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# Carcass, physicochemical and sensory characteristics of meat from genetic reserve ducks after two reproductive seasons

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## Abstract

The aim of the study was to compare carcass composition and meat quality of i) Pekin ducks of French origin (P9), ii) crosses of wild mallard and Pekin duck (K2), and iii) crosses of Khaki Campbell drakes and Orpington Fauve ducks (KhO1). Twenty carcasses from 110-week-old ducks of each genetic group were used. Carcass weight of P9 was significantly higher than that of K2 and KhO1. Carcasses of K2 ducks had a significantly lower percentage of neck and leg muscles and giblet weight compared with P9 and KhO1 ducks, while carcasses of KhO1 ducks had a significantly higher percentage of wing meat compared with K2 and P9, and a significantly lower percentage of breast muscles compared with P9 ducks. Breast and leg muscles of P9 contained significantly more water than those of K2 and KhO1, and the breast muscles of P9 ducks had more protein and less fat than those of KhO1 birds. The leg muscles of KhO1 contained significantly more protein, and those of K2 had significantly more fat than the other duck groups. Breast muscles of P9 and KhO1 ducks had significantly more collagen but had less in leg muscles compared with K2. Breast fillets from P9 ducks showed higher L*, a*, and b* colour values and shear force than K2 and KhO1 ducks.

**Keywords:** carcass composition, conservation flocks, meat quality, spent duck
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## Introduction

With the intensification of poultry production several decades ago, many local poultry breeds and varieties around the world began to be marginalized or eliminated (Ksiazkiewicz, 2002). In an effort to prevent the loss of genetic diversity, Poland was one of the few countries to develop comprehensive large-scale conservation programmes for local poultry breeds and varieties with a small population. By 2016, 15 breeds, strains and lines of hens, 14 of geese, and 10 of ducks were included in this programme.

In Poland, around 90% of duck meat is obtained from the slaughter of hybrid Pekin ducks at the age of 6 to 8 weeks. Spent duck meat is considered a by-product, which is obtained after the production season. It is tough and dry (Sumarmono & Wasito, 2010; Qiao *et al*., 2017), which limits its use for making dishes. In some countries, especially in Africa and Asia, spent duck carcasses are used to prepare strong aromatic broths and other soups (Qiao *et al*., 2017). In Poland, as in many other countries, the carcasses, meat, giblets and feet of spent ducks can be used to make soups and traditional regional dishes that have gained popularity in recent years. The meat of ducks after the reproductive season is also used for emulsion-type meat products, including sausages such as mortadella and frankfurters (Bhattacharyya *et al*., 2007; Sumarmono & Wasito, 2010; Naveen *et al*., 2016), homogeneous offal products (such as liverwurst), duck meat pickles, meatballs, and nuggets (Nurwantoro *et al*., 2010; Kanagaraju & Subramanian, 2012: Kumar *et al*., 2014).

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Carcasses from native ducks that are more than eight weeks old are characterized by a relatively high content of breast muscles (14.0 - 18.4%) and leg muscles (11.2 - 12.4%). Breast muscles from native ducks are high in valuable protein and low in fat, and are characterized by a favourable fatty acid profile (large amounts of polyunsaturated fatty acids (PUFAs), linoleic and linolenic acids), a desirable dark colour, high water-holding capacity, and relatively low cooking loss (Witkiewicz *et al.,* 2004; Muhlisin *et al.,* 2013; Kwon *et al.*, 2014; Gornowicz & Szukalski, 2015). Qiao *et al*. (2017) determined significantly higher contents of protein and fat, PUFA and n-6/n-3 ratio for fatty acids in breast muscles of spent layer ducks, aged 500 days, compared with young slaughter ducks aged 37 and 70 days.

The limited scientific evidence on the carcass composition and meat quality of ducks after the reproductive season (Sumarmono & Wasito, 2010; Qiao *et al*., 2017) encouraged the authors to conduct this research. Owing to its high nutritive value (Qiao *et al.*, 2017), the meat of spent ducks may add variety to the diet of modern consumers. Earlier Witkiewicz *et al.* (2004) and Kokoszyński (2011) reported higher crude protein content, lower muscle fibre diameter and higher sensory scores for breast and leg meat from the conserved ducks or their hybrids in Poland compared with pedigree ducks and commercial Pekin hybrids. The results of the evaluation of meat traits in P9, K2, and KhO1 ducks after two reproductive seasons are presented for the first time. In keeping with the Genetic Resources Conservation Programme, breeder flocks of ducks at the Waterfowl Genetic Resources Station in Dworzyska are liquidated after two reproductive seasons. The objective of the study was to compare 110-week-old P9, K2 and KhO1 ducks, which were included in the programme, after two reproductive seasons for carcass weight and composition, pH and electrical conductivity at 24 hours post mortem ($pH_{24}$ and $EC_{24}$, respectively) drip loss, cooking loss, colour coordinates (L*, a*, b*) (Commission Internationale de l'Eclairage (CIE) 1976), sensory properties of breast and leg muscles, and texture of the breast muscle.

## Materials and Methods

The study used 60 carcasses of ducks from three genetic reserve flocks, namely P9 (Pekin of French origin), K2 (bred from wild mallard (*Anas platyrhynchos* L.) and Pekin ducks) and KhO1 (hybrid of Khaki Campbell drake and Orpington Fauve duck). The carcasses were obtained from 110-week-old ducks after two reproductive seasons. The male-to-female ratio of the carcasses was 1:1. Prior to slaughter, birds were confined indoors in pens on litter, and were fed a complete diet for breeder ducks. The duck diet contained 18.5% crude protein (CP) and 11.1 MJ of metabolizable energy per kg.

Eviscerated carcasses with neck and edible giblets (heart, gizzard and liver) were cooled in a Hendi refrigerated cabinet (Hendi, Gądki, Poland) at 4 °C for 18 hours. After removal from the refrigerator, the chilled carcasses were weighed on a WLC 6/12/F1/R electronic balance (Radwag, Radom, Poland) and analysed for $pH_{24}$ and $EC_{24}$. $pH_{24}$ was measured with a pH-Star meter (Ingenieurbüro Matthaus, Nobitz, Germany) that was equipped with a combination glass electrode for meat analysis. pH values were read from a liquid crystal display with an accuracy of 0.01. Prior to $pH_{24}$ measurement, the pH meter was calibrated with standard solutions (pH 7.0 and pH 5.5) and adjusted to the meat temperature (4 °C). Electrical conductivity (mS/cm) was measured with an LF-Star device (Ingenieurbüro Matthaus, Nobitz, Germany). The $pH_{24}$ and $EC_{24}$ were determined in *Musculus pectoralis superficialis* and drumstick muscles.

The whole carcasses were dissected using the method provided by Ziolecki and Doruchowski (1989) into abdominal fat, followed by neck without skin, wings with skin, skin with subcutaneous fat from the whole carcass without wings, breast muscle, leg muscle, and the remainder of the carcass. The remainder of the carcass contained the skeleton with some small skeletal muscles (intercostal, dorsal, suprascapular and others), with kidneys, but without lungs, windpipe, testicles, ovary, spleen and other internal organs. The separated carcass components were weighed on the balance and their percentage of eviscerated carcass with neck was calculated. The same balance was used to weigh (in g) edible giblets, that is, the heart (without pericardial sac), liver (without gallbladder) and gizzard (without digesta).

