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Growth, carcass and meat quality in Zwartbles lambs slaughtered at different live weights

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Abstract: The aim of the study was to evaluate the effect of different live weights at slaughter (LWS) of Zwartbles lambs on their daily gain (DG), carcass traits (CT) and chemical and physical characteristics of the *quadriceps femoris* muscle (QFM). A total of four weight groups of lambs were evaluated: group A, LWS = up to 35 kg; group B, LWS from 35.1 to 40 kg; group C, LWS from 40.1 to 45 kg and group D, LWS from 45.1 to 50 kg. The LWS had a significant ($P < 0.05$) effect on DG and most CTs, when average DG and most weights of individual CTs increased with increasing LWS. The evaluation of the influence of LWS on the chemical and physical characteristics of QFM primarily shows that this factor had a significant ($P < 0.05$) effect only on the content of intramuscular fat (IMF) and redness index (RI), when in both cases the values of these traits increased (IMF: from 0.57 to 1.21%; RI: from 8.53 to 9.76) with increasing LWS. In conclusion, it can be stated that most of the monitored traits in all weight groups of Zwartbles lambs were comparable with their levels in specialized meat breeds of sheep.

Keywords: Zwartbles; live weight at slaughter; carcass traits; chemical characteristics of meat; physical characteristics of meat; *quadriceps femoris* muscle

Compared to lamb meat consumers from southern Europe who prefer meat from "light" lambs (Diaz et al. 2002), consumers in central Europe, including the Czech Republic, prefer meat of well conformed "heavy" lambs, slaughtered at live weights in the range from 25 to 40 kg (Zapletal et al. 2010). However, the consumption of lamb meat in the Czech Republic is relatively low compared to most European countries (Sredl et al. 2021). In our opinion, it is mainly influenced by the fact that lamb meat can be classified from consumers' point of view as non-traditional meat in the Czech Republic. The relatively high price of lamb is also a significant problem for the consumer. On the other hand, it can be stated that consumer interest in lamb meat is growing because it has an interesting and non-traditional taste for the domestic consumer. In addition, this meat is a good source of protein and important micronutrients (Cabrera and Saadoun 2014).

Many studies (Zapletal et al. 2010; Komprda et al. 2012; Liu et al. 2015; Khaldari and Ghiasi 2018; Prache et al. 2022) show that the growth of lambs, their slaughter quality and meat quality are influenced by a number of factors, while the most important ones are nutrition, health status, breed, genetics, live weight at slaughter (LWS),

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age at slaughter and gender. However, the final quality of meat is also fundamentally affected by preslaughter conditions, chilling, intramuscular fat (IMF) content, castration, microbiological hazards and carcass transport (Prache et al. 2022).

One of the interesting breeds that have recently started to be bred in the Czech Republic is the Zwartbles breed, originally from the Netherlands. This breed belongs to the combined dual-purpose breeds and was created by crossing the Schoonebeker breed with the Texel and East Friesian breeds. This breed is primarily appreciated by domestic breeders for its good prolificacy, relatively high growth rate, relatively good conformation, low fatness and their resilience in harsh climatic conditions (Komprda et al. 2012). Nevertheless, on some farms, ewes of this breed are crossed with rams of meat breeds to improve their conformation. However, information on chemical and physical characteristics of Zwartbles meat is very scarce**,** because this breed is rarely a subject of studies on this issue.

The Czech consumers actually prefer "heavy" lambs, i.e. the lambs usually weighing up to 40 kg. On the other hand, they are usually offered lambs slaughtered at higher weight. Considering the ever-increasing interest of domestic breeders in the Zwartbles lambs, as well as their relatively high weight at slaughter, the aim of our study was to evaluate the effect of different LWS in Zwartbles lambs on their growth, carcass traits and chemical and physical characteristics of the *quadriceps femoris* muscle (QFM).

