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The effects of sex and slaughter weight on muscle fibre characteristics and physico-chemical properties of lamb *longissimus thoracis* muscle

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The objective was to investigate the effect of sex and slaughter weight on muscle fibre and meat quality traits of *longissimus thoracis* (LT) muscle in lambs. Used were 22 female and 30 male lambs of Polish Longwool sheep from two slaughter weight groups: I – 15-20 kg and II – 25-30 kg. LT muscle samples were taken to categorize fibre types (I, IIA and IIB) according to their NADH-tetrazolium reductase activity and to determine the pH_{24}, colour L*a*b*, drip loss, thermal loss, and Warner-Bratzler shear force of meat. Fibre type percentage, fibre diameter and phenotypic correlation between fibre traits and meat quality traits were estimated. Sex and slaughter weight had no effect on muscle fibre types percentage, but affected the diameter of fibres. Likewise, pH_{24}, drip loss and thermal loss were not affected by these two factors. On the other hand, in males compared to females and with increasing slaughter weight, meat lightness decreased, whereas shear force values and diameter of muscle fibres increased. The phenotypic correlations between histological and meat quality traits were generally low. The percentage of type I, unlike that of type IIB fibres, positively correlated with meat pH_{24} and shear force, while negatively with meat lightness. Meat yellowness was positively related to percentage of type IIB fibres. A trend was found between redness and percentage of type I fibres. Moreover, increased diameter of type IIB fibres was found to be related to the increased shear force values.

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The quality of meat is markedly influenced by the biochemical characteristics of muscle. There are numerous studies on the biological mechanisms involved in the expression of meat quality traits showing the combined effects of various production factors (e.g. age, sex, feeding, breed) on both the sensory attributes (e.g. colour, texture, flavour) and biological characteristics of muscles (e.g. fibres, lipids, collagen) [Kłosowska *et al*. 1998, Dransfield *et al*. 1990, Jurie *et al*. 2005, Martinez-Cerezo *et al*. 2005]. Muscle size and weight are determined mainly by the total number of the muscle fibres as well as by their type and diameter. Most of the skeletal muscles have a heterogenic structure. Three main types of skeletal muscle fibres have been identified, generally referred to as type I (slow-twitch oxidative), IIA (fast-twitch oxidative) and IIB (fast-twitch glycolytic) fibres [Peter *et al*. 1972]. Traditionally, they are also distinguished as red (type I and IIA) and white (type IIB) fibres. The numerous biochemical and ultrastructural differences existing among the fibre types determine their distinct metabolic and physiological functions in a given muscle. Muscle metabolism is the summation of the activities of the individual muscle fibres which comprise the muscle. It is widely accepted that muscle fibre composition is an important source of variation in meat quality. Histochemical investigations on lamb muscles have revealed relationships between muscle fibre traits and meat quality [Kłosowska *et al*. 1998]. Data from the professional literature [Vergara *et al*. 1999, Diaz *et al*. 2003, Teixeira *et al*. 2005] indicate that animals' breed and body weight at slaughter could be the most important factors influencing many of the physico-chemical attributes of meat. Moreover, the sex has also been determined as the factor affecting muscle fibre type traits and thus influencing meat quality in lambs [Kłosowska *et al*. 1998].

In light of this, the purpose of the present study was to characterize the sex and slaughter weight effects on muscle fibre composition and meat quality traits of lamb meat.

Material and methods

The research was carried out in the year 2006 on sheep from the Bielany Experimental Station (Agricultural University of Cracow). In total 52 Polish Longwool lambs (22 females and 30 males) from two slaughter weight groups: I – 15-20 kg and II – 25-30 kg (26 lambs in each) were considered. Polish Longwool lambs (local breed) sucked their dams until 56 days-old. At that time they were weaned and fattened on concentrate and cereal straw offered *ad libitum*. When lambs reached the slaughter live weight, they were transported to the abattoir and slaughtered immediately after arrival, using standard commercial procedures. Carcasses were suspended by the Achilles tendon and maintained at ambient temperature (12±2°C) for 6 h to avoid cold shortening and subsequently chilled at 4°C until *post mortem* hour 24. Then all the carcasses were cut into carcass-sides and sampled.