A near-infrared spectrometer (FoodScan) was used to determine the water, protein, fat and collagen content in breast and leg muscles. Foss FoodScan™, which has an artificial neural network method, enjoys AOAC Official Methods$^{SM}$ status) (AOAC International, 2007).

A model CR410 colorimeter (Konica Minolta, Japan) was used to determine the colour parameters L* (lightness), a* (relative redness, on red-green axis), and b* (relative yellowness, on yellow-blue axis). Wide-area illumination/0 ° viewing angle, 50-mm aperture size, and illuminant $D_{65}$ were used during the measurement. The meter was calibrated against a white reference tile (Y = 94.40, x = 0.3159, y = 0.3325). Drip loss was determined from the difference in breast and leg muscle weights before and after 24 hours' storage at 4 °C. The loss in the meat sample weight was expressed as a percentage. To determine cooking loss, ground samples of meat (20 g) were wrapped in absorbent cheesecloth and placed in a water bath at 85 °C for 10 min. Next, the samples were chilled in a refrigerating cabinet at 4 °C for 30 min. Cooking loss was calculated as percentage difference in the weight of meat samples before and after heat treatment.

To determine the sensory properties, breast and leg muscles were cooked in a 0.6% brine solution. During the sensory assessment, the meat was analysed for tenderness, juiciness, aroma intensity and desirability, and taste intensity and desirability. The meat samples were chilled to 60 °C. The assessment was performed by a panel of trained healthy judges in a special laboratory equipped with individual sensory booths at the Department of Animal Sciences of the UTP University of Science and Technology in Bydgoszcz (Poland). They used a 5-point scale provided by Barylko-Pikielna & Matuszewska (2009). Scoring ranged from 1 (lowest) to 5 (highest). Determinations were made of aroma and taste intensity (1 = imperceptible, 2 = perceptible, 3 = slightly pronounced, 4 = pronounced, 5 = very pronounced); aroma and taste desirability (1 = very undesirable, 2 = slightly undesirable, 3 = neutral, 4 = desirable, 5 = very desirable); juiciness (1 = dry, 2 = slightly dry, 3 = slightly juicy, 4 = moderately juicy, 5 = juicy); and tenderness (1 = very tough, 2 = tough, 3 = slightly tender, 4 = tender, 5 = very tender. After each assessment, the meat samples were removed from the mouth.

The textural and rheological properties of heat-processed breast muscles were studied with an Instron 1140 testing machine (Instron Corp., USA). The texture of meat was determined using the texture profile analysis (TPA) double compression test and the Warner-Bratzler (WB) test. Rheological properties were determined with the stress-relaxation test.

The–texture profile analysis test involved a double immersion of the plunger, which was 0.96 cm in diameter and 20±1 mm high, at a depth of 80% (16 mm) of its height. The height of the compressed sample was 4 mm. The samples were compressed parallel to muscle fibre orientation. That is, the muscle fibres were parallel to the crosshead and plunger. With the curve representing the strength-deformation dependence, these parameters were determined, namely hardness (maximum height of peak I), cohesiveness (ratio of the area of peak II to that of peak I), springiness of the base of the rising part of peak II, gumminess (the product of hardness and cohesiveness), chewiness (the product of hardness), cohesiveness and springiness (Bourne, 1982).

The WB test involved cutting the sample across the muscle fibres with a cross-section of 10 × 10 mm, using a specially designed knife (the triangle knife). The working speed of the crosshead for the test was 50 mm/min. The test allowed the maximum cutting force to be determined.

In the relaxation test the plunger, which was 1.26 cm in diameter, was driven into the breast muscle samples 2 mm deep (10% deformation) for 90 seconds to record the changes in stress. The generalized Maxwell model was applied to calculate the springiness and viscosity moduli. It consisted of three elements connected parallel to one another, namely the Hooke body and two viscous-springy Maxwell bodies. The model equation assumes this form:

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

Where: $\delta$ = tension (kPa),
$\varepsilon$ = deformation,
$E_0$ = elasticity module for the Hooke body (kPa),
$E_1$ and $E_2$ = elasticity moduli for Hooke bodies 1 and 2 respectively (kPa),
$\mu_1$ and $\mu_2$ = viscosity moduli for Maxwell body 1 and 2 respectively(kPa × s) and
$t$ = time.

For each sample, the sums of elasticity moduli ($E_0$+$E_1$+$E_2$) and viscosity moduli ($\mu_1$+$\mu_2$) were calculated to provide for a more reader-friendly interpretation of the results.

The data pertaining to carcass composition and meat quality of P9, K2 and KhO1 ducks were analysed statistically using SAS software, version 9.4 (SAS Institute Inc., 2014). Normal distribution of the traits of carcass composition and meat quality was verified with the Shapiro-Wilk test. All the traits of carcass composition and physicochemical and sensory characteristics of meat were normally distributed. Two-way analysis of variance was used to determine the effect of genetic group and sex on these meat characteristics. To this end, the following linear model was used:

$$y_{ijk} = \mu + a_i + b_j + ab_{ij} + e_{ijk}$$

Where: $y_{ijk}$ = an observation from the kth duck,
$\mu$ = the mean of the analysed trait,
$a_i$ = the effect of the ith genetic group,
$b_j$ = the effect of the jth sex,
$ab_{ij}$ = the interaction of genetic group and sex, and

$e_{ijk}$ = th random residual effect which was error for the hypothesis tests.

Significant differences in the means were further assessed with Tukey's test at *P* <0.05.

## Results

The average carcass weight of 110-week-old P9 males and females was significantly (*P* <0.05) higher than that of K2 and KhO1 birds (Table 1). The KhO1 females had significantly heavier carcasses than K2 females. Significant differences (*P* <0.05) in the carcass weight between males and females were observed only for KhO1 ducks. Ducks did not differ significantly (P <0.05) in the content of skin with subcutaneous fat, abdominal fat, and the remainder of the carcass. The carcasses of P9 birds had a significantly higher content of breast muscle (%) compared with those of KhO1 birds. Male carcasses contained more breast muscle than female carcasses in all these duck groups. Significant differences were observed only in the KhO1 birds. In all the duck groups under comparison, the content of skin with subcutaneous fat and the content of abdominal fat were relatively small. The remainder of the carcass was high in all the genetic groups, being highest in K2 ducks. The P9 and KhO1 ducks of both sexes contained more (*P* <0.05) leg muscle compared with K2, and P9 males had significantly more leg muscle compared with K2 and KhO1 males. The carcasses of P9 and KhO1 males were characterized by a significantly higher neck percentage compared with K2 males. The same pattern was found for the birds of both sexes. No significant difference was noted between females of the genetic groups. The carcasses of KhO1 males showed significantly (*P* <0.05) higher neck content compared with females. The carcasses from KhO1 males and females were characterized by the highest percentage of wings. K2 ducks of both sexes had significantly lower weight of edible giblets (total weight of heart, gizzard and liver) compared with P9 and KhO1 birds. KhO1 ducks of both sexes had significantly lower giblet weight compared with P9 ducks. The same pattern was found for females. K2 and KhO1 males exhibited significantly (*P* <0.05) lower weight of edible giblets compared with P9 males. Higher weight of giblets (*P* >0.05) was observed in KhO1 males than in K2 males. The genetic group by sex interaction was significant for percentage of leg muscles and for weight of giblets.

