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THE SUITABILITY OF USING BROILER RABBIT LEATHERS IN GLOVES AND FOOTWEAR MANUFACTURING

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Abstract: The aim of the study was to learn about the structure of broiler rabbit skins, with the possibility of using them as dressing for gloves and shoe uppers. The histological structure, organoleptic and rheological properties of leathers such as tensile and puncture strength, energy state based on dynamic tests and topography map of their thickness were assessed. The study material included the skins of two groups of hybrid rabbits (F1), 24 pieces each, from breeds crossing: ♂ Belgian Giant Grey × ♀ Burgundy (BOS×BU), or ♂ Belgian Giant Grey × ♀ New Zealand White (BOS×BNZ). Histological, rheological, organoleptic and topography thickness studies of broiler rabbit leathers have proven that they can be intended for the production of not only gloves, but also shoe uppers. The leathers of BOS x BU hybrid proved to be a better raw material than BOS x BNZ for the production of both gloves and footwear.

Key Words: rabbit, skin, leather.

INTRODUCTION

The available literature contains only general information about the possibility of using rabbit skins to be tanned for grain leather when they are not suitable for use on fur (Kościański, 1983; Karłowicz, 1985; Herman, 1986; Gebler, 1996). However, the authors do not provide accurate information about the utility of the type or breeds from which rabbit skins were obtained. As we observed, these were skins from rabbits of different breeds, mostly from summer slaughter, which due to bad fur are not suitable for fur products. The tanning method was developed and a group of products was found for which rabbit skins can be used, namely children's footwear, producing 20 thousand pairs (Huszar and Koltai, 1987).

The use of rabbit broiler skins for footwear production seems justified, as they are selected as a model material for the dermis of vertebrates, due to the extreme tear resistance of the skin related to specific mechanisms within the collagen. According to Yang *et al.* (2015), the deformation, expressed in terms of the four mechanisms of activity of collagen fibres in the skin under tensile load, virtually eliminates the possibility of tearing in samples with a pre-cut. In Poland, rabbit meat production is at the level of 25 thousand tons per year (Składanowska-Baryza, 2017) and broiler body weight is between 2.0 and 4.0 kg, which means a loss of roughly 8 million skins. Due to the increase in demand for dietary food, research is mainly being carried out to improve the health values and sensory attractiveness of rabbit meat (Maj *et al.,* 2012; Martínez-Álvaro, 2016; Rodríguez *et al.,* 2017; Migdał *et al.,* 2018; Składanowska-Baryza and Stanisz, 2019). Due to the widespread fattening of young rabbits, the possibility of using their skins is important. In their studies, Nasr *et al.* (2020) showed that tanned rabbit furs are suitable for manufacturing leather garments when used alone, while reinforcing the fur with textile padding may increase their utility for other leather manufacturing purposes. Currently, few studies involve assessment of the quality and use of skins of modern rabbit

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breeds, especially broilers, for the production of soft grain leather (Kanuri *et al.*, 2019). Therefore, the aim of the research was to investigate the structure of rabbit broiler skins, given the possibility of using them in the production of glove and footwear leathers.

MATERIALS AND METHODS

Animals and management

Material for the study included two groups of hybrid rabbit skins, 24 pieces each: ♂ Belgian Giant Grey × ♀ Burgundy (BOS×BU), or ♂ Belgian Giant Grey × ♀ New Zealand White (BOS×BNZ). After weaning, at 35 d of age, the animals were fed (*ad libitum*) pellets containing 16.5% protein, 14% crude fibre, and 10.2 MJ metabolisable energy. The rabbits were kept until 90 d of age and then slaughtered at an average body weight of 2.6 kg. Treatment of animals before slaughter and at slaughter per se was conducted in accordance with current law in force in Poland (Journal of Laws 2009 No. 118 item 992). The slaughter of animals was preceded by a 24-h fast. After stunning and bleeding, the rabbits were skinned and gutted. The carcasses were dissected following the methods described by Bieniek (1997). During post-mortem processing of the carcass, each skin was numbered with a needle tattoo machine, stamping the number from the flesh side. Before tanning the skins of BOS×BU and BOS×BNZ hybrids, they were divided into four groups of 12. Two of them were subjected to a dressing for gloves and the others for shoes. Raw skins were subjected to a chrome tanning process according to the methodology developed at the Leather Industry Plant in Klęczany (Zapletal *et al.,* 2018).

Skin tanning

The methodology of tanning rabbit skins for gloves and footwear uppers is presented in Table 1. The difference in the tanning of the two types of skins concerned the bating and pressing steps. In the bating phase for gloves, after addition of the carbon preparation, skins were rotated in the drum for 60 min, and for footwear leathers only 30 min. In the final stage of the finishing process, the leather for footwear was pressed (ironed) more firmly than the leather for gloves.