MATERIAL AND METHODS

Animals and experimental design

The study was carried out on a sheep farm in Mohelno, located in the Vysocina region of the Czech Republic. The farm is situated at 345 m above sea level with an average annual temperature of 8.2 °C and precipitation of 449 mm. All experimental lambs (n = 48) were male twins of the Zwartbles breed. All lambs were born indoors in the period from mid-March to early April. From their births until mid-April, all the lambs were housed indoors with their mothers. The daily feeding ration (DFR) of ewes in the period from parturition to the beginning of grazing consisted of haylage (3 kg/ewe), meadow hay (*ad libitum*) and mineral lick (*ad libitum*). The DFR of lambs during the same period consisted of mother's milk (*ad libitum*) and organic mineral lick (*ad libitum*); the lambs also had free access to the feedstuff of their mothers. All the mothers and lambs also had free access to drinking water. In the second half of April the ewes with their lambs were placed on a permanent pasture, where the DFR of ewes consisted of pasture (*ad libitum*), meadow hay (*ad libitum*) and mineral lick (*ad libitum*). The DFR of lambs from the beginning of grazing to slaughter consisted of mother's milk, rolled oats (0.15 kg/day/lamb), pasture and mineral lick. Mother's milk, pasture and mineral lick were provided *ad libitum*. All the mothers and lambs also had free access to drinking water. Weaning of lambs was carried out just before slaughter. During the experiment, all of the lambs were reared in one flock under identical conditions without any discernible differences in nutrition or management. The dominant grass species of the pasture were: *Lolium perenne* (40%), *Trifolium repens* (15%), *Phleum pratense* (12%) and *Poa annua* (10%).

Slaughter and determination of carcass traits

Before slaughter, all lambs were divided into four groups according to their live weights at slaughter (LWS) as follows: group A (n = 10), LWS = up to 35 kg; group B (n = 12), LWS from 35.1 to 40 kg; group C (n = 14), LWS from 40.1 to 45 kg and group D (n = 12), LWS from 45.1 to 50 kg. These slaughter weights were chosen to represent a range within which lambs in the Czech Republic are traditionally slaughtered. The LWS of lambs were recorded after overnight fasting. The average age of all lambs at slaughter was 126 days (group A: 118 days; group B: 127 days, group C: 126 days and group D: 130 days). All lambs were slaughtered in a certified slaughterhouse according to the EU legislation. Procedures were conducted according to the guidelines of the Council Regulation (EC) No 1099/2009 on the protection of animals at the time of killing. Actual live weights at slaughter and age at slaughter were recorded on the day of slaughter; average daily gains in the period from birth to slaughter were calculated.

After 24 h of refrigeration (+4 °C), the conformation score and fatness score were evaluated.

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The conformation score (an extent of the scale from S = superior to P = poor conformation) and fatness score (the scale from 1 = very low to 5 = very high fatness) were assessed according to the S.E.U.R.O.P. evaluation system (Commission Regulation No. 461/93). For the purpose of statistical analysis, the scale of the conformation score was quantified from the grade S = 6 to the grade P = 1. The weights of cold carcass, kidney and kidney fat were recorded. Dressing percentage and proportions of kidney and kidney fat were calculated from the above values. Subsequently, both legs were separated from each carcass according to Kuchtik and Horak (2001), and their weights were determined. The proportions of both legs were calculated from the whole slaughter carcass. Subsequently, both legs were separated from each other according to Kuchtik and Horak (2001), and whole right legs were weighed. Due to sampling of the QFM for physical and chemical analyses from whole right legs, only bones were separated from the meat and fat. Bone proportions and total meat and fat proportions were calculated from the weight of the right leg. Subsequently, samples of QFM were taken from whole right legs for physical and chemical analyses (all four parts of QFM, *m. rectus femoris*, *m. vastus lateralis*, *m. vastus medialis* and *m. vastus intermedius*, were taken together as one total sample).

Chemical and physical analyses of the *quadriceps femoris* muscle

The concentration of protein (Kjeldahl nitrogen × 6.25) and collagen was determined according to the AOAC methods (AOAC 1996; AOAC 2000). The content of intramuscular fat (IMF) was assessed by extraction with diethyl ether in a Soxhlet extractor for 6 h; the extraction process was carried out without acid hydrolysis. The method of determining the ash content was burning in a laboratory furnace at 550 °C for 8 hours. The intramuscular fat and ash content was performed according to AOAC (2005).

