Carcass characteristics, chemical composition, physicochemical properties, texture, and microstructure of meat from spent Pekin ducks

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ABSTRACT The aim of the study was to compare P33 (Polish Pekin), P8 (Danish Pekin), and LsA (English Pekin) ducks after 2 reproductive seasons for carcass composition and some meat quality traits. A total of 48 duck carcasses (8 male carcasses and 8 female carcasses of each genotype) were studied. Whole carcasses were dissected, and pH and electrical conductivity of the breast and leg muscles were determined 24 h postmortem. After dissection, breast and leg muscles were sampled to determine proximate composition, some minerals, and physicochemical properties. Breast muscles were also analyzed for textural characteristics, microstructural characteristics, and rheological properties. At 112 wk of age, genotype and sex were found to have no significant effect on carcass weight and percentage of carcass components. The genotype of the birds had a significant effect on the water and fat content in the pectoral and leg muscles, as well as protein and collagen in the leg muscles. The origin of the ducks had a significant impact on the magnesium content in pectoral muscles and Warner–Bratzler shear force pectoralis muscle major, as well as the electrical conductivity of the leg muscles. The differences in duck genotype had a significant effect on the sum of elastic moduli, fiber cross-sectional area, fiber perimeter, and vertical fiber diameter of pectoralis major muscle. Regardless of the genetic origin, breast muscles from 112-week-old males had a lower fat content, and male leg muscles contained more water and protein and less fat and collagen than the female muscles. The genotype by sex interaction was significant for the content of breast muscles, skin with subcutaneous fat, and neck percentage and for the water and fat content in breast and leg muscles.

Key words: spent duck, genetic resource, carcass composition, meat quality

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INTRODUCTION

Despite their many advantages, duck meat and duck meat preparations have gained little interest from consumers worldwide except for China, countries of southeastern Asia, and some European countries, in which duck meat production and consumption are relatively high.

Compared with broiler chicken carcasses, duck carcasses contain less meat, in particular breast muscles, and a higher percentage of skin with subcutaneous fat. The high fat content, higher prices, and more difficult culinary treatment discourage consumers from buying duck carcasses in comparison with chicken carcasses. However, the meat from ducks, especially breast meat, has a high nutritive value. Compared with the breast muscles of broiler chickens, breast muscles from ducks contain less protein (22.04 vs. 20.06%) and ash (1.07 vs. 0.92%) and more water (75.47 vs. 76.41%) and fat (1.05 vs. 1.84%) (Ali et al., 2007). Duck breast muscles are characterized by a favorable amino acid profile with a higher content of leucine, lysine, tryptophan, phenylalanine, and tyrosine and by a higher proportion of polyunsaturated fatty acids, including linoleic and linoleic fatty acids, when compared with the breast meat of broiler chickens (Grabowski and Kijowski, 2004; Wołoszyn et al., 2006; Ali et al., 2007).

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In terms of microstructure, duck breast muscles most closely resemble breast muscles of geese and quails. Pectoralis major muscle contains from 61 to 75% red fibers and from 25 to 38% white fibers (Kiessling, 1977; Witkiewicz et al., 2004; Hašcik et al., 2006; Kokoszyński, 2011). Breast meat from Pekin ducks is fine-fibered; the diameter of white (49.7–55.6 μm) and red muscle fibers (26.0–32.5 μm) in duck breast muscles is lower than in broiler chickens (white, 68.2 μm; red, 48.1 μm), which has a beneficial effect on tenderness of the meat.

Around the world, most duck meat comes from Pekin-type ducks, which are subjected to slaughter between 6 and 8 wk of age. The birds are slaughtered when their carcass meat content, especially breast meat content, is large enough and when they have completed their rapid growth and no longer show good feed conversion.

The meat of spent ducks is a by-product obtained from slaughtered birds after they reached the end of their laying lives. In China, India, and southeastern Asia, spent duck meat is relatively important, reflecting that the ducks are also used for table egg production. In these parts of the world, duck eggs contribute 10 to 30% of all eggs consumed (Arthur, 2017). Meat from spent ducks is tough and dry, dark in color, and strong in odor, which negatively affects its culinary qualities and technological properties (Sumarmono and Wasito, 2010). Spent duck meat is mainly used for canning (meat, offal, meat and vegetables, soups), cured meats (sausages, smoked meats, offal products), as well as duck meat pickles, nuggets, meatballs, and so forth (Bhattacharyya et al., 2007; Souza et al., 2011; Rejesh et al., 2014, 2016; Naveen et al., 2016; Semwogerere et al., 2019). Spent duck carcasses and carcass components are quite often used to prepare strong aromatic broths and other soups, especially in African and Asian countries.

When looking for new products, consumers in recent decades have paid increasing attention to products obtained from native farm animals, including native ducks. The meat of native ducks is often characterized by higher nutritional value (more protein, less fat), fibrillarity (lower muscle fiber diameter), better sensory attributes (juiciness and tenderness, taste and aroma intensity, and desirability) compared with commercial hybrid ducks (Witkiewicz et al., 2004; Kokoszynski, 2011), which encourages consumers to buy it.