Histological studies of skins

The study material consisted of 2×2 cm skin samples cut with a scalpel from the rear of the animal (*regio radicis caudae*). After slaughter, skin tissue biopsies were taken from the left side of the body. The skin tissue samples were preserved in 10% formaldehyde solution. The histological treatment of the collected material was performed using the methodology contained in the works of Dempsey (1968) and Prévot (1973). Three dyeing techniques, as used by Mobini (2012) to study sheep skin, were applied. Microscopic observations were made using a light microscope fitted with an eyepiece micrometer. The histological examination of skins took into account primarily those elements that affect their suitability for tanning purposes (Zapletal *et al.*, 2001). Measurements of the thickness of collagen fibre bundles, their orientation (angle between bundles) and density of the weave (spaces among bundles) were taken in the middle of the reticular layer. Based on these measurements, the proportions of thermostatic and reticular layers and sublayers grain in the dermis were calculated. Five measurements were taken for each histological preparation.

Topographic thickness studies of leathers

Due to the presence of hair coat, the thickness of raw skin tissue was abandoned. This operation was carried out precisely after tanning and finishing the leather, using a thickness gauge in accordance with PN-EN ISO 2589: 2005. A description of the method of creating topographic maps of skin tissue thickness was found in the study by Juny and Leszczyński (1969). These studies were conducted on the raw skins, so our own method was developed for the measurements of leather thickness. Each leather was divided into 1 cm^2 and its shape outlined on graph paper. Thickness measurements were made using a spring thickness gauge with an accuracy of 0.1 mm, measuring this parameter in every cm^2 of leather, and the results were recorded on graph paper. This way, a thickness map of all tested leathers was obtained. The next stage was to create model leather for four groups. On the basis of individual

Table 1: Recipe for tanning rabbit skins.

Stage	Amount of chemicals added (%, kg, m^3)	Time (h)	Comments
Fleshing			Removal of pellicle membrane
Washing	100% H_2O		Removal of dirt, salt, blood and fatty substances
Dehairing[1]	Sodium sulphide 1.5 kg, hydrated lime 6 kg, table salt 4 kg, 1.5 m^3 H_2O	24 h	Rotating in the drum
Washing	100% H_2O		Rinsed three times
Liming	5 kg of hydrated lime to 1.5 m^3 H_2O	24 h	Rotating in the drum
Rinsing	100% H_2O		Rinsed three times
Deliming	I. Sodium metabisulphite 0.5 kg, ammonium sulphate 6 kg, 1.5 m^3 H_2O; II. sodium sulphate 6 kg, 1.5 m^3 H_2O, 1 kg of lactic acid	1 h 1.5 h	Rotating in the drum; lactic acid after 30 min the pH was checked (7.8-8.2); deliming and bating in the same bath
Bating	0.4 kg bovine pancreas extract	1 h	
Rinsing	100% H_2O		Rinsed three times
Pickling	9 kg NaCl, 1 kg sodium formate, Sulphuric acid	1.5 h	H_2SO_4 in 3 port., every 30 min (bath pH 3.2-3.4)
Tanning	6.5 kg Chrome (33% basicity); 0.5 kg of ammonia soda	10 h 3 h	Rotating in the drum
Rinsing[2]	150% H_2O, 0.2% formic acid	0.5 h	Rotating in the drum
Retanning	150% H_2O, 35°C, 2% Chrome, 2% PTA Synektan, 3% Corilene F275		(pH of the bath ca. 3.8)
Neutralisation	100% H_2O, 2% formic acid; 2% baking soda	1/3 h 1 h	Baking soda 2×0.5 h, bath pH about 5.9-6.1
Rinsing	200% H_2O	1/4 h	
Retanning and Dyeing	100% H_2O, 30°C, 2% Synektan BN, 1% mimosa, 1.5% Synektan DII; 1.5% LB ST, 1% CB NG,	1/4 h 1 h	Rotating to complete discoloration of the leather section, rinsing
Greasing	100% H_2O, 7% anionic liqueur, 1.5% cationic liqueur	2× 1/4 h	Rotating in the drum
Rinsing	200% H_2O		Rotating in the drum
Finishing			Ironing and drying

[1]The reagents and chemicals were calculated on 100 kg of raw skins.
[2]The reagents and chemicals were calculated in % for 100 kg of tanned leather with a thickness of 0.5 to 0.8 mm.

maps, a map was prepared for each of the four groups with mean values for a given group by calculating the average value for the corresponding point on each skin in a given group. The thickness ranges were determined and each of them assigned to the appropriate colour. The spread of leather thickness in individual groups allowed us to distinguish five thickness classes, namely: I-0.70-0.80 mm, II-0.60-0.69 mm, III-0.50-0.59 mm, IV-0.40-0.49 mm, V-0.30-0.39 mm. The results obtained were transferred to the AutoCad 2006 program, Autodesk, with the help of which four topographic maps of leathers were created, illustrating the distribution of their thickness by plotting the boundaries of ranges of individual classes. The percentage share of leather thickness of a given thickness was also calculated. In addition, leather thickness measurements were made at the standard point N and n (in the thinnest place) and the thickness loss was calculated according to PN-88 / P-22211.

