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COMPARATIVE ANALYSIS OF THE SUSCEPTIBILITY OF SELECTED MUSCLES OF PIETRAIN, DUROC AND POLISH LARGE WHITE×POLISH LANDRACE PIGS TO MASSAGE-INDUCED CHANGES*

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Muscles of Pietrain, Duroc and PLW×PL pigs show differences in structure, texture and rheological properties. The muscles that showed higher: hardness, springiness, gumminess, viscosity, and lower chewiness were characterised by thicker connective tissue (both peri- and endomysium), a higher muscle fibre cross-section area and a lower amount of intramuscular fat. Those muscles were also the least susceptible to massage--induced changes in their structural elements and textural parameters. The porkers whose muscles showed higher values of textural parameters had larger structural elements and were less susceptible to massaging.

INTRODUCTION

Texture is one of numerous meat quality attributes and, by definition, reflects meat structure [Bourne, 1982]. The opinion prevailing among researchers is that the harder the meat, the thicker its fibres and connective tissue, and the lower its content of intramuscular fat [Tyszkiewicz, 1979; Karlsson, 1994; Liu *et al.*, 1996; Fang *et al.*, 1999; Wichłacz *et al.*, 1996]. Consequently, such meat may be less susceptible to various processing technologies which, by disrupting meat structure, shape the final product's texture. Muscle massaging is one of such processes; massaging substantially reduces muscle hardness, thereby increases its tenderness [Tyszkiewicz, 1995]. Softening of muscle tissue is attributed to changes in meat structural elements, involving, *i.a*. loosening of fibre structure [Wajdzik, 1997; Xaragayo *et al.*, 1998], fibre swelling, increased water holding capacity [Rejt *et al.*, 1978; Tyszkiewicz, 1997] and increased collagen solubility [Cierach, 1996; Połczyńska & Szmańko, 1996].

The aim of the present study was to compare the susceptibility to massaging of three muscles (L, SM, and BF) taken from pure-bred (Pietrain and Duroc) and crossbred (Polish Large White × Polish Landrace – PLW×PL) porkers.

MATERIALS AND METHODS

Muscles of 30 porkers were examined. Twenty of them were purebreds: 10 Pietrain and 10 Duroc, and the remaining 10 were crossbreds of Polish Large White × Polish Landrace (PLW×PL). The porkers were slaughtered at 100±2 kg. Analyses were made on the following three muscles excised from the right half-carcass of each porker: *M. longissimus* (L), *M. semimebranosus* (SM), and *M. biceps femoris* (BF).

Following the pH_{24} measurement, each muscle was halved. Both halves were weighed and one was injected with curing brine (11% NaCl, 1.5% curing mixture, 87.5% water) in the amount of 25% by weight, and massaged in a vacuum massaging apparatus (-0.8 atm, 6 rpm drum speed) for 8 h (the 0.5 h massaging to 0.5 h rest cycle). The effective massaging time was 4 h. The unmassaged half of the muscle was a control sample.

A slab was cut out from the central part of both massaged and unmassaged muscles. Three samples were collected from the central part of the slab. Those samples intended for structure analysis were processed with the paraffin method, microtome-cut into $10\pm1\ \mu$m slices, placed on glass slides, stained with hematoxylin and eosin, and sealed with Canada balsam [Burck, 1975]. Histological analyses of the slides, involving measurements of the connective tissue (peri- and endomysium) thickness, muscle fibre cross-section area, and intramuscular fat content, were carried out with the MultiScan v. 6.02 computer image analysis software.