Significant differences (*P* <0.05) were found between these duck groups in the water, protein, fat and collagen content of breast and leg muscles (Table 2). The breast fillets of P9 ducks of both sexes contained significantly (*P* <0.05) more water than those of K2 and KhO1 ducks. The breast muscles of KhO1 birds contained significantly more water compared with K2 ducks. Breast muscles from P females contained significantly more water than the breast meat of K2 and KhO1 females. P9 and K2 females had a higher water content of breast muscles compared with P9 and K2 males. The leg muscles of P9 males had significantly higher water content (%) than those of K2 and KhO1 birds. The leg muscles of K2 females had more (*P* <0.05) water compared with P9 and KhO1 females. The leg muscles of P9 and KhO1 females were found to contain less (*P* >0.05) water than those of P9 and KhO1 males, and K2 females had higher water content than K2 males. The highest protein content was that in the breast muscle of Pekin P9 ducks. The breast muscles of P9 and K2 males were characterized by significantly higher protein content compared with those of KhO1 males, and those of P9 females compared with K2 and KhO1 females. Breast muscle protein content was higher in males than in females, but significant differences were noted only for K2 ducks. The leg muscles of P9 and KhO1 males had a higher (*P* <0.05) protein content compared with K2 males. A reverse pattern occurred in females. Male leg muscles were characterized by higher (*P* <0.05) protein content than in P9 and KhO1 females, but lower than in K2 females. The breast muscles of P9 males and females had significantly less fat compared with K2 and KhO1 birds. In the groups, the fat content of breast muscles was lower (*P* <0.05) in males than in females. In turn, the leg muscles of P9 and KhO1 birds were characterized by significantly lower fat content compared with the muscles of K2 birds. In all the groups, male leg muscles contained significantly (P <0.05) less fat than female muscles. In the breast muscles of P9 and KhO1 ducks, collagen content was higher than in the muscles of K2 ducks. The sex of birds had no significant effect on the collagen content of breast muscles. In turn, the leg muscles of P9 and KhO1 males had a significantly lower collagen content compared with the leg muscles of K2 males. Collagen content in the leg muscles of P9 and K2 females was significantly lower than in KhO1 females. Significant genetic group by sex interactions were found for all the chemical components except for the protein and collagen content of breast muscles.

**Table 1** Weight and composition of carcasses from 110-week-old ducks as affected by genetic group and sex

| Trait | Sex | Genetic group | | | *P*-value |
|---|---|---|---|---|---|
| | | P9 | K2 | KhO1 | Group*Sex |
| Carcass weight (g) | Total | $1878^{a} \pm 56.2$ | $1120^{b} \pm 46.3$ | $1206^{b} \pm 38.7$ | 0.400 |
| | Male | $1826^{a} \pm 66.8$ | $1125^{b} \pm 64.7$ | $1129^{b} \pm 93.3$ | |
| | Female | $1927^{a} \pm 57.3$ | $1115^{b} \pm 24.4$ | $1283^{c*} \pm 38.7$ | |
| Neck (%) | Total | $7.6^{a} \pm 0.2$ | $6.2^{b} \pm 0.2$ | $7.8^{a} \pm 93.3$ | 0.447 |
| | Male | $8.3^{a} \pm 0.1$ | $6.4^{b} \pm 0.1$ | $8.5^{a} \pm 32.7$ | |
| | Female | $7.0 \pm 0.2$ | $6.0 \pm 0.2$ | $7.2^{*} \pm 0.2$ | |
| Wings (%) | Total | $12.6^{a} \pm 0.2$ | $13.1^{a} \pm 0.2$ | $14.7^{b} \pm 0.3$ | 0.490 |
| | Male | $13.1^{a} \pm 0.2$ | $13.1^{a} \pm 0.3$ | $15.0^{b} \pm 0.3$ | |
| | Female | $12.0^{a} \pm 0.2$ | $13.1^{ab} \pm 0.2$ | $14.4^{b} \pm 0.3$ | |
| Breast muscles (%) | Total | $17.1^{a} \pm 0.4$ | $16.7^{ab} \pm 0.6$ | $15.8^{b} \pm 0.5$ | 0.362 |
| | Male | $17.4 \pm 0.1$ | $16.7 \pm 0.6$ | $17.2 \pm 0.5$ | |
| | Female | $16.7 \pm 0.5$ | $16.6 \pm 0.6$ | $14.4^{*} \pm 0.2$ | |
| Leg muscles (%) | Total | $12.4^{a} \pm 0.3$ | $10.1^{b} \pm 0.4$ | $11.9^{a} \pm 0.3$ | 0.049 |
| | Male | $13.4^{a} \pm 0.2$ | $10.3^{b} \pm 0.5$ | $11.3^{b} \pm 0.3$ | |
| | Female | $11.5^{*} \pm 0.2$ | $10.0 \pm 10.3$ | $12.5 \pm 0.2$ | |
| Skin and subcutaneous fat (%) | Total | $23.2 \pm 1.0$ | $23.8 \pm 0.9$ | $22.1 \pm 1.1$ | 0.237 |
| | Male | $20.3 \pm 0.7$ | $22.7 \pm 1.2$ | $18.3 \pm 0.5$ | |
| | Female | $26.1^{*} \pm 1.0$ | $24.8 \pm 0.5$ | $25.9^{*} \pm 0.7$ | |
| Abdominal fat (%) | Total | $0.2 \pm 0.1$ | $0.1 \pm 0.1$ | $0.1 \pm 0.1$ | 0.332 |
| | Male | $0.1 \pm 0.1$ | $0.1 \pm 0.1$ | $0.1 \pm 0.1$ | |
| | Female | $0.3 \pm 0.1$ | $0.2 \pm 0.1$ | $0.1 \pm 0.1$ | |
| Remainders of carcass (%) | Total | $26.9 \pm 0.5$ | $30.1 \pm 1.1$ | $28.2 \pm 0.7$ | 0.717 |
| | Male | $27.4 \pm 0.5$ | $30.6 \pm 1.3$ | $29.8 \pm 0.3$ | |
| | Female | $26.5 \pm 0.5$ | $29.6 \pm 1.1$ | $26.6^{*} \pm 0.7$ | |
| Edible giblets (g) | Total | $149.1^{a} \pm 5.7$ | $85.6^{b} \pm 2.9$ | $103.9^{c} \pm 5.0$ | 0.042 |
| | Male | $129.3^{a} \pm 1.3$ | $79.6^{b} \pm 1.5$ | $83.8^{b} \pm 2.1$ | |
| | Female | $168.8^{a*} \pm 4.6$ | $91.5^{b} \pm 2.8$ | $123.9^{c*} \pm 2.3$ | |

P9: Pekin ducks of French origin, K2: crosses of wild mallard and Pekin duck, KhO1: crosses of Khaki Campbell drakes and Orpington Fauve ducks
[a,b] Within a row, means with a common superscript do not differ at $P < 0.05$
* Within a trait, the asterisk indicates a significant difference between males and females