Organoleptic assessment of leathers

After tanning and finishing the leathers, their final classification was carried out using organoleptic scoring (Baryłko-Piekielna and Matuszewska, 2009). The assessment, on a five-point scale, included the type of finished leathers and the genetic group of rabbits (Zapletal, 1997; Zapletal *et al.,* 2012).

Tensile and puncture strength of leathers

Rheological tests of leathers included determination of tensile strength and elongation at break made in accordance with the applicable PN-EN ISO 3376: 2012 standard. For this purpose, 4 specimens, 2 perpendicular and 2 parallel to the dorsal line, were cut out of each leather from the standard site (in accordance with PN-EN ISO 2419: 2012). Strength parameters were determined using an Instron 5544 equipped with a 500 N force measuring head. The results obtained were compared with the requirements of the relevant standards for glove leathers (BN-86/7724-01) and leather for shoe uppers (PN-86/P-22225). The samples were conditioned for 24 h at 23±2°C and 50±5% relative humidity of the KEF 115 climate chamber (according to PN-EN ISO 2419: 2012).

Additionally, the puncture strength test of leathers was carried out, which is not provided for in the standard. The study was conducted from the flesh side of the leather with a flat cut mandrel with a diameter of 6 mm and a sample holder with a diameter of 10 mm. For this purpose, a 30 mm wide and 120 mm long sample was cut from each leather, from the same place, around the back of the left side of the body. Before testing, samples were conditioned for 24 h at 23±2°C and 50±5% relative humidity in the KBF 115 binding machine (according to PN-EN ISO 2419: 2012). The pre-cut strip was measured at five points along the entire length of the strip using a CD-15DCX calliper (Mitutoyo, Japan) integrated with TestXpert II testing machine software (Zwick / Roell, Germany). The tests were carried out using a Zwick/Roell 2.5 testing machine at a speed of 12 mm/min and a threshold force value of 2 N in five replicates for each leather sample. On the basis of the tests, the value of the puncture force was determined as the maximum value of the force recorded during the Fmax test (N) and the puncture height at Fmax (mm).

Dynamic method of assessing rheological parameters of leathers

The tests of dynamic properties of leathers were carried out only experimentally, not for a practical purpose, but as a supplement to static tests. Dynamic tests were carried out based on the analysis of the energy state of the tested material using the Reotest apparatus (Balejko, 2003). A 30 mm wide and 120 mm long sample was taken from each leather, from the same place, near the neck of the right side of the body. They were conditioned for 24 h at 23±2°C and 50±5% relative humidity according to PN-EN ISO 2419: 2012 and their thickness was measured with a calliper. The tests used a uniaxial compression test with a sinusoidal variable speed of a mandrel with a diameter of 10 mm, with a deformation of 50% of the initial height of the sample. Five replicates were performed for each sample. Based on the course of the force and deformation curves of the sample, the following parameters were determined using the Mathcad v 2000i program: accumulated energy (J/m^3), energy accumulated in the material during one cycle; dispersed energy (J/m^3), the relative amount of energy dissipated in the material over one cycle; the degree of elasticity (%), ratio of reversing work (shape recovery) to total work (Olkku and Sherman, 1979; Kaletunc *et al.,* 1991); relaxation time (s), the time after which the primary stress decreases 0.368 times is a measure of the degree of stress decay over time; energy accumulation module (Pa), real component of the complex modulus of elasticity; energy loss module (Pa), the imaginary component of the complex modulus of elasticity; complex modulus of elasticity (Pa), sum of energy accumulation module and energy loss module.

Statistical analysis

The results were analysed by the least squares method using the General Linear Model (GLM) procedure (SAS, 2014). For rheological parameters, the following model was used: $Y_{ij}=\mu+M_i+G_j+(M\times G)_{ij}+e_{ij}$, where: Y_{ij} – the observed value of trait; μ – the overall mean; M_i – the fixed effect *i*-th leather processing method; G_j – the fixed effect *j*-th animal genetic group; $(M\times G)_{ij}$ – the interaction between leather processing method and animal genetic group, e_{ij} – the random error. Data were presented as the least squares means and standard deviation (SD) with the significance levels of the effect. The mean least squares (LSM) for the studied groups were compared by Tukey's multiple comparison test. Values at $P<0.05$ were considered significant difference. A one-way analysis of variance (ANOVA) was used to examine the effect of animal genetic group on histological parameters. For variables expressed on a point scale (organoleptic assessment), the non-parametric Wilcoxon test (for independent groups) was used.