Both parts of the muscle (massaged and unmassaged) were weighed, packed separately in plastic bags, and scalded (in 75°C water) in a steam-cooker until the temperature in the muscle centre reached 68°C. After cooling down and re-weighing, the samples were stored for 12 h in a refrigerator (4°C). Subsequently, the muscles were cut across the fibre length to produce 20±1 mm thick slices. Texture and rheological measurements were performed in an Instron 1140 apparatus by applying the TPA test (0.96 cm punch diameter, 80% deformation) and relaxation test (1.26 cm punch diameter, 10% deformation for 120 s), at a crosshead rate of 50 mm/min. The TPA test allowed calculating the values of the following parameters: hardness, cohesiveness,

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springiness, chewiness and gumminess [Bourne, 1982]. The relaxation test allowed calculating the modulus of elasticity and the modulus of viscosity by the generalised Maxwell model, consisting of three parallel elements: the Hooke elastic body and two Maxwell viscous-elastic bodies; and expressed by the following equation:

$$\sigma = \varepsilon \cdot \left[E_0 \cdot \exp\left(\frac{-E_1 \cdot t}{\mu_1}\right) + E_2 \cdot \exp\left(\frac{-E_2 \cdot t}{\mu_2}\right)\right]$$

where: δ, stress (kPa); ε, deformation; E_0, Hooke body elastic modulus (kPa); E_1, E_2, Maxwell body elastic moduli 1 and 2; μ_1, μ_2, Maxwell body viscous moduli 1 and 2 (kPa × s); t, time

For each sample, the sum of elastic moduli ($E_0 + E_1 + E_2$) and the sum of viscous moduli ($\mu_1 + \mu_2$) were calculated.

Thermal drip from unmassaged and massaged samples was calculated in per cent from the difference in muscle weight before and after thermal processing.

Statistical treatment of data (STATISTICA v. 5.5A) involved the calculation of the mean values for each muscle and each breed of porkers. The Student's t-test (at $\alpha = 0.05$) was used to determine the differences between the muscles within a breed and between the breeds for each muscle.

RESULTS AND DISCUSSION

The results of the analyses performed show that the muscles of the three pig breeds compared differ in: texture (Table 1), rheological properties (Table 2), and amount of thermal drip (Table 3). The Pietrain pig muscles were characterised by the highest: hardness, cohesiveness, springiness, gumminess, and chewiness; they produced the highest viscous modulus and the highest thermal drip. The lowest values of textural parameters, as well as the smallest thermal drip, were typical of the Duroc muscles. The values of textural parameters of the PLW × PL muscles, although intermediate with respect to those shown by the purebreds, were more similar to the Duroc than Pietrain muscles. No significant inter-breed differences in pH_{24} were detected in any muscle (Table 2).

Simultaneously, particular muscles within each breed were found to differ in their: texture, rheological properties

TABLE 1. Mean values of textural parameters of the L, SM, and BF muscles of PLW×PL, Duroc and Pietrain porkers.

Texture attribute	PLW×PL			DUROC			PIETRAIN		
	L	SM	BF	L	SM	BF	L	SM	BF
CONTROL SAMPLES									
Hardness (N)	68.5^{a}_{1}	75.2^{a}_{1}	96.8^{b}_{1}	59.6^{a}_{2}	67.9^{a}_{2}	90.6^{b}_{1}	80.5^{a}_{3}	85.3^{a}_{2}	135.2^{b}_{2}
Cohesiveness (-)	0.410^{a}_{1}	0.402^{a}_{1}	$0.375^{a}_{1,2}$	0.390^{a}_{1}	0.397^{a}_{1}	0.360^{a}_{1}	0.450^{a}_{2}	0.425	0.426^{a}_{2}
Springiness (cm)	1.12^{a}_{1}	1.16^{a}_{1}	1.19^{a}_{1}	1.15^{a}_{1}	1.16^{a}_{1}	$1.21^{b}_{1,2}$	1.11^{a}_{1}	1.19^{a}_{1}	1.26^{b}_{2}
Gumminess (N)	31.5^{a}_{1}	35.1^{a}_{1}	43.2^{b}_{1}	26.7^{a}_{1}	31.3^{a}_{1}	39.5^{b}_{1}	40.2^{a}_{2}	43.1^{a}_{2}	72.6^{b}_{2}
Chewiness (N×cm)	28.1^{a}_{1}	30.2^{a}_{1}	36.3^{b}_{1}	23.2^{a}_{1}	27.0^{a}_{1}	32.6^{b}_{1}	36.2^{a}_{2}	36.3^{a}_{2}	57.6^{b}_{2}
MASSAGED SAMPLES									
Hardness (N)	40.5^{a}_{1}	42.4^{a}_{1}	65.8^{b}_{1}	30.6^{a}_{2}	36.7^{a}_{2}	58.1^{b}_{2}	63.8^{a}_{3}	69.9^{a}_{3}	123.2^{b}_{3}
Cohesiveness (-)	0.380^{ax}_{1}	0.340^{b}_{1}	0.335^{bx}_{1}	0.380^{ax}_{1}	0.381^{ax}_{2}	0.350^{bx}_{1}	0.415^{a}_{2}	0.390^{abx}_{1}	0.370^{bx}_{2}
Springiness (cm)	1.20^{a}_{1}	1.26^{b}_{1}	1.29^{b}_{1}	1.33^{a}_{2}	1.35^{a}_{2}	1.41^{b}_{2}	1.15^{ax}_{1}	1.24^{bx}_{1}	1.30^{bx}_{1}
Gumminess (N)	18.5^{a}_{1}	18.2^{a}_{1}	28.4^{b}_{1}	15.5^{a}_{1}	18.9^{b}_{1}	28.7^{c}_{1}	30.4^{a}_{2}	33.8^{a}_{2}	59.3^{b}_{2}
Chewiness (N×cm)	15.4^{a}_{1}	14.4^{a}_{1}	22.0^{b}_{1}	11.6^{a}_{1}	14.0^{a}_{1}	20.3^{b}_{1}	26.5^{a}_{2}	27.3^{a}_{2}	45.6^{b}_{2}