For histochemical examination muscle samples were taken from the *longissimus thoracis* (LT) muscle 15 min *post mortem* at the level of 11^{th} thoracic vertebra, and deep within the tissue. Samples were immediately cut into 1×1×1 cm blocks (parallel to the muscle fibres), frozen in isopentane cooled with liquid nitrogen, and stored at -80°C. Transverse sections (10 µm thick) were cut at -20°C in a cryostat (Slee MEV, Germany). The activity of NADH-tetrazolium reductase was detected using specific histochemical tests [Dubovitz *et al*. 1973] to distinguish muscle fibre types I, IIA and IIB. The Multi Scan v. 14.02 computer image analysis software was used to determine percentage and diameter of muscle fibres. A minimum of 300 fibres were counted in each section.

Samples for meat quality assessment were taken from the LT (5^{th}-10^{th} rib level) of both sides of the carcass and were evaluated after storage of meat for 24 h at +4°C. The meat colour was assessed by the L* (lightness), a* (redness) and b* (yellowness) system [CIE 1976] using Minolta colorimeter (Chroma Meter CR-310, Minolta Camera C., Osaka, Japan). The sample values were means from three measurements. The pH was measured using a Matthäus (Germany) pH meter with a glass electrode standardized for pH 4.01 and 7.0 according to Polish Standard PN-77/a-82058 with automatic correction for muscle temperature. Drip loss was measured in duplicate samples. After thorough weighing (e=0.001g), the samples were placed in sealed containers. After 24 h the samples were removed, towel-dried, and weighed again. For measurements of tenderness, samples of meat (80 g) were packed separately in plastic bags and cooked in a water bath in 95°C until core temperature reached 80°C. Then the samples were cooled, weighed for thermal loss determination, and prepared for the shear force measurements. One core 1.27 cm in diameter was excised from each sample parallel to the muscle fibre orientation, through the thickest portion of the cooked muscle. Shear force was determined as maximum force (N) perpendicular to the fibres, using INSTRON 5542 equipped with a Warner-Bratzler blade.

Statistical verification of results was done by the analysis of variance, according to the following model:

$$Y_{ijk} = \mu + G_{i(1..2)} + W_{j(1..2)} + GW_{ij} + E_{k(ij)}$$

where:

μ – arithmetic mean;

G_i – effect of sex;

W_j – effect of slaughter weight;

GW_{ij} – interaction sex × slaughter weight;

$E_{k(ij)}$ – residual experimental error.

The Newman-Keuls test was used to assess differences between means. No sex × slaughter weight interaction was identified, so only main effects are reported and discussed.

Additionally, phenotypic correlations were estimated between muscle fibre characteristics and meat quality traits.

Results and discussion

The arithmetic means and results of analysis of variance for the effect of sex and slaughter weight on muscle fibre characteristics and meat quality traits of LT muscle in lambs are presented in Table 1. Sex had no effect on muscle fibre percentage,

Table 1. Percentage (%) and diameter (µm) of muscle fibres of three types and physico-chemical properties of *longissimus thoracis* muscle as relatet to lambs' sex and live weight at slaughter