RESULTS

Histological structure of the skin tissue

The results of measurements characterising the histological structure of broiler rabbit skins are presented in Table 2. Pictures of histological specimens are presented in Figures 1 and 2.

There were no significant differences between the thickness of the dermis of BOS×BU and BOS×BNZ hybrids. Significant differences ($P<0.05$) between the groups were found in the thickness of the reticular layer, as well as between the percentage share of the thermostatic and reticular layers in the dermis, which was more favourable in BOS×BNZ skins. Bundles of collagen fibres in the dermis of BOS×BU broilers were thinner, while the distance between them was greater compared to BOS×BNZ. These parameters did not differ significantly.

Topographic thickness of leathers

The results of the measurements of glove leathers thickness are presented in Table 3 and Figure 3.

The BOS×BU glove leathers had a more even thickness. They were characterised by a smaller decrease in thickness between the standard point N and the measuring point n compared to the leathers of BOS×BNZ rabbits.

The results of thickness measurements of footwear leathers are shown in Table 4 and Figure 4.

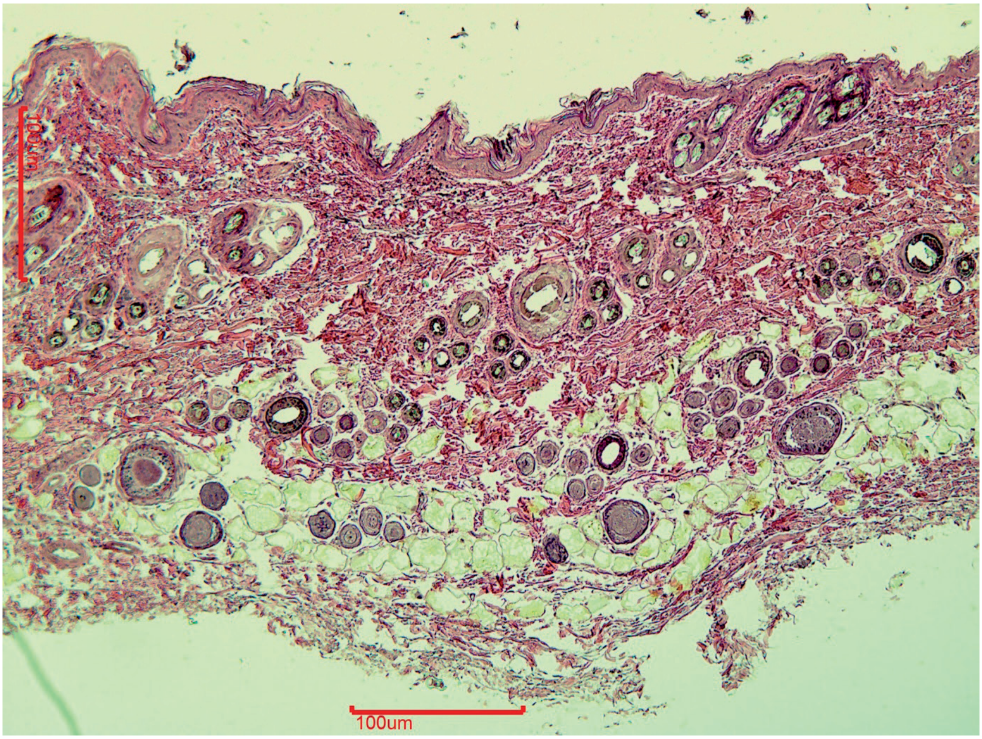

Figure 1: Belgian Giant Grey × Burgundy rabbit skin cross section, magnification ×100, haematoxylin+eosin staining.