a, b – samples in a row, denoted by different letters, were significantly different within a breed ($p \leq 0.05$); 1,2 – samples in a row, denoted by different numerals, were significantly different between breeds ($p \leq 0.05$); x – difference between massaged sample and the control was not-significant ($p \geq 0.05$)

TABLE 2. Rheological properties of the L, SM, and BF muscles of PLW×PL, Duroc and Pietrain porkers.

Rheological attribute	PLW×PL			DUROC			PIETRAIN		
	L	SM	BF	L	SM	BF	L	SM	BF
CONTROL SAMPLES									
Sum of elastic moduli (kPa)	250^{a}_{1}	330^{b}_{1}	$300^{ab}_{1,2}$	240^{a}_{1}	360^{b}_{1}	359^{b}_{1}	310^{a}_{2}	370^{a}_{2}	250^{b}_{2}
Sum of viscous moduli (kPa×s)	63500^{a}_{1}	72100^{a}_{1}	123000^{b}_{1}	60250^{a}_{1}	68200^{a}_{1}	115480^{b}_{1}	96540^{a}_{2}	88100^{a}_{2}	162870^{b}_{2}
Relaxation time (s)	254^{a}_{1}	218^{a}_{1}	410^{b}_{1}	251^{a}_{1}	189^{a}_{1}	322^{b}_{1}	311^{a}_{2}	238^{b}_{1}	651^{c}_{2}
MASSAGED SAMPLES									
Sum of elastic moduli (kPa)	375^{a}_{1}	490^{b}_{1}	465^{b}_{1}	420^{a}_{1}	530^{b}_{1}	626^{c}_{2}	319^{ax}_{2}	375^{bx}_{2}	260^{cx}_{3}
Sum of viscous moduli (kPa×s)	47900^{a}_{1}	61300^{abx}_{1}	91250^{b}_{1}	46850^{a}_{1}	61200^{abx}_{1}	82680^{b}_{1}	57980^{a}_{2}	65590^{a}_{2}	99800^{b}_{2}
Relaxation time (s)	127^{a}_{1}	125^{a}_{1}	196^{b}_{1}	112^{a}_{1}	115^{a}_{1}	132^{b}_{1}	182^{a}_{2}	190^{a}_{2}	384^{b}_{2}

a, b – samples in a row, denoted by different letters, were significantly different within a breed ($p \leq 0.05$); 1,2 – samples in a row, denoted by different numerals, were significantly different between breeds ($p \leq 0.05$); x – difference between massaged sample and the control was not-significant ($p \geq 0.05$)

TABLE 3. Mean values of pH_{24} and thermal drip of the L, SM, and BF muscles of PLW×PL, Duroc and Pietrain porkers.