The pH 24 of the *quadriceps femoris* muscle was measured using a stick probe (calibrated in the original calibration solutions at 25 °C) using a portable pH 340/SET-1 WTW apparatus (WTW Wissenschaftlich-Technische Werkstätten GmbH, Weilheim, Germany) with temperature compensation. Determination of intramuscular fat content, ash and pH 24 value was carried out according to Kuchtik et al. 2012. Water-holding capacity (WHC) was measured twice in fresh meat (5 g) according to the method of Grau and Hamm (1953) and subsequently expressed as a percentage of water expelled. Meat colour was evaluated using the L* a* b* system (CIE 1976) by a Konica Minolta CM-2600d spectrophotometer (Minolta Camera Co., Ltd, Osaka, Japan), using an integrated mirror component, illuminator D65 and 10° observer. Thickness of *quadriceps femoris* muscle samples was at least 12 mm. The analysis was performed at laboratory temperature without covering the samples. To determine the colour of the meat, each sample was measured five times and the average value was calculated. Evaluation of meat colour was determined according to the procedure given by Kuchtik et al. (2012).

Statistical analyses

For the purpose of statistical analysis, the scale of the conformation score was quantified from the grade S = 6 to the grade P = 1.

The statistical analysis was carried out using STATISTICA CZ v14 (StatSoft CR s.r.o., Prague, Czech Republic). GLM analysis was applied to study the influence of weight at slaughter on daily gain, carcass traits and chemical and physical characteristics of the *quadriceps femoris* muscle as four independent groups of live weights at slaughter. When the analysis of variance showed significant differences between the groups, the Tukey-Kramer test was applied. The differences were considered significant if $P < 0.05$. Each trait was analysed using a model with age at slaughter and birth weight covariates and fixed effect of weight at slaughter:

$$y_{ij} = \mu + b_1 age_i + b_2 wbirth_i + slweight_j + e_{ij} \qquad (1)$$

where:

y – dependent variable for each ram (i = 48);

μ – intercept;

age and *wbirth* – regressions on age at slaughter and birth weight for each ram i with corresponding regression coefficients b_1 and b_2;

slweight – fixed effect of weight at slaughter j (j = 4, A: up to 35 kg, B: 35.1–40 kg, C: 40.1–45 kg, D: 45.1–50 kg);

e – random residual error.

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RESULTS

Effect of LWS on daily gain and carcass traits

In all monitored groups, the average age at slaughter (Table 1) was comparable and ranged from 118 to 130 days, depending on the individual group. In contrast, the LWS was significantly ($P < 0.05$) different between all lamb groups. Specifically, for group A with LWS up to 35 kg, the average LWS was 33.32 kg, for group B where the range of LWS was from 35 to 40 kg, the average LWS was 38.92 kg, for group C the range of LWS was from 40 to 45 kg, when the average LWS was 42.53 kg and for group D, in which the range of LWS was from 45 to 50 kg, the average LWS was 47.14 kg. The LWS of lambs also had a significant ($P < 0.05$) effect on average daily gain (ADG) in the period from birth to slaughter. The highest ADG (295 g) was found in the group of lambs with the highest LWS (group D) and the lowest ADG (193 g) in the group of lambs with the lowest LWS (group A).

Regarding basic carcass traits, the LWS had a significant ($P < 0.05$) effect on cold carcass weight (CCW), weight of both legs (WBLs) and weight of the right leg (WRL). The LWS also had a significant ($P < 0.05$) effect on total weight of meat and fat from the right leg (TWMFRL) and weight of bones from the right leg (WBRL). The highest values of CCW (21.80 kg), WBLs (7.18 kg), WRL (3.56 kg), TWMFRL (2.73 kg) and WBRL (0.78 kg) were found in the group of lambs with the highest LWS (group D). In contrast, the lowest values of all these traits (CCW = 14.43 kg, WBLs = 5.63 kg, WRL = 2.46 kg, TWMFRL = 1.87 kg, and WBRL = 0.57 kg) were found in the group of lambs with the lowest LWS (group A).