The results of meat trait analysis in P33 (Polish Pekin), P8 (Danish Pekin), and LsA (English Pekin) ducks after 2 reproductive seasons have not been previously reported, which provided an incentive to perform this research. The present study investigated 112-week-old P33, P8, and LsA ducks which completed 2 reproductive seasons (flock liquidation in accordance with the breeding program) and were included in the Genetic Resources Conservation Program in Poland. The birds were compared for carcass weight and composition of eviscerated carcass with neck, chemical composition (content of water, protein, fat, collagen and some minerals), physicochemical traits (pH_{24}, EC_{24}, drip loss, cooking loss), color coordinates (L*, a*, b*) of breast and leg muscles, and texture (hardness, springiness, cohesiveness, chewiness, gumminess, WB shear force), as well as microstructural and rheological properties of breast muscles.

MATERIALS AND METHODS

Evaluation of Carcass Traits

The study used 48 eviscerated carcasses with neck, without giblets, from 3 genetic resources flocks: P33 (Pekin of Polish origin), P8 (Pekin of Danish origin), and LsA (Pekin of English origin). The purchased carcasses were collected from 112-week-old birds after 2 reproductive seasons. The ratio of male to female carcasses was 1:1. In accordance with the information from the breeder, birds before slaughter were kept indoors in a windowless house on deep litter. Birds of all lines were fed the same diet of the same nutritive value and were exposed to similar environmental conditions. During lay, ducks were fed a complete commercial diet for breeder ducks, which contained 16.1 CP, 11.1 MJ ME/kg feed, 3.02% calcium, 0.5% phosphorus, 0.85% lysine, and 0.37% methionine. Birds had 24-h access to water. Indoor temperature ranged from 4 to 20°C, and humidity was 65–75% depending on the month. The maximum lighting duration during the reproductive period was 14 h/d, and the building was illuminated by warm white lights (840 lm). Ducks were kept in accordance with the Genetic Resources Conservation Program for ducks (Książkiewicz et al., 2014) and the Institutional Animal Care and Use Committee (**IACUC**) policy.

Eviscerated carcasses with the neck were chilled in a chill cabinet (Hendi, Gądki, Poland) for 18 h at 4°C. After removal from the cabinet, the chilled carcasses were weighed to the nearest 0.1 g on an electronic balance (WLC 6/12/F1/R, Radwag, Radom, Poland), after which the pH_{24} and EC_{24} of breast and leg muscles were determined.

The whole eviscerated carcasses with the neck were subjected to dissection in accordance with the method developed and reported by Ziołecki and Doruchowski (1989). The carcasses were dissected into breast muscles (pectoralis major muscle and pectoralis minor muscle from both sides of the breast), leg muscles (all thigh and drumstick muscles), and skin with subcutaneous fat from the whole carcass without wing skin, abdominal fat, neck without skin, wings with skin, and remainder of the carcass, that is, skeletal muscles (intercostal, dorsal, suprascapular, and other) together with kidneys, but without other internal organs. The dissected carcass parts were weighed using the electronic balance previously mentioned, and their percentage in eviscerated carcass with the neck was calculated.

Evaluation of Meat Quality

Before dissection, pH_{24} and EC_{24} of the breast and drumstick muscles were measured (24 h postmortem).

The meat pH was measured using a pH-Star CPU (Ingenieurbüro R. Matthäus, Nobitz, Germany) equipped with a glass electrode for meat pH measurement. Before measurement, the pH meter was calibrated in buffers of pH 7.0 and pH 4.0 and then adjusted to the meat temperature of 4°C. The pH values were read from a liquid crystal display with an accuracy of 0.01. Electrical conductivity (mS/cm) of breast muscles (pectoralis major muscle) and leg muscles (drumstick) was measured using an LF-Star CPU device (Ingenieurbüro R. Matthäus, Nobitz, Germany). The electrodes were inserted into the breast or drumstick muscles at an angle of 90° along the muscle fibers. The measurement was accurate to 0.1 mS/cm.

After dissection, individual samples of the breast and leg meat were taken from each carcass to determine basic chemical composition, collagen, some minerals, drip and cooking losses, and meat color attributes.

The water, protein, fat, and collagen content in the breast and leg muscles were determined on a FoodScan device (FoodScan Laboratory, Foss, Cheshire, UK) by near-infrared transmission (**NIT**) spectroscopy.

To determine the content of minerals (Na, K, Mg, Zn, Fe, Cu), the meat samples were freeze-dried and wet mineralized in a Milestone Ethos Plus microwave system (Sorisole, Italy). The samples were analyzed by atomic absorption spectrometry (AAS, iCE 3,000 unit, Thermo Scientific, Cambridge, Great Britain). The samples of breast and leg muscles were also spectrophotometrically analyzed for phosphorus (**P**) content using a Marcel Media Eko spectrometer (Marcel, Warsaw, Poland). The preparation and determination of the mineral content in meat were performed in accordance with Polish standards.

