Characteristics of carcass and physicochemical traits of meat from male and female ducks fed a diet based on extruded soybean

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ABSTRACT Duck' meat is characterized by good nutritional properties and gaining popularity in the consumer market. Extruded soybean is potentially more digestible than commonly use soybean meal (**SBM**), and is expected to influence carcass traits and the quality of breast and leg muscles. The study' aim was to compare meat quality from both sexes' ducks fed a diet with extruded soybean (**ESB**) as a substitute for SBM. Cherry Valley ducks were divided into two groups. The control group (1) was fed an SBM-based diet, and the treatment group (2) with ESB. Each group was divided into sex subgroups with 50 birds in each (5 replicates, 10 ducks each). Dissection and analysis of meats' pH, colour, water-holding capacity (**WHC**), drip loss and chemical composition of breast and leg muscles were done. Interaction of Diet and Sex was calculated. In group 2 higher carcass weight, dressing percentage, weight of wings, leg muscles, total muscles, and better WHC were found. Dressing percentage, the proportion of neck with skin, breasts' and stomach' weight, and the weight and proportion of fat, and pH_{45min} were higher in females ($P < 0.05$). The interaction was found for the pre-slaughter body weight, the weight of carcass remains, WHC in breasts ($P < 0.05$). The ESB feed had no negative effect on the analyzed traits and can be used in the ducks' diet. Improved the WHC indicates the high suitability of meat for processing. A positive effect of diet on the muscles' proportion and dressing percentage was noticed, which is important for consumers' market. The sex-related differences and interactions between variables suggest separate rearing due to sex.

Key words: Cherry Valley ducks, extrusion, soybean, meat quality, water-holding capacity

2021 Poultry Science 100:101170
https://doi.org/10.1016/j.psj.2021.101170

INTRODUCTION

Soybean meal (**SBM**) is the main source of plant-derived protein in the diet of poultry and other farm animals (Kaczmarek et al., 2016). Balastreri et al. (2016) reported that SBM contains 47% protein, 2.08% lysine, and 0.603% methionine. There are many solutions to improve the digestibility of protein and other important nutrients, such as grinding, flaking, flaking-pressing-cooking, or extrusion (Sakkas et al., 2019). Extrusion involves processing grains at high temperature and pressure, which could effect on the antinutrients content, causes starch gelatinization and protein denaturation, and sterilizes feed components, and even odours of feed (Guo et al., 2018). SBM is mainly genetically modified products, and in the future, it could be ban on the GMO in animal feeding and production by polish law (Biesek et al., 2020). Extruded soybean from native non-GMO soya production could be an alternative for commonly used SBM, especially since most of the SBM used in polish livestock production comes from imports. As Degola et al. (2019) described, extruded soybean had 37.02 to 43.36% crude protein, but the soybean meal had from 43.8 to 49.0 or even more than 50%, depending on the type and method of processing (Banaszkiewicz, 2011). Of course, the feasibility of feed depends on many nutrients, but protein is one of the most important.

In 2020, downward trends in the production of ducks were noticed in Poland, although polish production increased, ranking in second place in the EU (between France and Hungary). In the first half of 2020, the production value in thousands of tonnes was recorded at the level of 36.79 (KIPDIP, 2020). Duck carcasses are characterized by a higher fat content compared to other types of poultry, which affects the nutritional value and sensory characteristics, and good palatability of meat (Ao and Kim, 2020). The quality of meat depends on many factors, including the physicochemical traits of

Received December 3, 2020.
Accepted March 17, 2021.