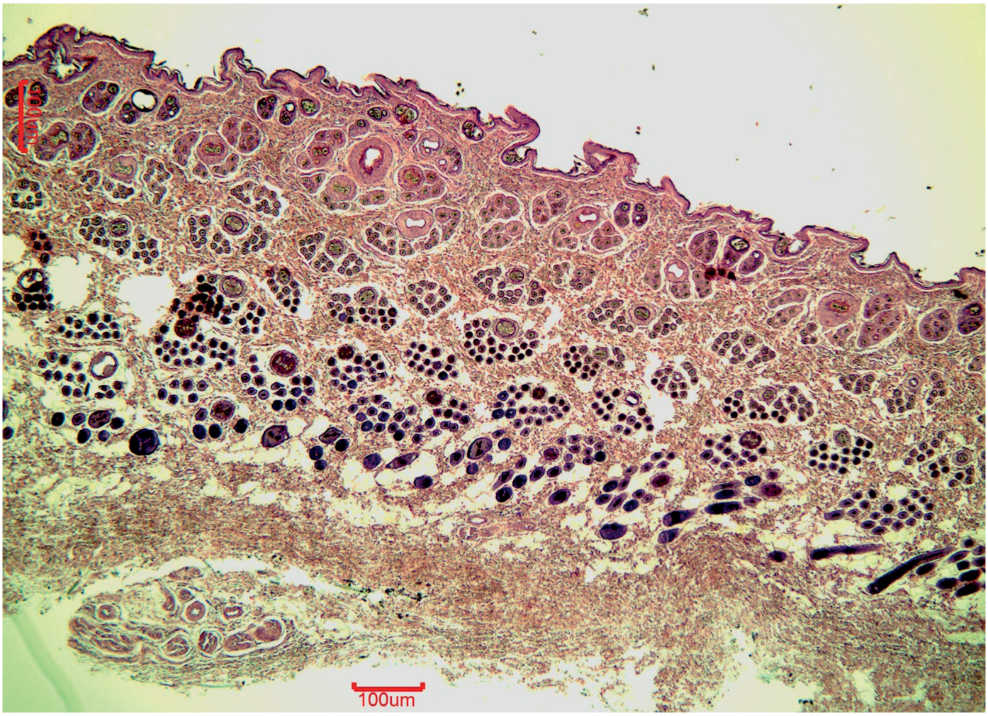

Figure 2: Belgian Giant Grey × New Zealand White rabbit skin cross section, magnification ×40, haematoxylin+eosin staining.

The footwear leathers of BOS×BU rabbits, like the glove leathers, had a more even thickness with less thickness reduction compared to the leathers of BOS×BNZ rabbits. These results also did not differ significantly.

Organoleptic assessment of leathers

The results of the organoleptic assessment of glove leathers are presented in Tables 5 and 6. BOS×BU hybrid glove leathers had better quality parameters compared to BOS×BNZ. They were characterised by greater fullness in touch and flexibility.

Table 2: Least square means ± standard deviation of histological structure parameters of rabbit skins.

	Genotype	
Parameters	BOS×BU	BOS×BNZ
Dermis thickness (μm)	1320±440	1480±440
Grain sublayer thickness (μm)	63±10	65±10
Thermostatic layer thickness (μm)	680±280	670±220
Reticular layer thickness (μm)	630±190[a]	820±200[b]
Subcutaneous layer thickness (μm)	600±80	580±160
Space between bundles of collagen fibres (μm)	17±3	16±2
Thickness of the collagen fibre bundles (μm)	28±4	28±4
Angle between bundles of collagen fibres (α°)	29±7	29±4
Participation of the reticular layer in the dermis (%)	48±6[a]	55±3[b]

[a,b]Values in the same row having different superscripts differ significantly ($P<0.05$).

BOS×BU:♂ Belgian Giant Grey × ♀ Burgundy, and BOS×BNZ: ♂ Belgian Giant Grey × ♀ New Zealand White.

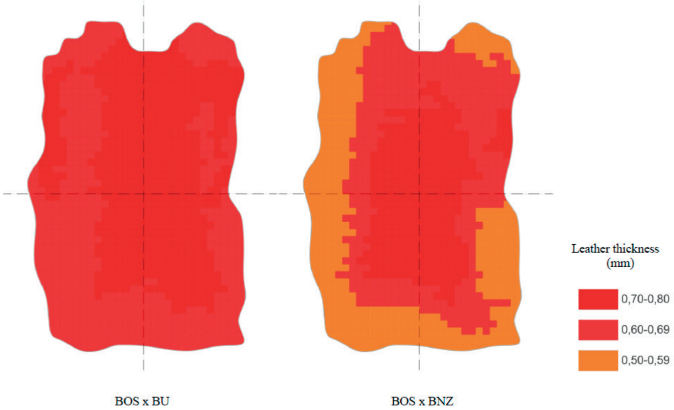

Figure 3: Topographic map of the thickness of rabbit broiler leathers made for gloves. BOS×BU: ♂ Belgian Giant Grey ×♀ Burgundy, and BOS×BNZ: ♂ Belgian Giant Grey ×♀ New Zealand White.

Footwear leathers obtained from BOS×BU hybrids, as in the case of glove leathers, were characterised by better quality parameters (Table 5). Leather for gloves was softer and more flexible than in footwear (Table 6).

Determining the leathers' tensile and puncture strength

The values of the tensile strength parameters and elongation at break of glove and footwear leathers are presented in Table 7. There were no significant differences in the tensile strength of the leathers, either between the groups of hybrids within a given assortment or between the types of their expedition. Slight but statistically significant differences were observed only in the elongation at break between the glove and shoe leathers of BOS×BU hybrids.

The parameters for puncturing glove and shoe leathers are shown in the same table. The puncture force and elongation at the puncture values for BOS×BU and BOS×BNZ did not differ significantly within the given product group. However, the leathers of the hybrids differed significantly ($P<0.05$) depending on the method of the dressing.