The LWS also had a significant ($P < 0.05$) effect on the proportions of both legs (PBLs) and kidney (PK), when the highest PBLs (38.93%), and PK (0.70%) were found in the group of lambs with the lowest LWS (group A). In contrast, the lowest PBLs (32.81%) and PK (0.61%) were found in lambs with the highest LWS (group D).

Table 1. The effect of live weights at slaughter on daily gain and carcass traits

Trait	Live weight at slaughter (x ± SE)				Significance
	up to 35 kg (group A)	35.1–40 kg (group B)	40.1–45 kg (group C)	45.1–50 kg (group D)	
Average live weight at slaughter (kg)	$33.32^{a} \pm 0.47$	$38.92^{b} \pm 0.37$	$42.53^{c} \pm 0.36$	$47.14^{d} \pm 0.39$	*
Average daily gain from birth to slaughter (g)	$193^{a} \pm 10.03$	$241^{a} \pm 8.04$	$260^{ab} \pm 7.68$	$295^{b} \pm 8.27$	*
Cold carcass weight (kg)	$14.43^{a} \pm 0.39$	$17.6^{b} \pm 0.32$	$19.25^{c} \pm 0.3$	$21.8^{d} \pm 0.32$	*
Dressing percentage (%)	$43.45^{a} \pm 0.71$	$45.23^{a} \pm 0.57$	$45.24^{a} \pm 0.55$	$46.19^{a} \pm 0.59$	ns
Weight of both legs (kg)	$5.63^{ac} \pm 0.3$	$6.2^{cd} \pm 0.24$	$6.72^{bd} \pm 0.23$	$7.18^{b} \pm 0.25$	*
Proportion of both legs (%)	$38.93^{a} \pm 1.52$	$35.22^{ab} \pm 1.22$	$35.01^{ab} \pm 1.16$	$32.81^{b} \pm 1.25$	*
Weight of right leg (kg)	$2.46^{a} \pm 0.07$	$2.9^{b} \pm 0.05$	$3.18^{c} \pm 0.05$	$3.56^{d} \pm 0.06$	*
Total weight of meat and fat from right leg (kg)	$1.87^{a} \pm 0.05$	$2.26^{b} \pm 0.04$	$2.44^{c} \pm 0.04$	$2.73^{d} \pm 0.04$	*
Total proportion of meat and fat from right leg (%)	$74.75^{a} \pm 1.0$	$76.57^{a} \pm 0.8$	$75.03^{a} \pm 0.77$	$74.69^{a} \pm 0.83$	ns
Weight of bones from right leg (kg)	$0.57^{a} \pm 0.02$	$0.65^{b} \pm 0.02$	$0.72^{b} \pm 0.02$	$0.78^{c} \pm 0.02$	*
Proportion of bones from right leg (%)	$23.4^{a} \pm 0.47$	$22.45^{a} \pm 0.38$	$22.52^{a} \pm 0.36$	$21.94^{a} \pm 0.39$	ns
Kidney (%)	$0.7^{a} \pm 0.02$	$0.64^{ab} \pm 0.02$	$0.62^{b} \pm 0.02$	$0.61^{b} \pm 0.02$	*
Kidney fat (%)	$0.34^{a} \pm 0.06$	$0.41^{a} \pm 0.05$	$0.46^{a} \pm 0.05$	$0.55^{a} \pm 0.05$	ns
Conformation score[1]	$3.54^{a} \pm 0.15$	$4.0^{a} \pm 0.12$	$3.92^{a} \pm 0.11$	$4.09^{a} \pm 0.12$	ns
Fatness score[2]	$2.03^{a} \pm 0.16$	$2.33^{ab} \pm 0.13$	$2.37^{ab} \pm 0.12$	$2.71^{b} \pm 0.13$	*

ns = not significant; SE = standard error of the mean; x = mean

*$P < 0.05$

[1]EEC Regulation 461/93, the S.E.U.R.O.P. system of classification: for statistical analysis, letters S (superior conformation) → P (poor conformation) were quantified as 6 → 1

[2]EEC Regulation 461/93, the S.E.U.R.O.P. system of classification: 1 (very low fatness) → 5 (very high fatness)