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breast and leg muscles, such as: pH, color, and water-holding capacity (Fletcher, 2002). Another important aspect is the chemical composition of meat, that is, the content of protein, collagen, salt, and intramuscular fat. These traits determine the suitability of breast and leg muscles, or the whole carcass, for further processing, and the culinary value of meat (Mazanowski et al., 2003). The quality of duck meat is also influenced by many interacting factors, for example, diet and sex of birds (Qiao et al., 2017). For example, Smith et al. (2015) reported sex-related differences in the texture of duck meat. Close relationship between the texture of meat and water-holding capacity and other physicochemical traits was noticed (Mazanowski et al., 2003). The available literature indicates that many studies investigated the effect of different sources of protein alternative to SBM on the growth performance of ducks (Kovitvadhi et al., 2019; Banaszak et al., 2020; Kowalska et al., 2020; Kuźniacka et al., 2020). However, no information is available on the use of extruded soybean as a vegetable protein source in the diet of broiler ducks. Studies conducted so far have focused on the impact of extrusion of seeds from other species of fodder plants (faba bean, pea, lupins) on the growth performance of broiler chickens (Hejdysz et al., 2017; 2018; 2019) or pigs (Tuśnio et al., 2017).

The tested hypothesis is: A complete balanced diet based on extruded soybean as an alternative to soybean meal affects carcass traits and the quality of duck meat. The aim of the study was to evaluate and compare carcass traits and the quality of meat from male and female Cherry Valley broiler ducks fed a diet based on extruded soybean as an alternative to soybean meal. The proposed studies were carried out according to the guidelines included in the project (Acknowledgment section).

MATERIAL AND METHODS

The purpose of the studies was to assess the quality of carcasses and meat obtained from ducks slaughtered on small-scale farm. The experiment was practical/implementing and was based on the principles adopted in the government's project on the use of alternative protein sources for soybean meal. Birds were slaughtered by qualified staff, and the research team participated in this process in order to inspect and select birds for further analyses. According to Directive no. 2010/63/EU and the regulations of the Ethics Committee of 17 June 2016 (No. 13/2016), the approval of the Local Ethics Committee was not required in this case.

The authors' task was to develop the results concerning the quality of the raw material. Feed rations and data on them were provided by the feed manufacturer, which was directly involved in the project.

Animals and Diets

Cherry Valley ducks (SM-3 Heavy) were reared on a small-scale farm. One-day ducklings were assigned to 2 dietary treatment groups (n = 100 per group) and divided into equal subgroups of male and female birds. There were 50 birds in each subgroup (5 replicates, 10 ducks each). Males and females were kept separate. Ducklings were sexed by qualified hatchery workers. Birds from the control group (1) were fed a diet based on soybean meal, while in the experimental group the birds received a diet in which the main source of protein was extruded soybean. The extrusion process was described in the studies by Hejdysz *et al.* (2019). In own research, the feed mixtures utilized in the present experiment were obtained from the Feed Manufacturing Plant, which directly participated in the tests of the project, therefore the paper did not include information on the extrusion method, as it was not the subject of meat quality research. Extruded soybean was obtained from native non-GMO soya production. The information on the composition of feed mixtures and their chemical composition was obtained from the feed producer. The rearing period lasted for 49 d and consisted of 2 feeding phases when ducks received starter (1–21 d)

Table 1. Composition of complete feeds for broiler ducks.

Feed[1]	Control (1)		Treatment (2)	
Ingredient	Starter (d 0–28)	Grower (d 29–49)	Starter (d 0–28)	Grower (d 29–49)
Maize	25.00	-	22.00	-
Triticale	30.29	63.40	25.00	57.25
Soybean meal (SBM), Hipro	27.00	17.00	-	-
Extruded soybean (ESB)	-	-	37.17	29.00
Rapeseed meal	10.00	12.00	10.00	9.00
Potato protein	-	-	1.50	-
Soybean oil	4.20	4.60	0.50	1.60
Limestone	1.40	1.40	1.30	1.20
Monocalcium phosphate	0.88	0.45	1.40	0.86
Premix 0.5%[2]	0.50	0.50	0.50	0.50
Sodium carbonate	0.36	0.37	0.26	0.26
Fodder salt	0.20	0.18	0.19	0.20
DL-Methionine[3]	0.17	0.10	0.18	0.13

Notes: *The composition of complete feeds was analysed and declared by the manufacturer of the feeds.
[1]Group 1, fed an SBM-based diet; group 2, fed an ESB-based diet.
[2]Premix, vitamin–mineral premix provided per kg of diet: Mn, 55 mg; Zn, 50 mg; Fe, 80 mg; Cu, 5 mg; Se, 0.1 mg; I, 0.36 mg; Na, 1.6 g, retinol, 2.48 mg; cholecalciferol 25 μg; DL-α-tocopherol, 60 mg; cyanocobalamin, 0.012 mg; menadione sodium bisulphite, 1.1 mg; niacin, 53 mg; choline chloride, 1020 mg; folic acid, 0.75 mg; biotin, 0.25 mg; riboflavin, 5.5 mg.
[3]Technically pure.