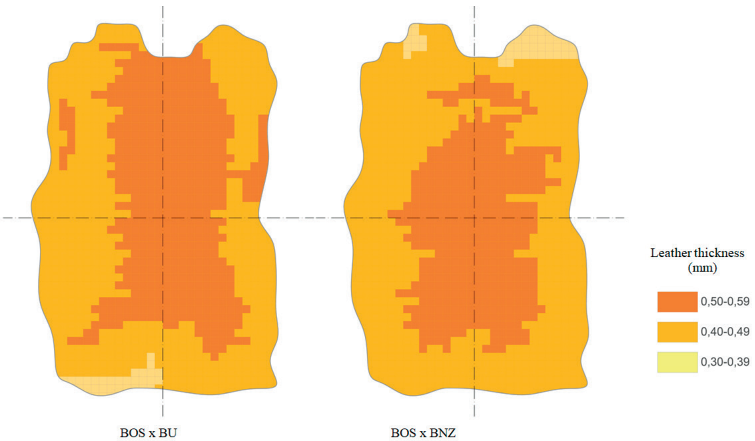

Figure 4: Topographic map of the thickness of rabbit broiler leathers made for footwear. BOS×BU: ♂ Belgian Giant Grey ×♀ Burgundy, and BOS×BNZ: ♂ Belgian Giant Grey ×♀ New Zealand White.

Table 3: Topography thickness of glove leathers.

Genotype	Leather thickness (mm)	Leather surface (%)	Leather thickness at the N point (mm)	Decrease in leather thickness (%)
BOS × BU	0.70-0.80	52	0.78±0.03	10
	0.60-0.69	48		
	0.50-0.59	0		
BOS × BNZ	0.70-0.80	29	0.72±0.06	14
	0.60-0.69	35		
	0.50-0.59	36		
Requirements for glove leathers BN-86/7724-01			0.6-1.5	<50

BOS×BU:♂ Belgian Giant Grey × ♀ Burgundy, and BOS×BNZ: ♂ Belgian Giant Grey × ♀ New Zealand White.

Analysis of rheological parameters of leathers based on their energy status

The results of dynamic tests carried out for glove and shoe leather samples are presented in Table 7. As in the case of static tests, no significant differences were observed in the values of the energy status parameters between the skins of two groups of hybrids within the same type of product. Significant differences in the values of dynamic parameters occurred depending on the method of dressing.

DISCUSSION

Histological structure

The histological structure of rabbit broiler skins was assessed in terms of their utility functions. Knowledge of the structure of skin tissue, in particular the collagen fibre system, allows us to determine the destination of a given batch of leather due to tanning requirements and is an important criterion for the use of proper technological treatment. In the study of the detailed microstructure of hides, including rabbits, modern imaging techniques such as multiphoton microscopy (MPM) are increasingly being used to generate second harmonic and two-photon excited fluorescence (Zhu *et al.*, 2015). The thickness of the skin tissue, and thus the mass of raw skin, is affected by the thickness of the dermis and the thickness of the subcutaneous layer, and in it the content of muscle fibres and fat cells (Zapletal, 2000). In histological studies, the skin thickness was 1916-2066 µm. Similar values for the skin thickness of New Zealand White rabbits are provided by Yagci *et al.* (2006), for males 2087.6 µm and females 1835.4 µm. Density and regularity of fibre arrangement in the reticular layer of the dermis has an impact on the leather accuracy and strength properties (Lanir and Fung, 1974; Morgan, 1984; Zapletal, 2000). The way the collagen fibres are interlinked affects the leather behaviour during technological processes, determining its susceptibility to deformation, stiffness and rheological reactions to loads (Váculik, 1986; Lokshin and Lanir, 2009). In the studies of the skins of adult New Zealand White rabbits, Oznurlu *et al.* (2009), obtained significantly higher results in the thickness of the reticular layer (1174.7 µm) than those shown in this paper. This is due to the fact that during the growth period,

Table 4: Topography thickness of footwear leathers.

Genotype	Leather thickness (mm)	Leather surface (%)	Leather thickness at the N point (mm)	Decrease in leather thickness (%)
BOS × BU	0.50-0.59	44	0.50±0.08	8
	0.40-0.49	54		
	0.30-0.39	2		
BOS × BNZ	0.50-0.59	36	0.52±0.09	12
	0.40-0.49	59		
	0.30-0.39	5		

Requirements for footwear leathers PN-86/P-22225. Thickness at the standard point to be agreed with the recipient <15.
BOS×BU:♂ Belgian Giant Grey × ♀ Burgundy, and BOS×BNZ: ♂ Belgian Giant Grey × ♀ New Zealand White.