**Table 2** Chemical composition of breast and leg muscles in 110-week-old ducks as affected by genetic group and sex

| Trait | Sex | Genetic group | | | *P*-value |
|---|---|---|---|---|---|
| | | P9 | K2 | KhO1 | Group*Sex |
| Water, breast muscles (%) | Total | $71.5^{a} \pm 0.1$ | $70.3^{b} \pm 0.1$ | $70.9^{c} \pm 0.1$ | 0.001 |
| | Male | $71.3^{a} \pm 0.1$ | $69.8^{b} \pm 0.1$ | $70.9^{c} \pm 0.1$ | |
| | Female | $71.8^{a*} \pm 0.1$ | $70.7^{b*} \pm 0.1$ | $70.9^{b} \pm 0.1$ | |
| Water, leg muscles (%) | Total | $67.5^{a} \pm 0.2$ | $66.8^{b} \pm 0.4$ | $65.4^{b} \pm 0.3$ | 0.001 |
| | Male | $68.2^{a} \pm 0.1$ | $65.4^{b} \pm 0.1$ | $66.7^{c} \pm 0.1$ | |
| | Female | $66.7^{a*} \pm 0.1$ | $68.2^{b*} \pm 0.2$ | $64.1^{c*} \pm 0.1$ | |
| Protein, breast muscles (%) | Total | $24.0^{a} \pm 0.1$ | $23.8^{ab} \pm 0.1$ | $23.6^{b} \pm 0.1$ | 0.131 |
| | Male | $24.1^{a} \pm 0.1$ | $24.0^{a} \pm 0.1$ | $23.8^{b} \pm 0.1$ | |
| | Female | $23.9^{a} \pm 0.1$ | $23.5^{b*} \pm 0.1$ | $23.5^{b} \pm 0.1$ | |
| Protein, leg muscles (%) | Total | $19.2^{a} \pm 0.3$ | $19.4^{a} \pm 0.2$ | $20.5^{b} \pm 0.2$ | 0.001 |
| | Male | $20.4^{a} \pm 0.1$ | $18.8^{a} \pm 0.1$ | $21.3^{c} \pm 0.1$ | |
| | Female | $18.0^{a*} \pm 0.1$ | $20.1^{b*} \pm 0.1$ | $19.6^{c*} \pm 0.1$ | |
| Fat, breast muscles (%) | Total | $1.8^{a} \pm 0.1$ | $2.2^{ab} \pm 0.1$ | $2.6^{b} \pm 0.1$ | 0.001 |
| | Male | $1.3^{a} \pm 0.1$ | $1.9^{b} \pm 0.1$ | $2.2^{c} \pm 0.1$ | |
| | Female | $2.3^{a*} \pm 0.1$ | $2.6^{b*} \pm 0.1$ | $2.9^{c*} \pm 0.1$ | |
| Fat, leg muscles (%) | Total | $7.6^{a} \pm 0.4$ | $9.9^{b} \pm 0.2$ | $7.1^{ac} \pm 0.1$ | 0.001 |
| | Male | $6.0^{a} \pm 0.1$ | $9.1^{b} \pm 0.1$ | $6.2^{c} \pm 0.1$ | |
| | Female | $9.1^{a*} \pm 0.1$ | $10.7^{b*} \pm 0.1$ | $7.9^{c*} \pm 0.1$ | |
| Collagen, breast muscles (%) | Total | $1.5^{a} \pm 0.1$ | $1.4^{b} \pm 0.1$ | $1.5^{a} \pm 0.1$ | 0.698 |
| | Male | $1.5^{a} \pm 0.1$ | $1.3^{b} \pm 0.1$ | $1.6^{a} \pm 0.1$ | |
| | Female | $1.6 \pm 0.1$ | $1.4 \pm 0.1$ | $1.5 \pm 0.1$ | |
| Collagen, leg muscles (%) | Total | $1.7^{a} \pm 0.1$ | $1.9^{b} \pm 0.1$ | $1.9^{b} \pm 0.1$ | 0.006 |
| | Male | $1.7^{a} \pm 0.1$ | $2.2^{b} \pm 0.2$ | $1.8^{a} \pm 0.1$ | |
| | Female | $1.7^{a} \pm 0.1$ | $1.6^{a*} \pm 0.1$ | $1.9^{b} \pm 0.1$ | |

P9: Pekin ducks of French origin, K2: crosses of wild mallard and Pekin ducks, KhO1: crosses of Khaki Campbell drakes and Orpington fauve ducks
[a,b] Within a row, means with a common superscript do not differ at $P < 0.05$
* Within a trait, the asterisk indicates a significant difference between males and females

Differences in $pH_{24}$ were observed among the genetic groups for the breast muscles of male ducks but were not significant. The $pH_{24}$ of breast muscles from P9 and KhO1 females was significantly ($P < 0.05$) higher compared with K2 females. P9, K2 and KhO1 ducks did not differ in the $pH_{24}$ of leg muscles. The leg muscles showed higher pH values measured 24 hours post-mortem compared with the breast muscles (Table 3). The breast fillets of P9 and K2 males and females were characterized by higher electric conductivity compared with the breast muscles of KhO1 birds. The leg muscles of P9 males and females showed significantly higher electrical conductivity compared with the muscles of K2 and KhO1 birds. The sex of birds had no significant effect on the $EC_{24}$ of breast and leg muscles from P9, K2 and KhO1 ducks. There was no significant effect of genotype on the cooking loss of breast and leg muscles and on the drip loss of breast muscles. The leg muscles of P9 and KhO1 males were characterized by higher ($P < 0.05$) drip loss compared with the leg muscles of K2 males. The drip loss of leg muscles from P9 females was higher than that of K2 and KhO1 muscles. In the leg muscles of K2 males, drip loss was significantly lower than in the female muscles from this group. Interactions of genetic group and sex were not significant for physicochemical traits except for the drip loss of breast muscles.

**Table 3** Physicochemical properties of breast and leg muscles in 110-week-old ducks as affected by genetic group and sex