[a–d]Means with different superscripts in lines differ at $P < 0.05$

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The effect of LWS on chemical and physical characteristics of the *quadriceps femoris* muscle

Regarding the effect of LWS on chemical and physical characteristics of QFM (Table 2), in this case the LWS had a significant ($P < 0.05$) effect only on the content of intramuscular fat (IMF) and redness index (RI), when the lowest content of IMF (0.57%) was found in the group of lambs with the lowest LWS (group A) and the highest (1.21%) in the group of lambs with the highest LWS (group D). The lowest value of RI (8.53) was found in the group of lambs with the lowest LWS (group A). In contrast, the highest RI value (9.76) was found in the group of lambs with LWS that ranged from 40 to 45 kg (group C).

DISCUSSION

The effect of LWS on daily gain and carcass traits

The ADG in the period from birth to slaughter in individual groups of Zwartbles lambs gradually increased with increasing LWS, which is in accordance with the trends found by Diaz et al. (2002) in "light" lambs and Gungor et al. (2022) in "heavy" lambs. The ADGs varied depending on individual weight groups in the range from 193 to 295 g, while all these values are higher than those reported by Komprda et al. (2012) in lambs of the same weight category.

The dressing percentage (DP) is one of the most important indicators in the evaluation of carcass quality, while this indicator can also significantly affect the monetization of lambs. Most studies show that the higher the LWS, the higher the DP. This trend was also observed in the present study, but the differences in DP between all individual groups were not significant, which, however, is consistent with the data of Gungor et al. (2022); Santos et al. (2015) and Yousefi et al. (2019).

The leg generally belongs to the most valuable cuts of carcass, while most studies show that as LWS increases, the weight of leg also increases. In contrast, as regards the proportion of leg in "heavy" lambs, Gungor et al. (2022) and Kecici et al. (2021) stated that the proportion of this cut decreases with increasing LWS. Both of the abovementioned trends were also found in our study, the LWS also had a significant effect on the weights of both legs, right leg and proportion of both legs. However, the proportions of both legs in our study were slightly higher than those reported by Gungor et al. (2022) and Kecici et al. (2021). The total weight of meat and fat and the weight of bones from the right leg increased gradually with increasing LWS, which was a reflection of the gradually

Table 2. The effect of live weights at slaughter on chemical and physical characteristics of the *quadriceps femoris* muscle

Trait	Live weight at slaughter (x ± SE)				Significance
	up to 35 kg (group A)	35.1–40 kg (group B)	40.1–45 kg (group C)	45.1–50 kg (group D)	
Dry matter (%)	$21.94^{a} \pm 0.19$	$21.96^{a} \pm 0.15$	$22.14^{a} \pm 0.14$	$22.16^{a} \pm 0.15$	ns
Intramuscular fat (%)	$0.57^{a} \pm 0.1$	$0.78^{a} \pm 0.08$	$1.03^{ab} \pm 0.08$	$1.21^{b} \pm 0.08$	*
Protein (%)	$19.95^{a} \pm 0.17$	$19.63^{a} \pm 0.13$	$19.86^{a} \pm 0.13$	$19.51^{a} \pm 0.14$	ns
Ash (%)	$1.13^{a} \pm 0.01$	$1.13^{a} \pm 0.01$	$1.14^{a} \pm 0.01$	$1.14^{a} \pm 0.01$	ns
Collagen (g/kg)	$1.78^{a} \pm 0.13$	$1.69^{a} \pm 0.1$	$1.7^{a} \pm 0.1$	$1.58^{a} \pm 0.1$	ns
pH 24	$5.58^{a} \pm 0.02$	$5.62^{a} \pm 0.02$	$5.61^{a} \pm 0.01$	$5.62^{a} \pm 0.02$	ns
Water holding capacity (%)	$26.0^{a} \pm 0.78$	$25.1^{a} \pm 0.63$	$24.5^{a} \pm 0.6$	$24.27^{a} \pm 0.64$	ns
Meat colour					
L*	$46.07^{a} \pm 1.21$	$46.03^{a} \pm 0.97$	$45.64^{a} \pm 0.93$	$46.42^{a} \pm 1.0$	ns
a*	$8.53^{a} \pm 0.42$	$8.72^{ab} \pm 0.34$	$9.76^{b} \pm 0.32$	$9.31^{ab} \pm 0.35$	*
b*	$11.69^{a} \pm 0.32$	$11.65^{a} \pm 0.26$	$11.98^{a} \pm 0.25$	$11.99^{a} \pm 0.27$	ns

a* = redness index; b* = yellowness index; L* = lightness index; ns = not significant; SE = standard error of the mean; x = mean