Item	Sex				Live weight at slaughter (kg)			
	males (n=30)	females (n=22)	SE	P-value	15-20 (n=26)	25-30 (n=26)	SE	P-value
Fibre type percentage (%)								
type I	14.4	13.7	0.97	0.09	13.8	14.5	0.85	0.26
type II A	34.4	35.6	1.08	0.23	33.9	34.1	0.97	0.08
type II B	51.2	50.7	1.89	0.18	52.3	51.4	1.59	0.13
Fibre diameter (µm)								
type I	29.61	28.11	0.85	0.28	24.31	31.12	0.63	0.03
type II A	37.52	34.73	0.61	0.04	32.57	39.76	0.74	0.01
type II B	46.06	40.74	0.83	0.03	42.15	48.61	0.79	0.01
pH_{24}	5.63	5.65	0.03	0.52	5.63	5.67	0.02	0.27
L*	42.55	40.54	0.51	0.02	43.13	39.92	0.65	0.02
a*	18.78	18.29	0.43	0.78	18.11	18.95	0.46	0.49
b*	6.16	5.87	0.52	0.09	6.33	5.40	0.25	0.02
Drip loss (%)	0.45	0.42	0.03	0.39	0.43	0.44	0.02	0.64
Thermal loss (%)	26.47	26.08	0.94	0.41	26.71	25.47	0.91	0.88
Shear force (N)	41.83	37.58	0.97	0.03	36.16	42.33	0.71	0.04

but it affected the diameter of fibres. In this case, males had larger diameter of type IIB and IIA fibres than females. A similar tendency was observed earlier in pigs [Wojtysiak *et al*. 2004] and in cattle [Wojtysiak *et al*. 2003]. On the other hand, these results still remain open to criticism, as some earlier studies in pigs did not report any significant differences between males and females in fibre type diameter [Sośnicki 1987]. Meanwhile, Larzul *et al*. [1997] observed larger diameter of type IIB fibres in females compared to male pigs and suggested this could be of biological importance in that females exhibit a higher lean per cent of carcass and higher loin eye area. It is well known that muscle fibre percentage and fibre diameter in animals are breed- and even line-specific. Thus, the presence or lack of differences in fibre type composition and size can be interpreted not only as a sex, but also as a breed effect. Moreover, the present study showed that increasing weight at slaughter affected diameter of all examined muscle fibre types, heavier lambs exhibiting larger fibres than the lighter ones (Fig. 1 and 2). This is in accordance with the findings of Kłosowska *et al*. [1998] and Jurie *et al*. [2005]. Additionally, in the current study, as in that by Kłosowska

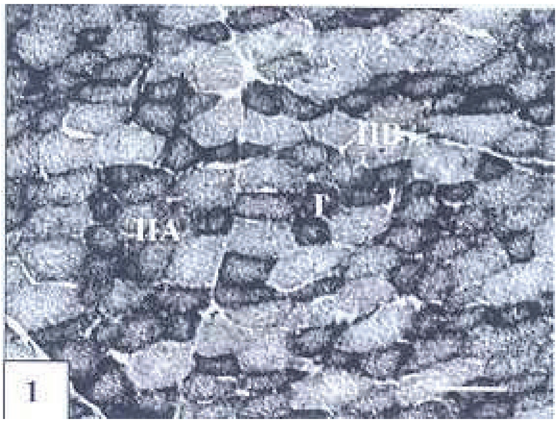

Fig. 1. Exemplary cross section of *longissimus thoracis* muscle of a lamb from 15-20 kg slaughter weight group. NADH-tetrazolium reductase activity: I – red fibres, IIA – intermediate fibres, IIB – white fibres. Bar = 50µm.

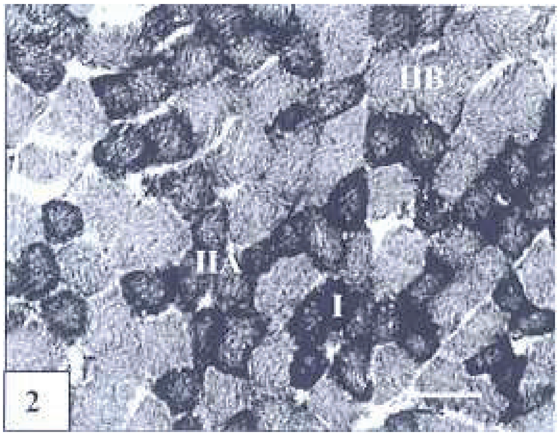

Fig. 2. Exemplary cross section of *longissimus thoracis* muscle of a lamb from 25-30 kg slaughter weight group. NADH-tetrazolium reductase activity: I – red fibres, IIA – intermediate fibres, IIB – white fibres. Bar = 50 µm.

et al. [1998] slaughter weight had no effect on fibre type percentage. However, the authors, who examined Merino and hybrid lambs, showed that with age and increasing body weight, there was a trend towards decreasing per cent of type I and IIA and increasing of type IIB fibres in Merino lambs. Such a trend was not found in hybrid lambs. The absence of any effect of slaughter weight on the percentage of different fibre types observed in the current study in LT corroborates the fact that muscle fibre differentiation is mainly completed during the early postnatal life.