| Trait | Sex | Genetic group | | | *P*-value |
|---|---|---|---|---|---|
| | | P9 | K2 | KhO1 | Group*Sex |
| $pH_{24}$, breast muscles | Total | $5.9 \pm 0.1$ | $5.9 \pm 0.1$ | $6.1 \pm 0.1$ | 0.069 |
| | Male | $5.9 \pm 0.1$ | $6.0 \pm 0.1$ | $6.0 \pm 0.1$ | |
| | Female | $6.0^{a} \pm 0.1$ | $5.8^{b*} \pm 0.1$ | $6.2^{a} \pm 0.1$ | |
| $pH_{24}$, leg muscles | Total | $6.4 \pm 0.1$ | $6.4 \pm 0.1$ | $6.3 \pm 0.1$ | 0.395 |
| | Male | $6.3 \pm 0.1$ | $6.4 \pm 0.1$ | $6.2 \pm 0.1$ | |
| | Female | $6.4 \pm 0.1$ | $6.4 \pm 0.1$ | $6.4 \pm 0.1$ | |
| $EC_{24}$, breast muscles (mS/cm) | Total | $7.4^{a} \pm 0.4$ | $6.4^{a} \pm 0.2$ | $3.6^{b} \pm 0.4$ | 0.954 |
| | Male | $7.2^{a} \pm 0.4$ | $6.4^{a} \pm 0.2$ | $3.4^{b} \pm 0.5$ | |
| | Female | $7.6^{a} \pm 0.4$ | $6.4^{a} \pm 0.3$ | $3.8^{b} \pm 0.3$ | |
| $EC_{24}$, leg muscles (mS/cm) | Total | $6.4^{a} \pm 0.3$ | $3.7^{b} \pm 0.3$ | $3.9^{b} \pm 0.2$ | 0.460 |
| | Male | $5.8^{a} \pm 0.3$ | $3.5^{b} \pm 0.4$ | $3.7^{b} \pm 0.2$ | |
| | Female | $7.1^{a} \pm 0.1$ | $3.8^{b} \pm 0.1$ | $4.1^{b} \pm 0.2$ | |
| Cooking loss, breast muscles (%) | Total | $38.4 \pm 0.6$ | $35.9 \pm 0.5$ | $39.2 \pm 0.5$ | 0.907 |
| | Male | $38.8 \pm 0.7$ | $35.8 \pm 0.7$ | $39.1 \pm 0.6$ | |
| | Female | $38.1 \pm 0.5$ | $36.1 \pm 0.6$ | $39.4 \pm 2.8$ | |
| Cooking loss, leg muscles (%) | Total | $36.9 \pm 0.6$ | $33.8 \pm 0.7$ | $35.5 \pm 0.4$ | 0.466 |
| | Male | $36.2 \pm 0.7$ | $34.3 \pm 0.4$ | $36.1 \pm 0.5$ | |
| | Female | $37.6 \pm 0.5$ | $33.4 \pm 1.0$ | $34.8 \pm 0.2$ | |
| Drip loss, breast muscles (%) | Total | $1.0 \pm 0.1$ | $1.2 \pm 0.2$ | $1.1 \pm 0.2$ | 0.024 |
| | Male | $1.0 \pm 0.2$ | $0.8 \pm 0.1$ | $1.5 \pm 0.1$ | |
| | Female | $1.0 \pm 0.1$ | $1.6 \pm 0.3$ | $0.6 \pm 0.2$ | |
| Drip loss, leg muscles (%) | Total | $1.9^{a} \pm 0.2$ | $1.1^{b} \pm 0.2$ | $1.3^{b} \pm 0.2$ | 0.168 |
| | Male | $1.6^{a} \pm 0.1$ | $0.8^{b} \pm 0.2$ | $1.6^{a} \pm 0.2$ | |
| | Female | $2.3^{a} \pm 0.3$ | $1.4^{b*} \pm 0.2$ | $1.0^{b} \pm 0.1$ | |

P9: Pekin ducks of French origin, K2: crosses of wild mallard and Pekin ducks, KhO1: crosses of Khaki Campbell drakes and Orpington Fauve ducks

$^{a,b}$ Within a row, means with a common superscript do not differ at $P < 0.05$

* Within a trait, the asterisk indicates a significant difference between males and females

Significant ($P < 0.05$) differences were observed in the L*, a*, b* colour parameters of breast muscles (Table 4). The breast muscles of P9 males were significantly ($P < 0.05$) lighter than those of K2 males. The arithmetic mean for the lightness (L*) of female breast muscles was higher than that of male breast muscles from the genetic groups. The breast muscles of P9 and KhO1 males exhibited higher redness (a*) and yellowness (b*) values than the muscles of K2 males.

The breast muscles of P9 and K2 female ducks had significantly ($P < 0.05$) higher redness (a*) and yellowness (b*) compared with KhO1 females. For the leg muscles, no significant ($P < 0.05$) differences were observed in the colour parameters of these genotypes. With regard to male leg muscles, L* value was highest in line P9, a* in KhO1, b* in K2. The highest values in females were found in K2 (L*), P9 (a*), and KhO1 (b*). The leg muscles of K2 and KhO1 males were characterized by significantly higher redness, and those of K2 males by significantly higher yellowness (b*) compared with those of the females ducks of different origin. The genotype by sex interaction was significant for redness and yellowness of breast muscles and for redness of leg muscles.

**Table 4** Colour of raw breast and leg muscles in 110-week-old ducks as affected by genetic group and sex

| Trait | Sex | Genetic group | | | *P*-value |
|---|---|---|---|---|---|
| | | P9 | K2 | KhO1 | Group*Sex |
| L* – lightness | Total | $39.4^{a} \pm 0.4$ | $37.1^{b} \pm 0.4$ | $38.1^{ab} \pm 0.4$ | 0.973 |
| of breast muscles | Male | $38.1^{a} \pm 0.2$ | $35.7^{b} \pm 0.3$ | $36.9^{ab} \pm 0.3$ | |
| | Female | $40.8^{*} \pm 0.4$ | $38.4^{*} \pm 0.4$ | $39.3^{*} \pm 0.5$ | |
| L* – lightness | Total | $43.1 \pm 1.1$ | $42.6 \pm 1.1$ | $42.8 \pm 1.1$ | 0.473 |
| of leg muscles | Male | $42.9 \pm 1.2$ | $39.9 \pm 0.7$ | $40.9 \pm 0.7$ | |
| | Female | $43.2 \pm 1.2$ | $45.2 \pm 1.1$ | $44.7 \pm 1.2$ | |
| a*, redness | Total | $18.1^{a} \pm 0.3$ | $16.7^{b} \pm 0.4$ | $16.7^{b} \pm 0.4$ | 0.002 |
| of breast muscles | Male | $17.4^{a} \pm 0.4$ | $15.2^{b} \pm 0.2$ | $17.4^{a} \pm 0.4$ | |
| | Female | $18.7^{a} \pm 0.1$ | $18.2^{a} \pm 0.3$ | $16.0^{b} \pm 0.2$ | |
| a*, redness | Total | $17.6 \pm 0.3$ | $17.4 \pm 0.6$ | $17.6 \pm 0.5$ | 0.038 |
| of leg muscles | Male | $17.5 \pm 0.5$ | $19.1 \pm 0.5$ | $19.3 \pm 0.5$ | |
| | Female | $17.8 \pm 0.5$ | $15.7^{*} \pm 0.4$ | $15.9^{*} \pm 0.3$ | |
| b*, yellowness | Total | $3.5^{a} \pm 0.3$ | $2.9^{b} \pm 0.3$ | $2.8^{b} \pm 0.4$ | 0.032 |
| of breast muscles | Male | $3.8^{a} \pm 0.3$ | $1.9^{b} \pm 0.2$ | $3.6^{a} \pm 0.5$ | |
| | Female | $3.2^{a} \pm 0.1$ | $3.8^{a} \pm 0.4$ | $2.1^{b} \pm 0.1$ | |
| b*, yellowness | Total | $5.7 \pm 0.4$ | $5.9 \pm 0.4$ | $6.0 \pm 0.2$ | 0.157 |
| of leg muscles | Male | $5.7 \pm 0.3$ | $7.1 \pm 0.4$ | $6.1 \pm 0.2$ | |
| | Female | $5.7 \pm 0.4$ | $4.8^{*} \pm 0.2$ | $5.9 \pm 0.3$ | |