*$P < 0.05$

[a,b]Means with different superscripts in lines differ at $P < 0.05$

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increasing weight of right legs with increasing LWS. Regarding the proportions of these tissues, LWS did not have a significant effect on these traits.

Regarding the conformation score (CS), Camacho et al. (2015) as well as Ekiz et al. (2019) stated in their studies that the higher the LWS, the significantly better the CS. A similar trend was also found in the present study, but the differences in CS between the individual groups were not significant, which is in accordance with the data of Oliveira et al. (2018). In contrast to the CS, the LWS had a significant effect on the fatness score (FS), which increased gradually depending on the increasing LWS. This trend is in line with the trends reported by Camacho et al. (2015) and Ekiz et al. (2019).

Gungor et al. (2022) as well as Ekiz et al. (2019) concluded in their studies that the higher the LWS, the higher the proportions of kidney fat. The same trend, but not a significant one, was also found in the present study, when, in our opinion, the increasing proportions of kidney fat were also a consequence of the increasing FS. On the other hand, the proportions of kidney decreased gradually with increasing LWS, which, however, is consistent with the findings of Liu et al. (2015) and Kecici et al. (2021).

The effect of LWS on chemical and physical characteristics of the *quadriceps femoris* muscle

In general, it can be stated that the content of dry matter (DM) in lamb meat ranges from 20 to 25% and is usually influenced by nutrition and weight of the lambs (Juarez et al. 2009; Liu et al. 2015). In our study, the content of DM in the QFM increased gradually with increasing LWS (from 21.94 to 22.16%) and was comparable with the DM content found by Liu et al. (2015) and Miguel et al. (2021). However, the LWS did not have a significant effect on this trait, which is in line with Liu et al. (2015); Yousefi et al. (2019); Miguel et al. (2021) or Juarez et al. (2009).

Studies by Miguel et al. (2021) or Juarez et al. (2009) show that IMF content in lamb meat is mainly influenced by nutrition, live weight, breed and gender, while its content usually ranges from 1.5 to 5%. In our study, however, all detected values of this trait were lower (from 0.57 to 1.21%). In our opinion, this fact was mainly influenced by relatively extensive nutrition of the lambs. On the other hand, it must be stated that the content of IMF increased gradually with increasing LWS. This trend is in accordance with the trends found in both "light" and "heavy" lambs by Miguel et al. (2021); Juarez et al. (2009); Hirata et al. (2019). Camacho et al. (2017) found the lowest IMF content in lambs with the lowest LWS. In our opinion, the increase in the content of IMF depending on the increasing LWS was also a reflection of the gradually increasing fatness score. At the same time, it should be added that despite the increasing IMF content, the meat from all the monitored groups of lambs can be considered lean meat, because the IMF content in all groups of lambs was significantly lower than the maximum limit of IMF content for lean meat.

In general, it can be stated that lamb meat is a relatively rich source of protein, when its content in this meat usually ranges from 18 to 25%. In the present study, protein content ranged from 19.51 to 19.95%, and the increasing LWS had no significant effect on this trait. Similar protein content and a non-significant effect of LWS on this trait were also found by Juarez et al. (2009) in "suckling" and "light" lambs, and by Yousefi et al. (2019) and Hirata et al. (2019) in "heavy" lambs.

The LWS had no significant effect on the ash content, its content ranged from 1.13 to 1.14%. Similar content of ash and an insignificant influence of LWS on this trait were found by Hirata et al. (2019) in "heavy" lambs. In conclusion to the contents of protein and ash, it is necessary to add that in all the weight groups of Zwartbles lambs, higher values of these traits were found in comparison with those reported by Komprda et al. (2012) in "heavy" lambs of specialized meat breeds. On the other hand, Li et al. (2021) found the ash content in "light" lambs at the level from 1.4 to 1.52%.