Table 2. Chemical composition of complete feeds for broiler ducks.

Feed[1]	Control (1)		Treatment (2)	
Ingredient	Starter (d 0–28)	Grower (d 29–49)	Starter (d 0–28)	Grower (d 29–49)
Dry matter, g	886	886	882	883
Metabolizable energy, MJ	13.7	13.7	13.3	13.5
Crude protein, g	222	200	231	204
Crude fat, g	63.3	61.1	87.5	78.5
Crude fibre, g	43.2	39.4	43.7	39.4
Crude ash, g	61.8	54.3	64.4	55.3

Notes: *The chemical composition of complete feeds was analysed and declared by the manufacturer of the feeds.
[1]Group 1, fed an SBM-based diet; group 2, fed an ESB-based diet, diets were iso-protein and isocaloric, all ingredients were balanced in accordance with the feeding standards of broiler ducks.

and then grower (22–49 d) feed, and their composition is presented in Table 1. The level of protein in feeds was balanced by a low-grade inclusion of protein from different sources (rapeseed meal, potato protein). The chemical composition of feeds for ducks is presented in Table 2. Tables 1 and 2 present information declared by the manufacturer of the feeds. The content of dry matter, energy, crude protein, crude fat, fiber, and crude ash was presented. Diets were isoprotein and isocaloric. All ingredients were balanced in accordance with the feeding standards of broiler ducks. Ducks were managed in compliance with the standards of broiler duck production. The birds had unlimited access to feed and fresh drinking water. Feed was in granulated form, and isoprotein and isocaloric. The temperature in the duck house was kept at 22 to 24°C in wk 1, and at 16 to 18°C in wk 7. Between wk 1 and 4 ducks had access to an additional source of heat set at 30°C (wk 1) and 18 to 20°C (wk 4). After 4 wk of rearing, the additional source of heat was removed. The lighting programme ensured 16 h of light per day, and a source of artificial light emitting 4 W/m^2 was installed for that purpose, considering that the light was kept at 24 h for the first 3 d. The rate of air exchange in the duck house was about $1m^3/s$, because of the warm spring (ducks were reared in May). The floor in the pens was covered with chopped wheat straw, and the maximum stocking rate was 17 kg of live weight of birds/m^2 of floor surface area.

Growth Performance

Broiler ducks reared on the farm were controlled during the rearing period. Body weight gain (g), feed intake (**FI**, g) and feed conversion ratio (kg/kg) were registered and calculated. Calculation was done by scientific team. Data refer to the growth performance of the whole flock (N = 50 per group). Due to the carcass characteristics and physicochemical characteristics of duck meat, birds from each group were selected for laboratory tests.

Slaughter and Dissection

Ducks were slaughtered at the age of 49 d. All birds in each group were weighed and the mean body weights were calculated. For further analyses we selected 10 males and 10 females from each dietary group, of body weight close to the mean for the whole group. During the selection, each bird was marked with a jiffy wing band with a number, so each bird was an individual experimental sample. Ducks were fasted for 12 h, stunned using an electric current, and then decapitated at the first cervical vertebra, which resulted in the dissection of the spinal cord and rapid exsanguination of the carcasses. After slaughter, the duck carcasses were eviscerated, and shanks were cut off at the ankle joint. Offal was removed, including the heart, stomach and liver. Prepared carcasses were analysed for the pH of breast muscles 45 min postmortem (pH_{45min}). The pH was measured using a CP-401 pH-meter (Elmetron, Zabrze, Poland) with a knife electrode inserted at a depth of 2 cm into the pectoralis major muscle. Carcasses were chilled in a refrigerator at 4°C for 24 h. After 24 h, the carcasses and offal were weighed with an accuracy of 0.01 g (Radwag scales, Radom, Poland). The pH of breast muscles was measured again ($pH_{24hours}$). The carcasses were dissected in accordance with the methodology described by Kowalska et al. (2020), and the following elements were separated: the neck with skin, wings with skin, breast muscles, leg muscles (boned, thighs, and drumsticks), skin with subcutaneous fat (without skin from the neck), abdominal fat and carcass remains (body and leg bones). The weight of the breast and leg muscles was the total weight of muscles, and the weight of the skin with subcutaneous fat and abdominal fat was the total fatness of the carcass. The proportion of each element in the carcass was calculated. Dressing percentage was calculated from the formula: (carcass weight / live body weight) × 100. Breast and leg muscles were marked with different numbers and used for further physicochemical analyses.