The color coordinates L* – color lightness, a* – relative redness (on red–green axis), and b* – relative yellowness (on yellow–blue axis) (CIE, 1978) were determined on the inner surface of raw pectoralis major muscle and leg muscles (thigh and drumstick muscles, after dissection of the patella and tendons) 24 h postmortem. The L*, a*, and b* parameters were determined using a model CR410 chroma meter (Konica Minolta, Japan). Wide-area illumination was used for the determinations (0° viewing angle, 50 mm aperture size, illuminant D_{65}), and the chroma meter was calibrated against a white reference tile (Y = 94.40, x = 0.3159, y = 0.3325).

To determine cooking loss, samples of pectoral major muscle and leg muscle (thigh and drumstick together) weighing 20 ± 2 g were placed separately in absorbent cheesecloth heated in a water bath at 85°C for 10 min. Heat-treated samples were chilled in a chill cabinet (Hendi, Gądki, Poland) at 4°C for 30 min. Then, the samples were weighed again on a Radwag PS 1000.R2 scale (Radwag, Radom, Poland) to the nearest 0.01 g. The cooking loss was expressed as the percentage of the initial sample weight.

Drip loss was also determined for pectoralis major muscle and for thigh and drumstick muscles together. Each meat sample was placed separately in a perforated bag (no. 1) and later in a second bag (no. 2) to prevent contact between dripping juice and the meat sample. The samples were placed in the Hendi chill cabinet at 4°C for 24 h. Drip loss was calculated from the difference in the weight of breast muscles or leg muscles before and after 24 h and expressed as the percentage of the initial sample weight.

The pectoral major muscles were also analyzed for textural traits, as well as rheological and microstructural properties.

The texture (hardness, cohesiveness, springiness, chewiness, gumminess, Warner-Bratzler [**WB**] shear force) and rheological properties (sum of elastic moduli and sum of viscous moduli) of 48 heat-treated pectoral major muscle samples of spent ducks were tested with an Instron 1,140 apparatus (Instron Corp., Norwood, MA) using the Texture Profile Analysis (**TPA**) double-piercing test, the WB test, and the relaxation test. For each sample, 5 replications were made (a total of 240 determinations). The test was performed with heat-treated samples in water heated until the temperature reached about 70.2°C in the geometric center. The sample was later chilled to 18°C. Slices that were 20±1 mm in thickness were cut out from different samples of the pectoralis major muscle perpendicular to the muscle fiber orientation, using a Siemens MS 6,000 electric slicer (Hausgeräte GmbH, Köln, Germany). Then, the plunger that was 0.62 cm in diameter was driven twice into the sample parallel to muscle fiber orientation. Eighty percent deformation and crosshead speed of 50 mm/min (TPA test) were applied. From the curve representing the strength deformation dependence, the following parameters were determined: hardness, cohesiveness, springiness, chewiness, and gumminess (Bourne, 1982).

The WB test involved cutting the samples of the pectoralis major muscle across the muscle fibers with a special triangular blade. The working speed of the crosshead was 50 mm/min. Maximum shear force was determined in the test (Bourne, 1982).

In the relaxation test intended to determine rheological properties, the plunger that was 0.96 cm in diameter was driven into the pectoralis major muscle sample 2 mm deep (a 10% deformation) to record the changes in tension over 90 s. To calculate the elasticity and viscosity moduli, the generalized Maxwell model was applied. This model is made up of 3 elements connected parallel: the Hooke body and 2 viscoelastic Maxwell bodies. The model equation assumes the following form:

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

where δ is the tension (kPa), ε is the deformation, E_0 is the elasticity modulus of the Hooke body (kPa), E_1 and E_2 are the elasticity moduli of the Hooke body 1 and 2, respectively (kPa), μ_1 and μ_2 are the viscosity moduli of the Maxwell body 1 and 2, respectively (kPa x s), and t is the time.

For a better interpretation of the results, the sum of elasticity moduli ($E_0 + E_1 + E_2$) and the sum of viscosity moduli ($\mu_1 + \mu_2$) were calculated for each sample.

For histological analysis, samples of the pectoralis major muscle were collected from 48 birds, 8 males and 8 females from each group of ducks slaughtered at 112 wk. From each bird after slaughter, 3 sections (0.5 × 0.5 × 1 cm each) were taken from the middle part of the breast muscle. Then, the samples were fixed with Sannomiya solution, dehydrated in alcohol and benzene, and embedded in paraffin blocks. The blocks were sectioned with microtome, and sections of 10 μm were placed on glass slides and counterstained with hematoxylin and eosin (Burck, 1975) and embedded in Canada balm.

The microstructural traits of the pectoralis major muscle were measured using the MultiScanBase, version 13, image analysis system (Computer Scanning System Ltd., Warsaw, Poland). The following microstructural traits of the pectoralis major muscle were measured: fiber cross-sectional area, fiber perimeter, fiber horizontal (**H**) and vertical (**V**) diameter, and thickness of the perimysium and endomysium. The determinations were made on 3 pectoralis major muscle preparations per duck. A total of 144 preparations of the pectoralis major muscle were used to determine the microstructure. Around 150–200 muscle fibers were measured in each preparation, and 50–100 measurements of the connective tissue thickness (perimysium and endomysium) were made. A magnification of 100 × was applied. Based on the data for horizontal (**H**) and vertical (**V**) diameters of the muscle fiber, the H:V diameter ratio was calculated.