P9: Pekin ducks of French origin, K2: crosses of wild mallard and Pekin ducks, KhO1: crosses of Khaki Campbell drakes and Orpington fauve ducks

[a,b] Within a row, means with a common superscript do not differ at $P < 0.05$

* Within a trait, the asterisk indicates a significant difference between males and females

Table 5 lists the mean values and standard error for sensory characteristics of breast and leg muscles in these bird genotypes. Significant variations in sensory properties of the meat were observed in both sexes, except for aroma and taste intensity and juiciness of the breast muscles. The breast muscles of P9 males were characterized by significantly ($P < 0.05$) higher aroma desirability, taste intensity and desirability compared with those of KhO1 males. Furthermore, the breast muscles of P9 males were characterized by significantly higher aroma desirability compared with those of K2 males. The breast muscles of P9 females showed significantly ($P < 0.05$) higher aroma and taste desirability compared with those of K2 and KhO1 females, and significantly lower taste intensity compared with those of KhO1 females. There were significant differences between males and females in the aroma desirability of the breast muscles for K2 and KhO1, in tenderness for KhO1, and in taste desirability for K2 birds. Analysis of the data for sensory properties of the leg muscles (Table 6) demonstrated that those of P9 males had significantly ($P < 0.05$) higher aroma intensity, desirability and juiciness compared with those of K2 males. They also had significantly higher juiciness and tenderness compared with the muscles of KhO1 males. The leg muscles of K2 males exhibited significantly lower aroma intensity and desirability, and significantly ($P < 0.05$) higher tenderness and taste intensity compared with the muscles of KhO1 males. The leg muscles of P9 females showed significantly ($P < 0.05$) higher tenderness, juiciness, and taste desirability compared with the muscles of KhO1 females. Also, the leg muscles of P9 females were tender and juicy compared with the those of K2 and KhO1. The genotype by sex interaction was significant for aroma desirability and taste intensity and desirability of breast muscles, and for aroma desirability of leg muscles.

**Table 5** Sensory properties of cooked breast and leg muscles from 110-week-old ducks as affected by genetic group and sex

| Trait | Sex | Genetic group | | | *P*-value |
|---|---|---|---|---|---|
| | | P9 | K2 | KhO1 | Genotype*Sex |
| *Breast muscles* | | | | | |
| Aroma intensity, pts. | Total | 4.0 ± 0.1 | 3.7 ± 0.1 | 3.8 ± 0.1 | 0.108 |
| | Male | 4.1 ± 0.1 | 4.0 ± 0.1 | 3.7 ± 0.1 | |
| | Female | 4.0 ± 0.1 | 3.3 ± 0.1 | 3.9 ± 0.1 | |
| Aroma desirability, pts. | Total | $3.9^{a} \pm 0.1$ | $3.4^{b} \pm 0.1$ | $3.0^{c} \pm 0.1$ | 0.002 |
| | Male | $4.0^{a} \pm 0.1$ | $3.6^{b} \pm 0.1$ | $2.7^{c} \pm 0.1$ | |
| | Female | $3.8^{a} \pm 0.1$ | $3.1^{b*} \pm 0.1$ | $3.3^{b*} \pm 0.1$ | |
| Juiciness, pts. | Total | 2.9 ± 0.1 | 2.7 ± 0.1 | 3.1 ± 0.1 | 0.057 |
| | Male | $3.0^{a} \pm 0.1$ | $3.0^{a} \pm 0.1$ | $3.6^{b} \pm 0.1$ | |
| | Female | 2.8 ± 0.1 | 2.4 ± 0.1 | $2.5^{*} \pm 0.1$ | |
| Tenderness, pts. | Total | $3.5^{a} \pm 0.1$ | $3.3^{a} \pm 0.1$ | $2.8^{*} \pm 0.1$ | 0.346 |
| | Male | 3.4 ± 0.1 | 3.4 ± 0.1 | 3.0 ± 0.1 | |
| | Female | 3.5 ± 0.2 | 3.1 ± 0.1 | $2.6^{*} \pm 0.1$ | |
| Taste intensity, pts. | Total | 3.4 ± 0.1 | 3.6 ± 0.1 | 3.3 ± 0.1 | 0.001 |
| | Male | $3.7^{a} \pm 0.1$ | $3.7^{a} \pm 0.1$ | $3.1^{b} \pm 0.1$ | |
| | Female | $3.1^{a} \pm 0.1$ | $3.4^{ab} \pm 0.1$ | $3.6^{b*} \pm 0.1$ | |
| Taste desirability, pts. | Total | $3.6^{a} \pm 0.1$ | $3.5^{a} \pm 0.1$ | $2.9^{b} \pm 0.1$ | 0.014 |
| | Male | $3.8^{a} \pm 3.1$ | $3.8^{a} \pm 0.1$ | $2.8^{b} \pm 0.1$ | |
| | Female | $3.5^{a} \pm 0.1$ | $3.2^{b*} \pm 0.1$ | $2.9^{c} \pm 0.1$ | |
| *Leg muscles* | | | | | |
| Aroma intensity, pts | Total | 3.6 ± 0.1 | 3.3 ± 0.1 | 3.7± 0.1 | 0.062 |
| | Male | $3.8^{a} \pm 0.1$ | $3.2^{b} \pm 0.1$ | $3.8^{a} \pm 0.1$ | |
| | Female | $3.3^{a} \pm 0.1$ | $3.5^{b} \pm 0.1$ | $3.5^{b} \pm 0.1$ | |
| Aroma desirability, pts | Total | $3.5^{a} \pm 0.1$ | $3.0^{b} \pm 0.1$ | $3.1^{b} \pm 0.1$ | 0.004 |
| | Male | $3.7^{a} \pm 0.1$ | $2.8^{b} \pm 0.1$ | $3.3^{a} \pm 0.1$ | |
| | Female | 3.3 ± 0.1 | 3.2 ± 0.1 | 3.0 ± 0.1 | |
| Juiciness, pts | Total | $3.8^{a} \pm 0.1$ | $3.1^{b} \pm 0.1$ | $3.0^{b} \pm 0.1$ | 0.091 |
| | Male | $3.7^{a} \pm 0.1$ | $3.1^{b} \pm 0.1$ | $2.7^{b} \pm 0.1$ | |
| | Female | $3.8^{a} \pm 0.1$ | $3.0^{b} \pm 0.1$ | $3.1^{b*} \pm 0.1$ | |
| Tenderness, pts | Total | $3.8^{a} \pm 0.1$ | $3.5^{a} \pm 0.1$ | $3.1^{b} \pm 0.1$ | 0.055 |
| | Male | $3.9^{a} \pm 0.1$ | $3.9^{a} \pm 0.1$ | $3.1^{b} \pm 0.1$ | |
| | Female | $3.8^{a} \pm 0.1$ | $3.2^{b*} \pm 0.1$ | $3.2^{b} \pm 0.1$ | |
| Taste intensity, pts | Total | $3.4^{a} \pm 0.1$ | $3.3^{a} \pm 0.1$ | $3.0^{b} \pm 0.1$ | 0.165 |
| | Male | $3.2^{a} \pm 0.1$ | $3.4^{a} \pm 0.1$ | $3.0^{ab} \pm 0.1$ | |
| | Female | $3.6^{a} \pm 0.1$ | $3.3^{a} \pm 0.1$ | $2.9^{ab} \pm 0.1$ | |
| Taste desirability, pts | Total | $3.2^{a} \pm 0.1$ | $3.5^{a} \pm 0.1$ | $2.8^{b} \pm 0.1$ | 0.077 |
| | Male | $3.0^{a} \pm 0.1$ | $3.5^{b} \pm 0.1$ | $2.9^{a} \pm 0.1$ | |
| | Female | $3.5^{a} \pm 0.1$ | $3.5^{a} \pm 0.1$ | $2.7^{b} \pm 0.1$ | |