Traits	PLW×PL			DUROC			PIETRAIN		
	L	SM	BF	L	SM	BF	L	SM	BF
pH_{24}	5.60^{a}_{1}	5.65^{a}_{1}	5.70^{b}_{1}	5.70^{a}_{1}	5.65^{a}_{1}	5.75^{b}_{1}	5.55^{a}_{1}	5.60^{a}_{1}	5.65^{b}_{1}
Cooking loss (%)	13.8^{a}_{1}	13.6^{a}_{1}	16.2^{b}_{1}	12.9^{a}_{1}	12.8^{a}_{1}	14.6^{b}_{1}	27.2^{a}_{2}	28.0^{a}_{2}	31.4^{b}_{2}
Cooking loss after massaging (%)	9.2^{a}_{1}	7.1^{b}_{1}	13.6^{c}_{1}	9.4^{a}_{1}	5.9^{b}_{1}	12.9^{c}_{1}	25.7^{ax}_{2}	19.5^{b}_{2}	28.9^{cx}_{2}

a, b – samples in a row, denoted by different letters, were significantly different within a breed ($p \leq 0.05$); 1, 2 – samples in a row, denoted by different numerals, were significantly different between breeds ($p \leq 0.05$); x – difference between massaged sample and the control was not-significant ($p \geq 0.05$)

TABLE 4. Mean values of structural elements of the L, SM, and BF muscles of PLW×PL, Duroc and Pietrain porkers.

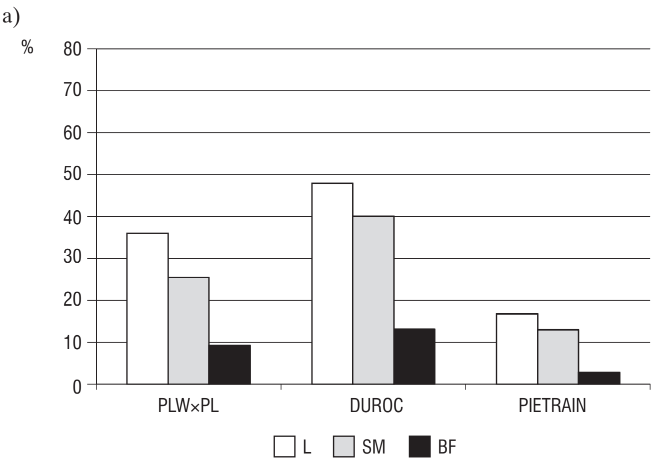
Structure attribute	PLW×PL			DUROC			PIETRAIN		
	L	SM	BF	L	SM	BF	L	SM	BF
CONTROL SAMPLES									
Perimysium thickness (μm)	12.34^{a}_{1}	13.95^{ab}_{1}	$16.98^{b}_{1,2}$	8.25^{a}_{2}	10.68^{b}_{2}	15.24^{c}_{1}	16.53^{a}_{1}	17.82^{a}_{3}	19.95^{a}_{2}
Endomysium thickness (μm)	1.38^{a}_{1}	$1.42^{a}_{1,2}$	$1.50^{a}_{1,2}$	1.10^{a}_{2}	1.12^{a}_{1}	1.28^{b}_{1}	1.60^{a}_{1}	1.64^{a}_{2}	1.89^{b}_{2}
Fibre cross-section (μm^2)	1111^{a}_{1}	1520^{b}_{1}	1682^{b}_{1}	1220^{a}_{1}	1867^{b}_{2}	2381^{c}_{2}	2168^{a}_{2}	2350^{a}_{3}	3062^{b}_{3}
Area of intramuscular fatty tissue (μm^2)	261200^{a}_{1}	385540^{a}_{1}	175950^{a}_{1}	315200^{a}_{1}	542150^{a}_{1}	230780^{a}_{1}	110000^{a}_{1}	260100^{a}_{1}	95200^{a}_{1}
MASSAGED SAMPLES									
Perimysium thickness (μm)	16.78^{a}_{1}	$17.51^{ax}_{1,2}$	18.56^{ax}_{1}	12.20^{a}_{2}	14.96^{b}_{1}	17.23^{cx}_{1}	19.31^{a}_{1}	20.13^{a}_{2}	20.51^{ax}_{1}
Endomysium thickness (μm)	1.25^{ax}_{1}	$1.29^{abx}_{1,2}$	1.45^{bx}_{1}	0.98^{ax}_{2}	1.06^{abx}_{2}	1.21^{bx}_{2}	1.50^{ax}_{1}	1.56^{ax}_{2}	1.82^{ax}_{3}
Fibre cross-section (μm^2)	1568^{a}_{1}	1972^{b}_{1}	2046^{bx}_{1}	1952^{a}_{2}	2846^{b}_{2}	3174^{b}_{2}	2810^{a}_{3}	2850^{a}_{2}	3300^{ax}_{2}