Statistical Analysis

Statistical analysis was performed for data on basic chemical composition, physicochemical and sensory traits, and textural, microstructural and rheological traits of the meat. Arithmetic means and standard error of mean (**SEM**) were calculated for each trait (for all groups together). Normal distribution of the traits was analyzed according to the Shapiro–Wilk test. Two-way analysis of variance was used to determine the effect of genotype and sex on the analyzed meat quality traits of spent Pekin ducks at the age of 112 wk. Finally, the following linear model was used: $Y_{ijk} = \mu + a_i + b_j + (a \cdot b)_{ij} + e_{ijk}$, where Y_{ijk} is the value of the analyzed trait, μ is the overall mean of the analyzed trait, a_i is the effect of the i-th genotype, b_j is the effect of the j-th sex, $(a \cdot b)$ is an interaction of genotype with regard to sex, e_{ijk} is the random error.

The analyzed traits were statistically characterized using SAS software, version 9.4 (SAS Institute Inc., 2014). Significant differences (at $P < 0.05$) between the compared genotypes and between males and females were determined using the Tukey test. For all the analyzed traits of the carcass and meat quality, the individual bird was the experimental unit.

RESULTS AND DISCUSSION

No significant ($P > 0.05$) effect of genotype, sex, and their interaction on the weight of eviscerated carcass with the neck was found (Table 1). The average carcass weight in 112-week-old P33 males was higher than in P8 and LsA males, and that in P8 females was higher than in P33 and LsA females of the same age. Gornowicz and Szukalski (2015) reported significantly higher carcass weight in P8 ducks than in P33 and LsA ducks aged 8 wk. The carcass weight in 8-week-old LsA ducks was higher, and that in P8 and P33 birds was lower than in the 112-week-old ducks from our study. The carcasses of LsA males had a nonsignificantly ($P > 0.05$) higher content of breast muscles (%) than the carcasses of P33 and P8 males. The carcasses of 112-week-old P33 females contained more ($P > 0.05$) breast muscle than the carcasses of P8 and LsA females. Breast muscle percentage in eviscerated carcass with the neck from 112-week-old P33, P8, and LsA ducks was higher than in ducks of the same genotype at the age of 8 wk (Gornowicz and Szukalski, 2015), which may be indicative of the continued growth of breast muscles in the studied ducks after 8 wk of age. Genotype and sex did not have a significant effect on leg muscle content in the eviscerated carcasses from 112-week-old ducks under study. The carcasses of LsA males had a higher ($P > 0.05$) leg muscle percentage than the carcasses of P33 and P8 males, while the carcasses of P33 females had a higher leg muscle percentage than the carcasses of P8 and LsA females. The leg muscle percentage in the carcasses from P33 females was higher ($P > 0.05$) than in male carcasses, while the carcasses from P8 and LsA ducks had a higher leg muscle percentage in males than in females. Another study (Gornowicz, 2011) found leg muscle percentage in eviscerated carcasses with the neck, without giblets, to be higher in P33 ducks (12.6%) than LsA birds (11.5%).

Table 1. Effect of genotype and sex on carcass traits of 112-week-old Pekin ducks from genetic resources flocks.

	P33		P8		LsA			*P* Value		
Item	Male (n = 8)	Female (n = 8)	Male (n = 8)	Female (n = 8)	Male (n = 8)	Female (n = 8)	SEM	Genotype (**G**)	Sex (**S**)	G*S
Carcass weight (g)	1,856	1,757	1,823	1,960	1,762	1,732	27.2	0.089	0.952	0.179
Breast muscle (%)	15.8	18.5	18.0	17.5	18.5	17.4	0.3	0.511	0.493	0.013
Leg muscle (%)	12.0	13.0	12.4	12.1	12.5	12.1	0.2	0.799	0.816	0.196
Skin with subcutaneous fat (%)	27.9	19.8	23.2	24.7	21.6	21.3	0.8	0.305	0.133	0.033
Abdominal fat (%)	0.1	0.1	0.1	0.2	0.1	0.1	0.1	0.332	0.629	0.853
Neck (%)	6.8	8.5	8.0	7.4	8.4	7.7	0.2	0.280	0.529	0.001
Wings (%)	12.9	14.3	12.7	12.9	13.3	13.2	0.3	0.159	0.158	0.156
Remainders (%)	24.5	25.8	25.6	25.2	25.6	28.2	0.5	0.906	0.737	0.801

Table 2. Effect of genotype and sex on basic chemical composition of breast and leg muscles of 112-week-old Pekin ducks from genetic resources flocks.