When the meat quality traits were compared, no differences occurred in pH_{24} between slaughter weights of animals. Our results are similar to those reported by

Vergara *et al*. [1999] and Martinez-Cerezo *et al*. [2005]. However, Beriain *et al*. [2000] and Teixeira *et al*. [2005] showed that slaughter weight had no effect on meat pH measured 1h post slaughter, but when the measurements were made 24 h post slaughter, the heavy lambs showed higher pH values. In addition, in the present study, in accordance with Vergara and Gallego [1999], Fogarty *et al*. [2000], Diaz *et al*. [2003] and Teixeira *et al*. [2005], no significant differences in pH_{24} were identified between males and females. On the other hand, marked differences were noted in the meat colour as affected by sex. L* values were higher in males than in females, being in accordance with Teixeira *et al*. [2005]. In contrast, Diaz *et al*. [2003] did not show any effect of sex on meat colour parameters in sucking lambs. Moreover, the present study showed that slaughter weight affected meat colour. As body weight increased, meat lightness (L*) and yellowness (b*) decreased. This corroborates the findings of Sanudo *et al*. [1997] who compared three carcass weights from the Rasa Aragonesa breed. Similarly, Vergara *et al*. [1999], Fogarty *et al*. [2000] and Teixeira *et al*. [2005] showed an effect of slaughter weight on meat lightness (L*) and yellowness (b*). Sanudo *et al*. [1997] suggested that light lambs have lower yellow index probably due to the milk diet of low-iron content. Concurrent to our findings, Dransfield *et al*. [1990], Diaz *et al*. [2003] and Martinez-Cerezo *et al*. [2005] reported that body weight had an effect also on the meat redness (a*) index.

In general, no marked differences were found in drip loss and thermal loss between sexes as well as between slaughter weights. On the other hand, shear force was influenced by both factors. The lower values of shear force were found in females than in males. In contrast, the earlier study by Teixeira *et al*. [2005] did not show any differences in shear force between males and females. On the other hand, our present results are similar to those of Sanudo *et al*. [1997], Beriain *et al*. [2000] and Teixeira *et al*. [2005], who found that heavier lambs had higher shear force values than lighter lambs.

The presence (or lack) of differences in meat shear force values is associated not only with sex and slaughter weight of animals, but probably with many other factors (e.g. collagen content, sarcomere length and calpastatin content), which contribute to the tenderness of muscle [Wheeler *et al*. 2000].

Phenotypic correlations between muscle fibre traits and physico-chemical properties of lamb LT muscle are presented in Table 2.

The pH at 24 h was negatively correlated with percentage of type IIB fibres and positively with type I percentage. Another important quality parameter, *i.e*. lightness (L*), occurred to be negatively related to type I muscle fibre per cent and positively to the per cent of type IIB fibre. Moreover, the phenotypic correlation between type I fibre content and redness (a*) was found to be positive. Similar tendencies ocurred between the per cent of type IIB fibres and yellowness (b*). On the other hand, phenotypic correlations between muscle fibre diameter and meat pH_{24}, colour parameters (L*, a*, b*) were not significant. Similarly, drip loss and thermal loss of LT muscle were not found correlated with muscle fibre traits. The fact that muscle fibre traits (including

Table 2. Coefficients of phenotypic correlation between fibre types and physico-chemical properties of *loggissimus thoracis* muscle in lambs