a, b – samples in a row, denoted by different letters, were significantly different within a breed ($p \leq 0.05$); 1,2 – samples in a row, denoted by different numerals, were significantly different between breeds ($p \leq 0.05$); x – difference between massaged sample and the control was not-significant ($p \geq 0.05$)

and thermal drip (Tables 1, 2, 3). Regardless of the breed, BF proved to be the hardest, most springy, gummiest, most viscous, and least chewy; it produced the largest thermal drip and the highest pH_{24}. The lowest values of textural parameters were recorded for L, whereas SM showed intermediate values; and L and SM did not differ significantly in the amount of thermal drip and pH_{24} (Table 3).

A comparison of muscle structure between the breeds revealed that the Pietrain muscles had the thickest peri- and endomysium, the thickest muscle fibres, and the lowest amount of intramuscular fat. The thinnest connective tissue and the largest amount of intramuscular fat were typical of the Duroc muscles, whereas the PLW × PL muscles consisted of the thinnest fibres (Table 4). Other authors who compared different pig breeds in terms of muscle structure also reported inter-breed differences in muscle fibre thickness [Skorjanc *et al.*, 1994], amount of collagen [Lan *et al.*, 1993], and amount of intramuscular fat [Jacyno *et al.*, 1995; Enfält *et al.*, 1997; Falkowski & Milewska, 1999].

The data obtained allow concluding that the harder or the more springy a muscle, the larger its fibre cross-section area and the thicker its peri- and endomysium. This conclusion is supported by data reported by other authors who found muscles with larger fibres to be harder [Prost, 1975; Tyszkiewicz, 1979; Lachowicz *et al.*, 1998 a, b], to have thicker connective tissue [Pełczyńska, 1979; Liu *et al.*, 1996; Fang *et al.*, 1999], and to contain less intramuscular fat [Dransfield, 1977; Wichłacz *et al.*, 1996; Kirchheim *et al.*,



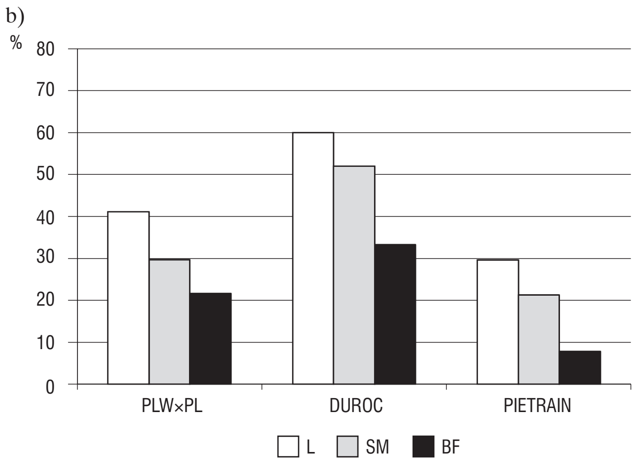


FIGURE 1. Effects of massaging on changes, expressed as percentages, in: a) perimysium thickness; b) muscle fibre cross-section area in the muscles of the PLW×PL, Duroc and Pietrain porkers examined.