Item	P33		P8		LsA		SEM	*P* Value		
	Male (n = 8)	Female (n = 8)	Male (n = 8)	Female (n = 8)	Male (n = 8)	Female (n = 8)		Genotype (**G**)	Sex (**S**)	G*S
Water (%)										
BM	70.1[b]	69.4[b]	71.1[a]	71.0[a]	70.7[a]	70.9[a]	0.1	0.001	0.281	0.023
LM	66.2[b]	64.1[b]	68.0[a]	66.7[a]	67.5[a]	67.9[a]	0.2	0.001	0.001	0.001
Protein (%)										
BM	23.5	23.7	23.9	24.2	23.9	23.8	0.1	0.129	0.462	0.587
LM	21.0[b]	21.4[a]	21.1[b]	19.6[b]	21.8[a]	21.2[a]	0.1	0.001	0.001	0.090
Fat (%)										
BM	2.4[a]	3.4[a]	1.9[b]	2.2[b]	2.4[a]	2.3[b]	0.1	0.001	0.003	0.007
LM	8.0[a]	11.1[a]	6.3[b]	9.3[b]	6.8[b]	7.0[b]	0.3	0.001	0.001	0.001
Collagen (%)										
BM	1.6	1.4	1.4	1.4	1.6	1.4	0.1	0.291	0.101	0.201
LM	1.9[a]	2.3[a]	1.7[b]	1.8[b]	1.9[a]	2.0[b]	0.1	0.001	0.001	0.052

[a,b]are the mean values of traits in rows, marked with different letters, which differ significantly between strains ($P < 0.05$).
Abbreviations: BM, breast muscle; LM, leg muscle.

In all the compared groups of ducks, the percentage of skin with subcutaneous fat and abdominal fat was relatively low. The percentage of skin with subcutaneous fat in eviscerated carcass with the neck from the analyzed strain ducks did not exceed 25% and was lower than in the experiments by Gornowicz (2011) and Kokoszyński and Bernacki (2011). The percentage of skin with subcutaneous fat was higher in male than in female carcasses (mean for 3 strains), which is in contradiction with the dissection results for 8-week-old ducks of the same genotype (Gornowicz and Szukalski, 2015). The abdominal fat content (0.1–0.2%) in the carcasses from the analyzed ducks was much lower than in young Pekin ducks investigated by Kwon et al. (2014), Gornowicz and Szukalski (2015) and Oh et al. (2015). The low carcass fatness in breeder ducks is a desirable trait allowing for better development of the internal organs, and the relatively low body weight enables the maintenance good motor activity and leg quality, which has a positive effect on egg fertility. Earlier experiments with ducks showed that diet has a large effect on carcass composition and fatness (Sigolo et al., 2017; Xie et al., 2017; Liu et al., 2019).

The carcasses of LsA males were characterized by a higher percentage of neck and wings than the males from the other strains, while the carcasses of P33 females contained more neck and wings than the carcasses of P8 and LsA females (Table 1). The carcasses from the analyzed ducks showed a high percentage of the remainder carcass (skeleton with some small skeletal muscles), which is used to make broths and other soups. Qiao et al. (2017) found that broth from spent layer ducks has a more preferable aroma and flavor than broth made from the meat of young ducks. Our study also demonstrated a significant effect of the genotype by sex interaction for the content of breast muscles, skin with subcutaneous fat, and neck percentage in eviscerated carcasses with the neck.

The compared groups of ducks differed ($P < 0.05$) in water and fat percentage in breast and leg muscles and in protein and collagen content in leg muscles. The breast and leg muscles of P33 ducks had a significantly lower water content than the breast and leg muscles of P8 and LsA ducks, while the leg muscles of P33 ducks contained significantly more fat than the leg muscles of ducks of the other strains. The leg muscles of P33 and P8 males contained significantly less protein than those of LsA males, while the leg muscles of P8 females had a significantly lower protein and collagen content than the leg muscles of P33 and LsA females. Regardless of genetic origin, males contained significantly less fat in breast muscles and significantly more water and protein and less ($P < 0.05$) fat and collagen in the leg muscles than the females. In our study, we found the genotype by sex interaction to be significant for the water and fat content of breast and leg muscles (Table 2). The breast and leg muscles of the analyzed P33, P8, and LsA ducks had a lower water and fat content and a higher protein content than Pekin ducks aged 16 wk evaluated by Huda et al. (2011). Qiao et al. (2017) reported lower water content and higher protein content in the breast and thigh muscles from spent laying ducks aged 500 days than Cherry Valley broiler ducks at the age of 38 days and hybrid Cherry Valley and Chinese native ducks at the age of 70 days. In turn, Boni et al. (2010) reported lower water, protein, and ash content and higher fat content in the breast muscles of spent quails (aged 8 mo ±3 D) than in the breast muscles of young quails (aged 8 wk ±3 D).

