and B&H lamb.

Table 3 shows average values and standard errors (SE) of intramuscular fatty acid composition (mg/100 g meat). The concentrations of total fatty acids were age dependent. Sheep had more total fatty acids than lambs, and WB sheep more than NO in agreement with their amount of total fat (Table 2). The concentration of the polyunsaturated fatty acids C18:2 (*n*-6) and C18:3 (*n*-3) showed the greatest variation, as indicated by their SE, while the concentration of C20:4 (*n*-6), C20:5 (*n*-3), C22:5 (*n*-3) and C22:6 (*n*-3) showed the lowest SE. The total amount of saturated fatty acids (SFA), monounsaturated fatty acids (MUFA) and PUFA was also age dependent, and significantly higher in older animals. The percentage of PUFA dropped with age, but was also significantly dependent on production systems, as described by *Enser et al. (1998)*. The nominally highest % SFA was found in MN sheep.

**Table 3. Fatty acid composition (mean and standard error square).**

	Norwegian white sheep			WB Pramenka sheep		
	NO old	NO young	NO lamb	MN sheep	B&H sheep	B&H lamb
C18:2 n-6 Linoleic acid*	1.81(±1.58) <sup>ab</sup>	1.93(±0.72) <sup>ab</sup>	0.98(±0.27) <sup>c</sup>	2.34(0.84) <sup>a</sup>	2.21(±0.69) <sup>a</sup>	1.17(±0.24) <sup>bc</sup>
C18:3 n-3 $\alpha$ - Linolenic acid*	1.15(±1.33) <sup>a</sup>	1.49(±0.73) <sup>a</sup>	0.49(±0.17) <sup>b</sup>	1.42(±0.76) <sup>a</sup>	1.06(±0.45) <sup>ab</sup>	0.43(±0.10) <sup>b</sup>
C20:4 n-6 Arachidonic acid*	0.32(±0.03) <sup>b</sup>	0.39(±0.08) <sup>ab</sup>	0.33(±0.06) <sup>b</sup>	0.33(±0.04) <sup>b</sup>	0.38(±0.04) <sup>ab</sup>	0.43(±0.07) <sup>a</sup>
C20:5 n-3 Eicosapentaenoic acid*	0.20(±0.02) <sup>b</sup>	0.24(±0.05) <sup>a</sup>	0.20(±0.04) <sup>b</sup>	0.17(±0.03) <sup>bc</sup>	0.17(±0.03) <sup>c</sup>	0.16(±0.03) <sup>c</sup>
C22:5 n-3 Docosapentaenoic acid*	0.26(±0.11) <sup>b</sup>	0.36(±0.10) <sup>a</sup>	0.21(±0.04) <sup>b</sup>	0.27(±0.06) <sup>b</sup>	0.25(±0.05) <sup>b</sup>	0.22(±0.04) <sup>b</sup>
C22:6 n-3 Docosahexaenoic acid*	0.07(±0.02) <sup>bc</sup>	0.10(±0.04) <sup>a</sup>	0.06(±0.02) <sup>c</sup>	0.09(±0.03) <sup>ab</sup>	0.09(±0.01) <sup>ab</sup>	0.09(±0.02) <sup>ab</sup>
n-6/n-3*	1.37(±0.17) <sup>b</sup>	1.12(±0.15) <sup>c</sup>	1.44(±0.15) <sup>b</sup>	1.46(±0.15) <sup>b</sup>	1.73(±0.20) <sup>a</sup>	1.84(±0.14) <sup>a</sup>
SFA*	30.87(±42.48) <sup>a</sup>	27.66(±14.77) <sup>ab</sup>	8.67(±1.87) <sup>b</sup>	47.41(±23.20) <sup>a</sup>	29.51(±10.61) <sup>a</sup>	7.51(±2.69) <sup>b</sup>
MUFA*	29.12(±41.93) <sup>a</sup>	22.11(±12.69) <sup>ab</sup>	6.78(±1.68) <sup>c</sup>	36.77(±16.54) <sup>a</sup>	24.97(±10.41) <sup>ab</sup>	6.5(±2.57) <sup>bc</sup>
PUFA*	3.88(±3.09) <sup>ab</sup>	4.58(±1.65) <sup>a</sup>	2.33(±0.55) <sup>c</sup>	4.71(±1.70) <sup>a</sup>	4.23(±1.21) <sup>a</sup>	2.55(±0.46) <sup>bc</sup>

\* mg/100g meat

<sup>abcd</sup>Row means within factors with different letters indicate statistically significant differences at ( $P < 0.001$ ).

Total amounts of C18:2 (*n*-6) was higher in sheep compared to lamb. Total amounts of  $\alpha$ -Linolenic acid C18:3 (*n*-3) tended to follow this pattern. Sañudo et al. (2006) reported similar results for Spanish and British lambs. Old NWS had the greatest amount of *n*-3 LC-PUFA.

The ratio *n*-6/*n*-3 was still favorable for lamb/sheep (Russo, 2009). Interestingly, this ratio showed no variation with age in both NO and B&H systems. But the *n*-6/*n*-3 ratio was significantly higher for B&H sheep and lamb (Table 3) than other systems. The ratio *n*-6/*n*-3 was the lowest in young NO sheep. C18:3 (*n*-3) is regarded as the preferred fatty acids leading to C20:5 (*n*-3), docosapentaenoic acid C22:5 (*n*-3), and docosahexaenoic acid C22:6 (*n*-3) (Brenna et al., 2009). Additionally, it inhibits the conversion of C18:2 into the others *n*-6 LC-PUFA (Smink et al., 2012).