P9: Pekin ducks of French origin, K2: crosses of wild mallard and Pekin ducks, KhO1: crosses of Khaki Campbell drakes and Orpington Fauve ducks
[a,b] Within a row, means with a common superscript do not differ at $P < 0.05$
* Within a trait, the asterisk indicates a significant difference between males and females

The groups of ducks differed significantly in the textural characteristics of cooked breast muscles. The various genotypes had no significant effect on the differences in the values of rheological properties (Table 6). The breast muscles of P9 and KhO1 males were characterized by significantly lower hardness, chewiness and gumminess compared with the muscles of K2 males. In addition, the breast muscles of KhO1 and P9 males were more cohesive than K2 males. The breast muscles of KhO1 males exhibited more springiness compared with the muscles of P9 and K2 males. The hardness and gumminess of breast muscles from P9 and KhO1 females were found to be significantly lower compared with the breast meat of K2 females. The breast muscles of K2 females were also characterized by significantly lower cohesiveness and springiness and significantly higher chewiness compared with the breast muscles of the other genotypes. The breast fillets of P9 males and females had significantly higher shear force (poorer tenderness) values than K2 and KhO1 ducks. There were significant differences between males and females in the sum of elastic moduli in K2 birds. Significantly, higher sums of elastic moduli were observed in male than in female K2 ducks. The genotype by sex interaction was significant for chewiness, gumminess and sum of viscous moduli of breast muscle.

**Table 6** Texture and rheological properties of cooked breast muscles from 110-week-old ducks as affected by genetic group and sex

| Trait | Sex | Genetic group | | | *P*-value |
|---|---|---|---|---|---|
| | | P9 | K2 | KhO1 | Genotype*Sex |
| Hardness (N) | Total | $39.3^{a} \pm 2.1$ | $67.5^{b} \pm 2.4$ | $31.9^{c} \pm 1.3$ | 0.216 |
| | Male | $37.8^{a} \pm 1.8$ | $70.3^{b} \pm 1.0$ | $27.7^{c} \pm 0.9$ | |
| | Female | $40.9^{a} \pm 2.4$ | $64.6^{b} \pm 3.4$ | $36.1^{a} \pm 1.2$ | |
| Cohesiveness | Total | $0.4^{a} \pm 0.1$ | $0.3^{b} \pm 0.1$ | $0.4^{a} \pm 0.1$ | 0.579 |
| | Male | $0.4^{a} \pm 0.1$ | $0.3^{b} \pm 0.1$ | $0.4^{a} \pm 0.1$ | |
| | Female | $0.4^{a} \pm 0.1$ | $0.3^{b} \pm 0.1$ | $0.4^{a} \pm 0.1$ | |
| Springiness (cm) | Total | $1.1^{a} \pm 0.1$ | $1.1^{a} \pm 0.1$ | $1.3^{b} \pm 0.1$ | 0.081 |
| | Male | $1.1^{a} \pm 0.1$ | $1.2^{a} \pm 0.1$ | $1.4^{b} \pm 0.1$ | |
| | Female | $1.1^{a} \pm 0.1$ | $1.0^{b} \pm 0.1$ | $1.2^{a} \pm 0.1$ | |
| Chewiness (N x cm) | Total | $16.4^{a} \pm 0.8$ | $24.4^{b} \pm 0.9$ | $15.1^{a} \pm 0.7$ | 0.037 |
| | Male | $15.5^{a} \pm 0.8$ | $27.0^{b} \pm 0.3$ | $14.1^{a} \pm 0.7$ | |
| | Female | $17.2^{a} \pm 1.1$ | $21.8^{b} \pm 0.8$ | $16.0^{a} \pm 0.7$ | |
| Gumminess (N) | Total | $14.5^{a} \pm 0.8$ | $21.9^{b} \pm 0.7$ | $12.3^{a} \pm 0.5$ | 0.041 |
| | Male | $13.8^{a} \pm 0.5$ | $23.7^{b} \pm 0.3$ | $10.9^{c} \pm 0.3$ | |
| | Female | $15.1^{a} \pm 1.0$ | $20.1^{b} \pm 0.7$ | $13.7^{a} \pm 0.5$ | |
| W-B shear force (N) | Total | $128^{a} \pm 5.9$ | $84.7^{b} \pm 4.1$ | $66.9^{c} \pm 3.1$ | 0.385 |
| | Male | $128^{a} \pm 4.6$ | $91.8^{b} \pm 2.9$ | $73.9^{b} \pm 3.8$ | |
| | Female | $127^{a} \pm 7.6$ | $77.5^{b} \pm 4.7$ | $59.8^{b} \pm 1.0$ | |
| Sum of elastic moduli (kPa) | Total | $362 \pm 32.7$ | $427 \pm 13.5$ | $392 \pm 11.0$ | 0.384 |
| | Male | $398 \pm 26.2$ | $466 \pm 14.0$ | $389 \pm 16.3$ | |
| | Female | $327 \pm 26.2$ | $388^{*} \pm 4.8$ | $395 \pm 6.4$ | |
| Sum of viscous moduli (Kpa x S) | Total | $17674 \pm 671$ | $17074 \pm 469$ | $18497 \pm 454$ | 0.042 |
| | Male | $16333 \pm 831$ | $17831 \pm 507$ | $19697 \pm 258$ | |
| | Female | $19015 \pm 311$ | $16318 \pm 448$ | $17297 \pm 466$ | |

P9: Pekin ducks of French origin, K2: crosses of wild mallards and Pekin ducks, KhO1: crosses of Khaki Campbell drakes and Orpington fauve ducks

[a,b] Within a row, means with a common superscript do not differ at $P < 0.05$

* Within a trait, the asterisk indicates a significant difference between males and females

## Discussion

This is one of few studies of the carcass composition and meat quality of spent ducks. In Poland, no results have been published to date for meat traits of P9, K2, and KhO1 ducks after two reproductive seasons. These results show that these genetic groups of ducks differ in their suitability for meat production. The carcasses of the duck lines showed good muscling, especially a high content of breast muscle, and a relatively low fatness, expressed as percentage of skin with subcutaneous fat and of abdominal fat in eviscerated carcass. The breast and leg muscles of the duck groups differed in the content of water, protein, fat and collagen, which is indicative of their nutritive values and technological suitability. The present study demonstrated a strong effect of bird genotype on the sensory properties of the breast and leg muscles, except for the aroma intensity of the breast muscles. However, these results could have been influenced by the relatively small number, because the carcasses, meat and giblets from 10 males and 10 females were evaluated in each group.