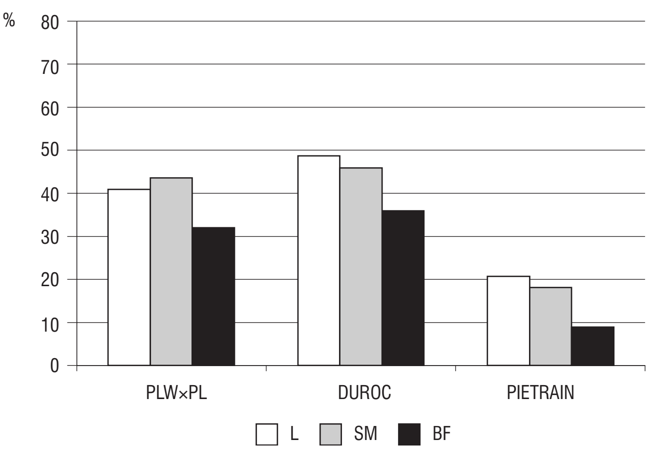
1997]. Lachowicz *et al.* [1998 a, b] found the muscle fibre diameter to be positively correlated with elastic and viscous moduli. They also showed that the higher the intramuscular fat content, the lower the relaxation test results.

The present work shows that the pigs whose muscles were characterised by a more delicate structure, with smaller structural elements, were more susceptible to massage-induced changes in those elements (Table 4). The muscles of pure-bred Duroc pigs, with the thinnest connective tissue and the largest amount of intramuscular fat, were the most susceptible to structural changes. For example, their perimysium thickness increased by about 13–48%, depending on the muscle, and the fibre cross-section area increased by about 33–60% (Figure 1). On the other hand, muscles of Pietrain porkers, with the thickest connective tissue, the largest fibre cross-section area and the lowest amount of intramuscular fat, were the most resistant to massage-induced changes.

A similar pattern emerged from inter-breed comparisons of the muscles (Table 4). The L muscle, with fibres having the smallest cross-section area, as well as the SM one, with the thinnest connective tissue and the highest amount of intramuscular fat, showed the most extensive massage-induced changes. The muscle fibre cross-section area in L increased, depending on the breed, by about 29–60%, while the perimysium thickness in SM increased by about 13–40%. The BF muscle which, regardless of the breed, showed the thickest connective tissue, the largest fibre cross-section area, and the smallest amount of intramuscular fat, was the least responsive to massaging effects. Its fibre cross-section area and perimysium thickness increased by about 8–30 and 3–9%, respectively. Monin *et al.* [1997], Knight *et al.* [1989], and Minelli *et al.* [1994] explained differences in the susceptibility of various muscles to conditioning by the differences in the histological structure of the muscles. Numerous authors, *i.a*. Knight *et al.* [1989] and Katsaras & Budras [1993], are of the opinion that connective tissue forms a barrier to brine penetration, thereby limiting muscle fibre swelling. On the other hand, by loosening muscular tissue, intramuscular fat facilitates brine access to fibres [Albrech *et al.*, 1996], which most probably results in their more extensive changes.

The next result of higher susceptibility to massaging of a muscle is a more extensive change in its textural parameters and rheological properties; the same conclusion applies to differences between the breeds (Figures 1–3). As a result of massaging, muscle hardness in the Duroc was reduced by 36–49%, whereas a 9–21% reduction was recorded in the

a)