According to Miguel et al. (2021), the content of collagen, within the same species and breed, is influenced by both age and type of muscle. In their study, the effect of LWS on collagen content was also found, when the content of collagen significantly decreased as LWS increased. Collagen is also one of the most important factors that affect the tenderness of muscle (Komprda et al. 2012), the higher its content, the tougher the meat.

In our study, the increasing LWS did not have a significant effect on collagen content, its lowest value was found in the group of lambs with the highest LWS, similarly to the study conducted

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by Miguel et al. (2021). In our opinion, the above finding indicates that the tenderness of lamb meat can be at an optimal level even with relatively high LWS of lambs.

In general, the pH of lamb meat decreases after slaughter, and the rate of pH decline is mainly influenced by stress and chilling temperature. Diaz et al. (2003) showed that the pH of meat can be influenced by slaughter weight, gender, age or breed, while this trait affects meat tenderness and WHC. In our study, the LWS had no significant effect on pH 24. In particular, pH 24 ranged from 5.58 to 5.62, which are the values comparable with those reported by Kuchtik et al. (2012); Gao et al. (2022); Hirata et al. (2019). The detected values of pH 24 also indicate that the lambs were not stressed at the time of their slaughter and that pH had no significant effect on WHC.

The WHC, expressed as the proportion of the liquid expelled, similarly to the findings of Diaz et al. (2003), was not significantly affected by LWS and pH 24 had no effect on this trait. However, the values of WHC slightly decreased with increasing LWS.

Lamb meat colour is one of the most important factors in meat marketing. The Czech consumers generally prefer a pale, pink colour (Kuchtik et al. 2012). Many studies (Diaz et al. 2002; Diaz et al. 2003; Kuchtik et al. 2012) show that the values of L* (lightness), a* (redness) and b* (yellowness) vary in lamb meat because these traits can be affected by nutrition, production system, slaughter weight, breed, gender and muscle type. The results of our study mainly show that the LWS had a significant effect only on a*, while the higher the LWS, the redder the meat. Ekiz et al. (2022) also reported a significant increase of meat redness with the increasing LWS. However, the authors further noted a significant decrease in the lightness of meat. Also, Ripoll et al. (2018) found decreasing lightness of meat with increasing LWS.

Regarding the changes in L* in our study, the values of this trait were quite balanced. However, the lightest meat was found in the group of lambs with the lowest LWS, which was expected to some extent. The b* values were also quite balanced, which means that the meat was stably yellow in all weight groups. In conclusion to this part, it should be added that Komprda et al. (2012) found slightly higher values of all three meat colour traits in Zwartbles lambs with an average LWS of 38.1 kg compared to the group of lambs in our study whose LWS ranged from 35 to 40 kg.

CONCLUSION

The live weight at slaughter had a significant effect on daily gain and most of the monitored carcass traits, when both average daily gain and most weights of individual carcass traits increased with increasing LWS. In contrast, the opposite trend was found in proportions of both legs, bones from the right leg and kidney. All these proportions were highest in the group of lambs with the lowest LWS. The best conformation and fatness scores were also found in this group. On the other hand, the highest values of both traits mentioned above were found in the group with the highest LWS.

As for the effect of LWS on the physical and chemical characteristics of the *quadriceps femoris* muscle, this factor had a significant effect only on the content of IMF and on the redness index. In both cases the values of these traits increased with LWS. A trend of increasing IMF content was assumed due to increasing fatness score with increasing LWS. The IMF content in all groups was relatively low, and therefore the meat from all the groups can be considered lean. The contents of protein and ash were quite balanced in all the groups and comparable with the values of these traits in specialized meat breeds. The content of collagen and pH 24 were also balanced, which suggests that the higher LWS of lambs should not have a negative effect on meat tenderness.

In conclusion, it can be stated that even with higher LWS, in the meat of Zwartbles lambs, both the values of most carcass traits and chemical and physical characteristics are at an optimal level and often comparable with specialized meat breeds of sheep.

Conflict of interest

The authors declare no conflict of interest.

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