Correlated traits	pH24	L*	a*	b*	Drip loss	Thermal loss	Shear force
Fibre type percentage (%)							
type I	0.08*	-0.12	0.11*	-0.09	-0.14	0.08	0.13*
type II A	0.13	-0.09	-0.16	-0.06	-0.19	0.11	-0.06
type II B	-0.15*	0.17**	-0.08	0.16*	0.28	-0.16	-0.09*
Fibre diameter (µm)							
type I	0.08	-0.07	-0.14	-0.16	-0.12	-0.12	-0.06
type II A	-0.17	0.06	-0.18	-0.19	0.08	-0.15	-0.08
type II B	0.18	-0.14	-0.17	-0.14	0.10	-0.13	0.02*

*P<.05 **P<0.01.

different fibre type proportion), may be a source of variation in meat quality and especially in meat colour, confirmed the earlier results of Larzul *et al*. [1997].

The phenotypic correlation coefficients between muscle fibre traits and shear force values generally occurred low. Percentage of type IIB fibres, unlike that of type I, was negatively correlated with shear force values, similarly to the results reported by Ryu and Kim [2005]. Moreover, diameter of type IIB fibres was positively correlated with shear force values, confirming the data of O'Halloran *et al*. [1997]. However, these results still remain open to criticism as in the literature diverse opinions on the subject can be found [Wojtysiak and Migdał 2007]. Sazili *et al*. [2005] claim that it is unclear how muscle fibre composition and meat tenderness are correlated and a number of inconsistent reports exist. Renand *et al*. [2001] in a study with bulls showed a positive correlation between meat toughness and per cent of type I fibres and sensory tenderness as well as a negative correlation between per cent of type IIB fibres and tenderness.

Summarizing, muscle fibre per cent was not found affected by sex and slaughter weight of lambs. Also, neither pH_{24} nor drip loss and thermal loss were influenced by both examined factors. However, as body weight increased and in males compared to females, meat lightness decreased, whereas shear force and diameter of muscle fibres increased.

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Wpływ płci i ubojowej masy ciała na charakterystykę włókien mięśniowych i cechy fizykochemiczne mięśnia *longissimus thoracis* jagniąt

S t r e s z c z e n i e

Badania przeprowadzono na jagniętach polskiej owcy długowełnistej (22 maciorki i 30 tryczków) ubijanych przy masie ciała 15-20 oraz 25-30 kg. Na podstawie aktywności dehydrogenazy NADH-TR w mięśniu *longissimus thoracis* (LT) zidentyfikowano trzy typy włókien mięśniowych (I, IIA i IIB). Określono udział procentowy i średnicę włókien mięśniowych wszystkich typów oraz pH_{24}, barwę w skali L* a* b*, wyciek swobodny, straty termiczne oraz siłę cięcia badanego mięśnia. Nie stwierdzono istotnego wpływu płci ani masy ciała przy uboju na udział procentowy włókien poszczególnych typów w LT, wykazano natomiast wpływ obu tych czynników na średnicę włókien. Nie udowodniono także zależności pH_{24}, wycieku swobodnego oraz strat termicznych od płci i ubojowej masy ciała jagniąt. Z drugiej strony, w przypadku samców w porównaniu z samicami, a także wraz ze wzrostem masy ciała samców, obniżały się wartości parametru L*, podczas gdy siła cięcia i średnica włókien mięśniowych rosły. Analizowane fenotypowe korelacje między badanymi cechami włókien mięśniowych a jakością mięsa okazały się niskie. Udział procentowy włókien typu I, w przeciwieństwie do włókien typu IIB, korelował dodatnio z pH_{24} i siłą cięcia oraz ujemnie z wartościami parametru L*. Dodatnie zależności wykazano także między wartościami parametru b* a udziałem procentowym włókien typu IIB. Podobne tendencje oszacowano dla zależności między parametrem a* a udziałem procentowym włókien typu I. Ponadto, wraz ze wzrostem średnicy włókien typu IIB rosła istotnie wartość siły cięcia.