Duck genotype had no significant effect on the sodium, potassium, phosphorus, zinc, iron, and copper content of the breast and leg muscles, nor on the magnesium content of the leg muscles. LsA and P8 drakes had significantly more magnesium in the breast muscles than the breast muscles of P33 drakes, while LsA and P33 females had significantly more magnesium in the breast muscles than P8 females (Table 3). The sex of birds did not have a significant effect on the content of analyzed minerals (Na, K, P, Mg, Zn, Fe, Cu) in the breast and leg muscles of 112-week-old Pekin ducks from genetic resources flocks. Compared with females, male breast muscles contained more sodium; less potassium, phosphorus, magnesium, and iron; and as much zinc and copper. The male leg muscles had a higher

Table 3. Effect of genotype and sex on content of some minerals in mg/100 g of breast and leg meat of 112-week-old Pekin ducks from genetic resources flocks.

Item	P33		P8		LsA		SEM	*P* Value		
	Male (n = 8)	Female (n = 8)	Male (n = 8)	Female (n = 8)	Male (n = 8)	Female (n = 8)		Genotype (**G**)	Sex (**S**)	G*S
Na – sodium										
BM	122.3	114.0	112.7	104.4	115.1	105.0	3.0	0.574	0.273	0.994
LM	105.4	113.1	96.5	96.4	96.6	99.7	2.5	0.250	0.595	0.889
K − potassium										
BM	301.9	351.0	321.4	315.7	347.1	350.4	5.2	0.118	0.201	0.145
LM	299.0	307.8	315.5	312.7	296.3	298.1	3.7	0.377	0.792	0.890
P − phosphorus										
BM	48.6	45.6	45.6	50.4	47.1	47.2	0.5	0.386	0.329	0.382
LM	40.3	42.9	38.2	41.0	42.5	38.9	0.6	0.309	0.592	0.056
Mg − magnesium										
BM	22.7^{b}	25.9^{a}	23.7^{a}	24.6^{b}	26.5^{a}	28.6^{a}	0.2	0.032	0.381	0.705
LM	21.1	24.8	24.3	23.7	21.9	22.3	0.1	0.596	0.445	0.468
Zn – zinc										
BM	1.6	1.6	1.7	1.7	1.5	1.5	0.1	0.470	0.967	0.984
LM	3.0	3.3	2.7	2.8	3.0	3.2	0.1	0.360	0.518	0.970
Fe − iron										
BM	5.4	6.3	5.7	6.1	6.3	5.6	0.1	0.996	0.699	0.411
LM	4.7	3.8	4.7	4.2	4.8	4.2	0.1	0.529	0.211	0.647
Cu − copper										
BM	0.4	0.4	0.3	0.4	0.4	0.4	0.3	0.499	0.490	0.435
LM	0.3	0.3	0.3	0.3	0.3	0.3	0.6	0.519	0.071	0.880

[a,b]Mean values of traits in rows, marked with different letters, which differ significantly between strains ($P < 0.05$).
Abbreviations: BM, breast muscle; LM, leg muscle.

content of iron; a lower content of sodium, potassium, phosphorus, magnesium, and zinc; and the same content of copper as the female leg muscles. The genotype by sex interaction was not significant for the analyzed minerals in the breast and leg muscles. Zabuir Siddiqi et al. (1994) noted differences in the mineral (Ca, P, Na, K, Zn, Fe, Cu, Mn) content of breast and leg muscles from spent layers (Desi, Lyallpur Silver Black, White Plymouth Rock, White Leghorn). In turn, Kokoszyński et al. (2015) reported lower sodium, potassium, phosphorus, magnesium, and zinc content in the breast muscles of spent broiler breeder Ross 308 (age 64 wk) than in broiler chickens (age 6 wk) of the same origin.

The breast muscles of P8 ducks had higher pH_{24} and the leg muscles of P33 ducks had lower pH_{24} than the muscles of the ducks of the other genotypes. Males exhibited higher ($P > 0.05$) pH_{24} of breast and leg muscles than females. Electrical conductivity was highest in the breast muscles of P8 ducks and lowest in P33 ducks. The leg muscles of LsA ducks had higher ($P < 0.05$) electrical conductivity than the leg muscles of P33 and P8 birds. The breast muscles of P33 ducks showed highest drip loss on average. Cooking loss of breast and leg muscles was highest in LsA ducks and lowest in P8 birds. The sex of birds did not have a significant ($P > 0.05$) effect on the acidity (pH_{24}), electrical conductivity (EC_{24}), and drip and cooking losses of the breast and leg muscles from 112-week-old ducks of the compared genotypes (Table 4). The genotype by sex interaction for physicochemical properties was not significant. In an earlier

Table 4. Effect of genotype and sex on some physicochemical properties of breast and leg muscles of 112-week-old Pekin ducks from genetic resources flocks.