A favorable *n*-6/*n*-3 ratio is important for the regulation of SFA in human body. The dietary SFA can raise unfavorable blood lipids, but sufficient intake of *n*-3 PUFA can neutralize this effect (Dias et al., 2014), and prevent coronary heart diseases, diabetes 2, obesity and cancer. The SFA intake is a major contributor to calcium, vitamin D, vitamin B12 and the other essential nutrients absorption; a reducing of SFA without substituting lower-fat versions may result in serious unintended nutritional consequences (Huth et al., 2013).

### ***Oxidative stability measurements***

The total antioxidant activity method detects the ability of a matrix to eliminate an unpaired valence electron in DPPH (Dawidowicz, Wianowska, and Olszowy, 2011). Low DPPH values are therefore favorable. The total antioxidant activity was highest in NO meat (Table 2). Antioxidant activity was not affected by the age of the animals.

TBARS values above 0.5 are considered as critical and indicate a lipid oxidation level which produces a rancid odor and taste that can be recognized by consumers (Wood *et al.*, 2008). TBARS was significantly different among the groups (Table 2). After 7 days of aging at 4°C, TBARS accumulation in NO old and young was equal. NO lamb had the lowest TBARS value, while MN sheep and B&H lamb had the highest. B&H sheep had the lowest TBARS among sheep groups. The TBARS value of 0.47 in MN sheep was near the threshold of 0.5 suggesting that the high fat content and poor ratio vitamin E/fat content may have some impact on its low oxidative stability (Table 2). All together factors such as concentration of the fat, heme pigment and antioxidant status in the muscle tissue can influence color stability and FA oxidation, and are tightly related to the diet (Ponnampalam *et al.*, 2012). Lourenço *et al.* (2007) suggested that different grazing regions can induce changes in the rumen microbial population, and therefore differences in the biohydrogenation of PUFA. Dietary effects in form of different grass types might have an impact on the FA composition in ruminants. Lee *et al.* (2003) suggested that white clovers (*Trifolium repens*) can limit biohydrogenation of *n-3* PUFA. It seems that vitamin E had a positive impact on color stability in MN sheep, but not on FA oxidation stability.

Polar peroxides (0.12-0.39 mmol/kg meat) originating from lipids (Volden *et al.*, 2011) were highest in VP lamb followed by NO old and young. Proteins bound peroxides (Yi *et al.*, 2013) also varied significantly among groups from 0.09 in MN sheep to 0.191 mmol/kg in NO old. No significant difference was found for unpolar (chloroform soluble) peroxides. These data are partly in agreement with TBARS (Table 2).

### **Conclusion**

The different production systems influenced meat color, pH, tenderness and fatty acid composition. Pramenka sheep, collected from their natural grazing areas, were smaller animals with more fatty carcasses relative to NWS from Hardangerevidda and Jotunheimen regions. WB meat (*LTL*) had higher pH<sub>24</sub>, and a low protein to *IMF* ratio. Its total antioxidant capacity was lower, and the *n-6/n-3* ratio tended to be higher. The marketing potential of PS meat seems to be related to its higher color stability and good tenderness. This quality can be used to

encourage the production of B&H sheep and lamb in future. The marketing advantages of NO carcasses seemed related to their high protein/fat ratio, low  $n-6/n-3$  ratio and good antioxidant capacity.

B&H sheep were muscular but with more fat, lower water content and lower cooking losses, lower  $L^*a^*b^*$  with higher  $n-6/n-3$  and became more rancid than MN sheep. The B&H lambs were smaller than NO lambs, with a higher level of vitamin E, but lower antioxidant capacity, more TBARS and less EPA and higher  $n-6/n-3$  ratio. Its marketing potential seemed only related to its high vitamin E content while the marketing potential of NO lamb seems related to its good oxidative stability with a favorable  $n-6/n-3$  ratio.

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## Uticaj različitih proizvodnih sistema na kvalitet mesa trupova ovaca i jagnjadi Zapadnog Balkana i Norveške

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## Rezime

Definisanje kvaliteta mesa odabranih rasa ovaca i jagnjadi koje su bile na ispaši u posebnim regijama je od velike važnosti u postizanju tržišne konkurentnosti. U ovom eksperimentu korišten je mišić *Longissimus thoracis at lumborum* (LTL) autohtonih zapadno-balkanskih(WB) ovaca i jagnjadi vlašičke pramenke (VP) koje su bile na ispaši na planini Vlašić u Bosni i Hercegovini. Također je korišten LTL od ovaca pivske pramenke (PP) koje su bile na ispaši na planini Ljubišnja u Crnoj Gori. Kvalitet mesa trupova i LTL-a autohtonih balkanskih ovaca upoređivani su sa trupovima norveških belih ovaca i jagnjadi (NWS), koje su bile na ispaši u regionu hardangerske visoravni i Jotunheimen regiona. Jagnjeće meso iz ovih regiona smatra se gurmanskim proizvodom.

U poređenju sa NWS ovcama rase pramenka ovaca imale su nižu prosečnu težinu, manji oksidativni kapacitet, veću konačnu pH vrednost, intramuskularnu masnoću kao i viši odnos n-6/n-3, bolju mekoću mesa i stabilnost boje. Jagnjad zapadno-balkanske pramenke su imala nešto manju masu, viši odnos n-6/n-3, slabiji oksidativni kapacitet, njihovo meso je veoma brzo užeglo, bez obzira na viši sadržaj  $\alpha$ -tocopherola. Tržišna prednost mesa zapadno-balkanskih rasa je u njihovoj mekoći, dok NWS jaganjci imaju bolji nutritivni profil.

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