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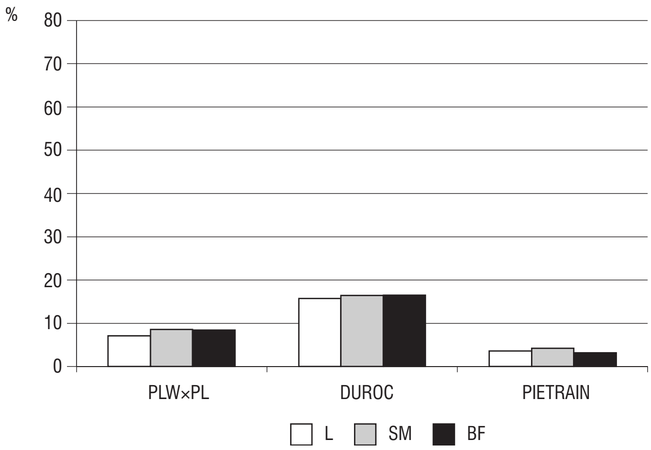
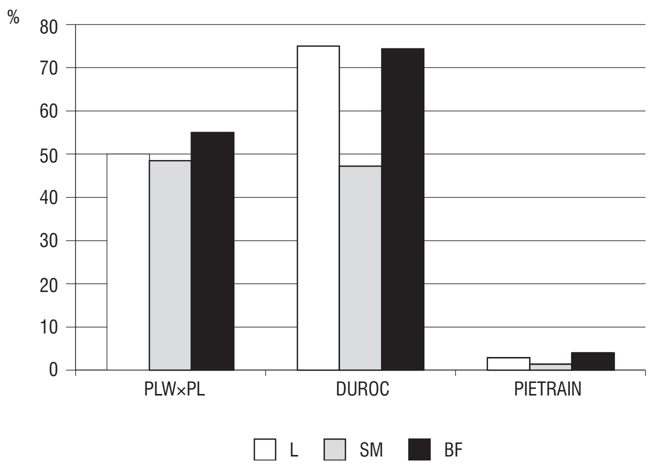


FIGURE 2. Effects of massaging on changes, expressed as percentages, in: a) hardness; b) springiness of muscles of PLW×PL, Duroc, and Pietrain porkers examined.

a)



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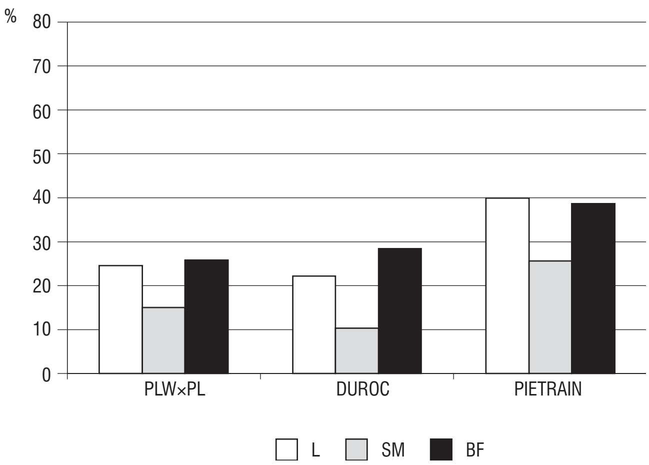

FIGURE 3. Effects of massaging on changes, expressed as percentages, in: a) elastic modulus; b) viscous modulus of muscles of PLW×PL, Duroc, and Pietrain porkers examined.

Pietrain. The L and SM muscles, regardless of the breed, showed a larger (by *ca*. 30% in the Duroc and PLW × PL, and by *ca*. 50% in the Pietrain) drop in hardness than the BF muscle.

CONCLUSIONS

1. The muscles examined were found to differ in the size of their structural elements as well as in their textural parameters and susceptibility to massaging, both within a breed and between the breeds.

2. The muscles of Duroc porkers were the most responsive to massaging; the least susceptible were the muscles of Pietrain porkers.

3. Of the muscles examined, regardless of the breed, L and SM muscles were the most responsive to massaging. Those muscles showed the most delicate structure and texture.

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PORÓWNANIE PODATNOŚCI NA MASOWANIE WYBRANYCH MIĘŚNI ŚWIŃ RASY PIETRAIN, DUROC ORAZ MIESZAŃCÓW WBP×PBZ

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W badaniach stwierdzono zróżnicowanie struktury, tekstury i właściwości reologicznych mięśni świń rasy pietrain, duroc i mieszańców wbp×pbz. Mięśnie bardziej twarde, sprężyste, gumowate, lepkie i trudniej żuwalne charakteryzowały się grubszą tkanką łączną (peri i endomysium), większą powierzchnią włókna mięśniowego oraz mniejszą zawartością tłuszczu śródmięśniowego. Jednocześnie były one najmniej podatne na zmiany elementów struktury i parametrów tekstury w czasie masowania. Grupy tuczników, których mięśnie wykazywały wyższe wartości parametrów tekstury charakteryzowały się większymi elementami struktury oraz gorszą podatnością na proces masowania.