Item	P33		P8		LsA		SEM	*P* Value		
	Male (n = 8)	Female (n = 8)	Male (n = 8)	Female (n = 8)	Male (n = 8)	Female (n = 8)		Genotype (**G**)	Sex (**S**)	G*S
pH_{24}										
BM	5.7	5.8	6.1	5.7	6.0	5.7	0.1	0.764	0.135	0.249
LM	5.8	6.0	6.4	5.8	6.1	6.2	0.1	0.458	0.624	0.118
EC_{24} (mS/cm)										
BM	6.4	7.5	8.3	7.7	7.9	7.6	0.2	0.102	0.784	0.207
LM	4.0^{b}	3.6^{b}	2.9^{b}	3.8^{b}	4.8^{a}	4.6^{a}	0.2	0.024	0.824	0.381
Drip loss (%)										
BM	0.8	1.2	1.4	0.5	0.8	0.8	0.1	0.683	0.457	0.061
LM	0.7	0.8	1.3	0.5	1.0	1.0	0.1	0.344	0.206	0.511
Cooking loss (%)										
BM	32.1	31.1	32.2	29.2	32.4	32.7	0.3	0.097	0.058	0.099
LM	34.4	31.5	30.7	30.2	34.0	31.7	0.3	0.112	0.069	0.348

[a,b]are the mean values of traits in rows, marked with different letters, which differ significantly between strains ($P < 0.05$).
Abbreviations: BM, breast muscle; LM, leg muscle.

Table 5. Effect of genotype and sex on color of breast and leg muscles of 112-week-old Pekin ducks from genetic resources flocks.

Item	P33		P8		LsA		SEM	*P* Value		
	Male (n = 8)	Female (n = 8)	Male (n = 8)	Female (n = 8)	Male (n = 8)	Female (n = 8)		Genotype (**G**)	Sex (**S**)	G*S
L* − lightness										
BM	38.3	39.9	39.5	41.1	39.0	39.5	0.4	0.380	0.117	0.806
LM	45.8	45.8	42.6	45.7	47.3	45.2	0.2	0.316	0.756	0.228
a* − redness										
BM	18.1	18.9	18.7	18.2	17.1	18.2	0.2	0.297	0.287	0.345
LM	21.8	19.6	20.1	20.9	18.1	20.6	0.6	0.401	0.687	0.100
b* − yellowness										
BM	2.9	3.0	3.6	3.1	2.5	3.9	0.5	0.757	0.380	0.124
LM	8.0	6.6	7.1	7.2	5.7	5.7	0.3	0.054	0.488	0.484

Abbreviations: BM, breast muscle; LM, leg muscle.

experiment, Qiao et al. (2017) found significantly lower drip loss in the breast muscles of spent layer ducks than Cherry Valley ducks aged 38 days as well as significantly lower cooking loss in the breast muscles of spent layer ducks than the breast muscles of 70-day-old hybrids of Cherry Valley and Chinese native ducks. Furthermore, the breast muscles of spent layer ducks had significantly higher pH than the muscles of 38-day-old Cherry Valley ducks. Boni et al. (2010) observed significantly higher pH value for the meat of spent quails (aged 8 month ±3 D) than young quails (aged 8 wk ±3 D). In turn, Onk et al. (2019) found higher cooking loss from male than female Pekin ducks, which is consistent with our findings.

The analysis of our results (Table 5) shows that the analyzed 112-week-old P33, P8, and LsA ducks did not differ significantly in the color lightness (L*), redness (a*), and yellowness (b*) of breast and leg muscles. The sex of birds had no significant effect on the color parameters of breast and leg muscles. The genotype by sex interaction for the color attributes of breast and leg meat was not significant, either. Qiao et al. (2017) observed significantly lower L* and b* values (darker color) of breast muscles in spent layer ducks aged 500 days than in the ducks aged 38 days (Cherry Valley broiler ducks) and 70 days (Cherry Valley × Chinese native ducks). Hoffman and Fisher (2001) and Boni et al. (2010) found color lightness (L*) to increase significantly and redness (a*) and yellowness (b*) to decrease with increasing age, with the meat becoming darker and redder.

Our study determined, for the first time, the textural traits (hardness, springiness, cohesiveness, chewiness, gumminess, WB shear force) and rheological properties (sum of elastic moduli and sum of viscous moduli) of the pectoralis major muscle in P33, P8, and LsA ducks after 2 reproductive seasons (Table 6). The heat-treated breast muscle (*m. pectoralis major*) of P33 and LsA ducks had significantly poorer tenderness (higher maximum shear force) and lower sum of elastic moduli than the breast muscles of P8 ducks. The effect of sex and the genotype by sex interaction were not confirmed statistically ($P > 0.05$). Balowski et al. (2015) noted lower hardness, springiness, chewability, and gumminess of the breast muscle from wild male mallards (*Anas platyrhynchos* L.) older than 12 months than the 112-week-old P33, P8, and LsA ducks from our study. Lee et al. (2015) reported higher tenderness (lower WB shear force) of female than male breast muscles of Korean native ducks and commercial Pekin ducks, which was confirmed in our experiment. However, another study (Michalczuk et al., 2016) found that breast muscles were more tender in young male than in female Pekin ducks.