Table 5: Median and interquartile range of organoleptic properties of glove and footwear leathers depending on the group of hybrid rabbits.

Parameters	Glove leathers BOS×BU	Glove leathers BOS×BNZ	Glove leathers *P*-value	Footwear leathers BOS×BU	Footwear leathers BOS×BNZ	Footwear leathers *P*-value
Fullness in touch (points)	5 (4.5-5)	4.5 (4-5)	0.1670	5 (4.5-5)	4.5 (4-5)	0.1265
Softness (points)	5 (5-5)	5 (5-5)	1.0000	5 (4.5-5)	5 (4.5-5)	1.0000
Ductility (points)	5 (5-5)	5 (4.5-5)	0.3944	4 (3-4)	3 (3-4)	0.1224

$P<0.05$ is considered statistically significant.
BOS×BU:♂ Belgian Giant Grey × ♀ Burgundy, and BOS×BNZ: ♂ Belgian Giant Grey × ♀ New Zealand White.

the dermis becomes thicker, due to the increase in the thickness of the reticular layer. The thickness of the facing sublayer should be considered when assessing the histological parameters of the dermis. According to Russel (1988), parameters such as skin tensile strength or tearing depend more on the share of the facing sublayer (upper part of the thermostatic layer) in the derma, and less on the technological process. According to Sherman *et al.* (2017), there are approximately 250 sheets of different orientations of curved collagen fibres in the dermis of a rabbit. The presence of some extremely wavy filaments is responsible for the large amounts of strain that the skin can undergo before straightening. The combined elastic and viscous effects lead to the unique tensile response of skin, as well as its strength, versatility and tear resistance. The results of skin histological examination indicate a slightly more favourable structure of BOS×BNZ broiler skins in terms of performance. These skins were characterised by a higher reticular layer content in the dermis. It should be emphasised, however, that the skins of both hybrid groups were characterised by a well-shaped weave of collagen fibres. There were no significant differences between the groups of hybrids with regard to the angle at which the bundles of collagen fibres were arranged and in the space between the bundles of collagen fibres. This was clearly confirmed by the results of the strength parameters of the static tests, in which no significant differences were noted between the groups of hybrids. In both groups studied, the fibre bundles were thin and evenly distributed, which gave the leathers softness and elasticity.

Thickness topography

Livestock skins have a specific thickness distribution over their entire surface. The thickness of the skin decreases from the croup to the neck and from the dorsal line towards the abdomen (Reddy *et al.,* 1974). The thicker the skin, the more durable. The accuracy (firmness) of the skin depends on the weave of the fibres of the reticular layer. The thicker and more compact it is, the more resistant it is to tears, abrasion and the less water permeable (Bailey *et al.,* 1998). In the available literature, however, we found no information on the topography of rabbit broiler leather thickness. The measurement results were compared with the requirements for glove and footwear leathers contained in the standards BN-86/7724-01 and PN-86/P-22225. The standard point thickness of the tested skins was within the requirements of the value included in the standards. Kopański (1965) reports that the skin thickness of small rabbits is 0.4 mm, and for large breeds 0.7 mm, and varies in individual topographic parts of adult rabbits: the thickest in the area of the head and back, thinner on the sides of the body and lower abdomen, and the thinnest around the groin. Rabbit broiler leathers showed a slight decrease in thickness (8-14%), with a permissible 15% for footwear leathers and 50% for glove leathers. The glove and footwear leathers of BOS×BU rabbits had a more even thickness compared to BOS×BNZ. A more even thickness over the entire surface of the leather allows for a larger surface pattern, especially in the production of shoe uppers (Zapletal *et al.,* 2012).

Organoleptic assessment

At work, the quality of tested leathers was evaluated on the basis of sensory evaluation of the raw material after obtaining the finished product. Organoleptic tests performed during leather sorting are the basis for assessing the raw material intended for cutting out footwear components. Soft leathers for the production of gloves, clothing, and furniture or shoe uppers should not only have adequate strength and flexibility, but also appropriate softness and elasticity. Organoleptically, these properties are usually assessed by touch (Duda and Marcinkowska, 2010). BOS×BU leathers both glove and footwear were characterised by greater filling (fullness to the touch). All glove leathers were softer, more elastic and ductile compared to those made for footwear.

Table 6: Median and interquartile range of organoleptic properties of glove and footwear leather depending on the dressing.

Parameters	Glove leathers	Footwear leathers	*P*-value
Fullness in touch (points)	5 (4-5)	5 (4-5)	0.8557
Softness (points)	5 (5-5)	5 (4.5-5)	0.0040
Ductility (points)	5 (5-5)	3.5 (3-4)	<0.0001

$P<0.05$ is considered statistically significant.

Table 7: Least square means±standard deviation of rheological properties of glove and footwear leathers.