The breast muscle percentage in the carcasses of 110-week-old K2 ducks was higher than in the ducks of the same genotype that was reported by Kisiel and Ksiazkiewicz (2004), indicating that the breast muscles continued to grow after seven weeks old. The same authors found a higher content of leg muscles and skin with subcutaneous fat in seven-week-old K2 ducks compared with the values that the authors found for 110-week-old ducks of the same genotype. The abdominal fat content of the carcasses from the ducks was much lower than in younger Pekin ducks that were investigated by Bang *et al*. (2010), Kwon *et al.* (2014), Oh *et al*. (2015) and Steczny *et al*. (2017). All the duck flocks that were analysed were characterized by a large proportion of carcass remainders, which was made up of some small skeletal muscles and the kidneys. This part of the carcass with skin is often used to make broths and soups. Qiao *et al*. (2017) found that broth from spent layer ducks aged 500 days was preferable in aroma and flavour to broth made from the meat of 70-day-old Cherry Valley ducks, Chinese native duck hybrids, and 38-week-old Cherry Valley ducks.

The breast and leg muscles of the two-year-old ducks had a lower water and a higher protein content compared with the ducks at the age of 7 - 8 weeks that were evaluated by Muhlisin *et al*. (2013), and Heo *et al*. (2015). The breast muscles of the ducks in the current study had similar fat content to those of the ducks that were studied by Muhlisin *et al*. (2013) and had higher fat content than that reported by Bang *et al.* (2005). Similar to the study by Muhlisin *et al*. (2013), the female breast muscles from the current study were characterized by significantly higher fat content than the male muscles. All ducks in the current study had a high content of fat in leg muscles, which was higher than in young ducks that were studied by Witak (2008). Qiao *et al*. (2017) reported lower water content, and higher crude protein and intramuscular fat content in breast and thigh muscles of spent layer ducks aged 500 days compared with the meat of 38-day-old Cherry Valley and 70-day-old hybrids of Cherry Valley and Chinese native duck. The collagen content of the breast and leg muscles from the two-year-old ducks was higher than in seven-week-old SM3 Heavy ducks that were evaluated by Kokoszynski *et al*. (2017).

Meat pH is one of the most important indicators of its quality. The $pH_{24}$ values of breast muscles from the ducks in the current study were higher than those reported by Bernacki *et al*. (2008), and similar to the findings of Kokoszynski *et al*. (2017). The pH of leg muscles from ducks in the current study was lower than that reported by Erdem *et al*. (2015), and similar to the results of Kisiel & Ksiazkiewicz (2004). There were no significant differences in the $pH_{24}$ of breast muscles from Cherry Valley ducks, spent layer ducks, hybrid Cherry Valley and Chinese native ducks (5.96, 5.94 and 5.81, respectively) in a study by Qiao *et al*. (2017). However, the $pH_{24}$ of leg muscles from Cherry Valley ducks was lower than that of spent layer ducks and hybrid Cherry Valley and Chinese native ducks (6.24 vs 6.57 and 6.62).

Another important indicator of meat quality is the value of its EC. Normal meat is generally characterized by low EC post-mortem. The differences obtained in the present study in EC were because of the differences in the genotypes of the bird groups. To date, few studies have shown the EC values for duck meat, and these results point to great differences (Chen *et al*., 2015; Kokoszynski *et al*., 2017). The $EC_{24}$ values of the duck breast and leg muscles were lower than those reported by Kokoszynski *et al*. (2017) for the meat of seven-week-old SM3 Heavy commercial hybrids.

The present study also determined drip loss and cooking loss, of which the reported values were beneficial because they enable a higher weight of the final product to be obtained (Huda *et al*., 2011). Qiao *et al*. (2017) found the cooking loss and drip loss (%) of the breast and leg muscles of spent layer ducks aged 500 days to be lower than in the meat of 38-day-old Cherry Valley ducks and 70-day-old hybrids of Cherry Valley and Chinese native duck. This was probably associated with the lower water content of the meat from the older birds (Boni *et al*., 2010).

Colour is an important factor, which determines the quality of meat and the decision to purchase it (Fletcher, 2002). The present study showed significant differences among the ducks in the L*, a*, and b* coordinates, which is consistent with the results of Puchala *et al*. (2014), which were obtained for hens of various origins (four breeds) after the end of the laying period. Qiao *et al*. (2017) reported the colour of breast and leg meat was significantly darker (lower L* and b* values) in spent layer ducks than in young slaughter ducks.

The meat of ducks that was evaluated in the present study had much lower scores for tenderness and juiciness, and also for aroma and taste intensity and desirability compared with the sensory scores of the breast and leg muscles of young slaughter ducks (Wawro *et al*., 2004). In the experiment of Okruszek *et al.* (2006) breast muscles of Pekin duck (lines P8 and P33) were characterized by higher tenderness and juiciness compared with the breast muscles of Khaki Campbell, Orpington and K2 duck.

To evaluate the sensory properties of meat, measurements are sometimes performed of texture, including maximum shear force, which determines meat tenderness,. The heat-treated breast muscles of the heaviest P9 ducks were characterized by significantly greater shear force, equivalent to less tender meat, compared with the meat of K2 and KhO1 ducks. This was probably because of the greater muscle fibre diameter in the heavier birds. Smolinska *et al*. (2009) reported that meat tenderness depends principally on the type, percentage, diameter and contraction of muscle fibres, and on the amount of connective tissue and its fractions (epimysium, perimysium). The P9, K2 and KhO1 ducks aged 110 weeks exhibited significantly lower tenderness of breast muscles compared with the eight-week-old Pekin, Khaki Campbell and Mini Duck that were studied by Woloszyn *et al.* (2011), which was associated with greater diameter of the muscle fibres, in particular with greater thickness and more closely meshed connective tissue of breast muscle in older birds (Balowski *et al*., 2015).

## Conclusions

These genetic reserve ducks differed significantly in carcass and giblet weight, percentage of neck, wings, and breast and leg muscles. The P9, K2 and KhO1 ducks had significant differences in chemical composition, $EC_{24}$, most sensory attributes of breast and leg muscles, and drip loss from the leg muscles. Breast fillets from the ducks differed in the L* (lightness), a* (redness), and b* (yellowness) colour coordinates and textural properties. These results show differences in the nutritive, dietetic and technological values of the meat from these ducks. Further research should be conducted to establish their fatty acid profile, amino acid profile, mineral content, microstructure of meat, and morphometric characteristics of the body and internal organs.

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**Authors' Contributions**

DK and ZB wrote the manuscript and developed the methodology. DK, MB, MS, KS, RZ, MK, MS, JZK, PDW, TB, MK described the methods that were used to determine the traits for methodology and laboratory analyses. DK did the calculations. Finally, all the authors commented on the early and final response to the manuscript.

**Conflict of Interest Declaration**

None of the authors of this work has a financed or other relationship with people or organizations that could influence inappropriately or bias the contents of this paper.

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