The compared genetic groups of the ducks differed significantly ($P < 0.05$) at 112 wk of age in fiber cross-sectional area, fiber perimeter, and vertical diameter of the muscle fiber. LsA ducks (English Pekin) were characterized by lower values of these traits than P33 and P8 ducks. The effect of sex and the genotype by sex interaction for the microstructural traits of pectoralis major muscle of the analyzed ducks were not confirmed

Table 6. Effect of genotype and sex on textural traits of pectoralis major muscle of 112-week-old Pekin ducks from genetic resources flocks.

Item	P33		P8		LsA		SEM	*P* Value		
	Male (n = 8)	Female (n = 8)	Male (n = 8)	Female (n = 8)	Male (n = 8)	Female (n = 8)		Genotype (**G**)	Sex (**S**)	G*S
Hardness (N)	51.8	45.8	49.7	49.8	57.6	53.2	1.5	0.183	0.278	0.713
Cohesiveness	0.5	0.4	0.4	0.5	0.5	0.5	0.1	0.097	0.386	0.056
Springiness (cm)	1.5	1.6	1.6	1.5	1.4	1.5	0.1	0.121	0.081	0.072
Chewiness (N × cm)	36.1	30.5	32.6	33.7	39.8	36.5	1.3	0.215	0.330	0.579
Gumminess (N)	24.6	20.2	21.3	22.4	27.6	24.2	1.0	0.141	0.230	0.434
WB shear force (N)	93.1[a]	91.7[a]	89.9[b]	68.9[b]	100.7[a]	95.3[a]	3.2	0.045	0.153	0.401
Sum of elastic moduli (KPa)	269.6[b]	305.4[b]	383.6[a]	345.4[a]	344.4[a]	311.0[b]	9.4	0.002	0.468	0.128
Sum of viscous moduli (KPa × s)	12,842	10,140	14,539	13,613	13,116	10,756	562.0	0.246	0.254	0.352

[a,b]Mean values of traits in rows, marked with different letters, which differ significantly between strains ($P < 0.05$).

Table 7. Effect of genotype and sex on microstructure of pectoralis major muscle of 112-week-old Pekin ducks from genetic resources flocks.

Item	P33		P8		LsA		SEM	*P* Value		
	Male (n = 8)	Female (n = 8)	Male (n = 8)	Female (n = 8)	Male (n = 8)	Female (n = 8)		Genotype (**G**)	Sex (**S**)	G*S
Fiber cross-sectional area (μm^2)	50.1a	58.1^a	51.7^a	46.8^b	38.2^b	46.9^b	1.7	0.018	0.220	0.154
Fiber perimeter (μm)	30.6^a	32.1^a	31.1^a	29.6^a	26.8^b	26.1^b	0.7	0.016	0.868	0.670
Fiber diameter H (μm)	8.1	8.3	8.1	7.8	7.2	7.8	0.2	0.052	0.692	0.833
Fiber diameter V (μm)	8.3^a	9.0^a	8.6^a	8.0^b	7.0^b	8.1^b	0.2	0.016	0.198	0.084
H:V diameter ration (x)	1.0	0.9	0.9	1.0	1.0	0.8	0.1	0.894	0.169	0.229
Perimysium thickness (μm)	5.2	4.4	3.9	4.0	4.0	4.7	0.2	0.099	0.948	0.223
Endomysium thickness (μm)	1.2	1.0	1.0	1.0	1.0	1.0	0.1	0.584	0.596	0.101

[a, b]Mean values of traits in rows, marked with different letters, which differ significantly between strains ($P < 0.05$).

statistically (Table 7). Kokoszynski et al. (2018) observed no significant differences between 110-week-old P9 (French Pekin), K2 (bred from wild mallards–*A. platyrhynchos* L. and Pekin ducks), and KhO1 ducks (hybrid of Khaki Campbell drake and Orpington Fauve duck) after 2 reproductive seasons in fiber cross-sectional area, fiber perimeter, and fiber vertical diameter, which is contrary to the results of the present experiment. On the other hand, the same authors found significantly thicker endomysium (connective tissue surrounding a single muscle fiber) and perimysium (connective tissue surrounding a muscle fiber bundle) in the pectoralis major muscle of K2 ducks and in KhO1 ducks a significantly greater endomysium than heavier P9 ducks, but this was not confirmed by our study. Balowski et al. (2015) found clearly thicker perimysium (15.93 μm) and endomysium (3.14 μm) in wild mallards (*A. platyrhynchos* L.) older than 12 months than in the 112-week-old P33, P8, and LsA from our study, which is probably due to the higher activity of breast muscles in wild mallards than in farmed ducks (Geldenhuys et al., 2014).

In summary, the carcasses obtained from P33, P8, and LsA ducks after 2 reproductive seasons were characterized by high content of meat, in particular breast muscle, and low content of skin with subcutaneous fat and abdominal fat, which meets the requirements of consumers. Their meat was dark in color (low L*, high iron content) and had relatively high amounts of protein. The evaluated ducks differed in WB shear force, sum of elastic moduli, fiber cross-sectional area, fiber perimeter and vertical fiber diameter of the pectoralis major muscle, the content of water, fat and magnesium in breast muscles, electrical conductivity, and water, protein, fat, and collagen content of leg muscles.

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