	Glove leathers		Footwear leathers		*P*-value		
Parameters	BOS×BU	BOS×BNZ	BOS×BU	BOS×BNZ	G	M	G×M
Static methods							
Leather thickness (mm)	0.61±0.09	0.60±0.05	0.55±0.06	0.44±0.08	0.2354	0.0594	0.2856
Tensile strength (N/mm^2)	16±6	13±2	15±5	15±3	0.3192	0.5036	0.3207
Elongation at break (%)	58±5	62±4	55±3	59±5	0.0474	0.0354	0.9376
Puncture force (N)	192±56	165±27	94±19	87±13	0.6253	<.0001	0.1835
Elongation at the puncture (mm)	4.60±0.60	4.40±0.40	3.80±0.40	3.60±0.30	0.7567	0.0001	0.4766
Dynamic methods							
Leather thickness (mm)	0.74±0.13	0.78±0.04	0.54±0.06	0.50±0.08	0.9502	<.0001	0.2042
Accumulated energy (J/m^3)	22000±4300	24000±4400	21000±1900	22000±2700	0.2606	0.3402	0.5310
Dispersed energy (J/m^3)	15000±3701	17000±4400	16000±2300	18000±3300	0.0974	0.5071	0.7721
The degree of elasticity (%)	67±7	72±6	76±7	82±12	0.0788	0.0036	0.8571
Relaxation time (s)	0.53±0.10	0.69±0.28	0.19±0.05	0.16±0.10	0.2953	<.0001	0.1115
Energy accumulation module (Pa)	259000±57000	298000±49000	220000±61000	215000±99000	0.0566	0.0213	0.3771
Energy loss module (Pa)	82000±12000	89300±41000	194000±24000	176000±56000	0.6909	<0.0001	0.3524
Complex modulus of elasticity (Pa)	272000±56000	315000±42000	296000±54000	294000±63000	0.3208	0.9557	0.2665

[a,b]The values in the same row having different superscripts differ significantly ($P<0.05$). G-animal genetic group, M-leather processing method (glove and footwear leathers).
BOS×BU:♂ Belgian Giant Grey × ♀ Burgundy, and BOS×BNZ: ♂ Belgian Giant Grey × ♀ New Zealand White.

Leather tensile and puncture strength

In the conducted tests of the leathers of BOS×BU and BOS×BNZ hybrids, both gloves and shoes had a higher tensile strength, as presented in the study by Souza *et al.* (2016) (10.84 N/mm^2) a performed on 70-d old New Zealand White rabbits. However, the values of this parameter were similar to the results of the studies by Kanuri *et al.* (2019), which were 15.93 N/mm^2 and 17.09 N/mm^2, respectively, for leather tanned with mimosa and chrome.

In the experiment, the method used for testing the strength of plastic packaging puncture was adapted for rabbit glove and footwear leathers, which due to their thin structure are susceptible to puncture. In the burst tests for footwear, rabbit leathers showed similar strength to that of cow leathers (Zapletal *et al.,* 2018). There was also a significant correlation between bursting force and puncture force for footwear rabbit leathers (0.913). During the production and use of both gloves and footwear, the surface of the leather is subjected to various pressures by the user, both internal and external. The greater the leather's resistance to a burst, the less potential for damage to the product and the user's body. The burst test is a measure of material resistance to rupture. These results testify to the possibility of using the puncture strength leather test as a method to determine its strength. In the case of thinner footwear leathers, the puncture resistance may inform the manufacturer about the stitch strength when sewing the shoe upper parts. The leather for footwear was pressed more firmly than the leather for gloves. As a result of this operation, which was aimed at stiffening the leathers, their thickness was slightly reduced. As a consequence, this led to a reduction in the strength parameters of footwear leathers of both groups of hybrids, which differ significantly from glove leather in puncture force and elongation at the puncture.

Rheological parameters of skins based on the analysis of the energy state of the tested material

Analysis of the thermodynamic state of the tested material allows for the preparation of dynamic rheological characteristics by determining the composite components of dynamic elasticity modules as well as energy balance using the uniaxial compression method. The degree of elasticity reflects structural changes in the examined material caused by deformation (Balejko, 2003). Leather pressing also contributed to a slight decrease in the value of dynamic parameters of shoe leather. The greater adhesion of collagen fibres of footwear leather as a result of ironing resulted in a significantly lower value of the energy accumulation module. There were significantly higher energy modulus losses related to inelastic deformation due to friction between the fibres. In the footwear of hybrids, the primary stress (relaxation time) decreased significantly faster.

CONCLUSIONS

In summary, histological, rheological, organoleptic and topography thickness studies of broiler rabbit leathers have proven that they can be used not only for gloves, but also for shoe uppers. The leathers of BOS×BU hybrid rabbits were a better raw material than BOS×BNZ for the production of both gloves and footwear.

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