Physicochemical Traits of Breast and Leg Muscles

Breast and leg muscles marked with relevant numbers were placed on aluminium trays, right and left muscles separately from each obtained carcass after the slaughter and dissection. The right breast and leg muscles were analysed for color using a colorimeter (Konica Minolta, Tokyo, Japan) and the CIE L*a*b* system. The muscles were analysed for lightness (L*), redness (a*) and yellowness (b*). The measuring aperture was placed on the outer side of the muscles and the measurement was taken. The left breast and leg muscles, divided into groups, were minced for further analysis of water-holding capacity. Samples of muscles (0.295−0.305 g; M1) were weighed on a laboratory scales (Radwag, Radom, Poland), placed on absorbent Whitman 1 filter paper, covered with another piece of filter paper and pressed with a 2 kg weight for 5 min. After 5 mes meat samples were removed from the filter paper and reweighed (M2). Water loss from meat (in %) was calculated from the difference between M1 and M2. Water-holding capacity was analysed according to the method proposed by Grau and Hamm (1952). In addition, the ability of breast muscles to retain water was analysed based on drip loss (Honikel, 1987). Whole right breast muscles were weighed (M1) and packed in plastic bags with a zip closure and perforations on the bottom to enable spontaneous dripping of liquid. Prepared samples were packed in larger bags with a zip closure to collect water. Bags were hung for 24 h in a cold room at 4°C, and muscles were weighed again (M2). Water loss in percent was calculated from the difference between M1 and M2. Samples of minced breast and leg muscles were analysed for chemical composition (content of protein, collagen, salt, intramuscular fat, water) using near infrared transmission spectrometry (FoodScan, FOSS, Hilleroed, Denmark) (PN-A-82109:2010, 2010). We analyzed 10 samples of minced breast and leg muscles (total weight 90 g) from each group of birds. Methods used for the analysis of physicochemical traits were also described in a previous publication (Kuźniacka et al., 2020).

Statistical Analysis

Statistical analyses of the data were performed using Statistical software (Statsoft, Poland). Data were analyZed by two-way ANOVA, including diet and sex with interactions. Each duck was considered as the experimental unit. Data were presented as means ±SEM (standard error of the mean), and a value of $P < 0.05$ was used to indicate statistical significance.

RESULTS

Growth Performance

The falls of ducks in the experiment were recorded and did not exceed 1% of the total flock. The recorded falls were related to weak and crippled chicks. The production results of the ducks are presented in Table 3. No statistically significant differences were found, however, numerical differences are visible. The males in the control group and in the experimental group were heavier than the females. The feed consumption in the experimental groups (both sexes) was lower compared to the males and females (by sex, respectively) than in the control group, as was the feed conversion rate.

Carcass Characteristics

The weight of carcass was significantly higher in ducks from group 2 fed extruded soybean ($P = 0.019$), but the difference in pre-slaughter body weight between the two groups was insignificant ($P = 0.099$). Dressing percentage was also higher in group 2 ($P = 0.023$) as was the weight of wings ($P = 0.035$). There were no significant differences between the two diets in the other analysed traits presented in Table 4 ($P > 0.05$). The comparison of analysed traits with consideration of sex showed significantly higher dressing percentage for carcasses from female ducks ($P < 0.001$). The proportion of neck with skin and the weight of stomach were significantly lower in females than in males ($P = 0.026$, $P < 0.001$, respectively). There were no significant differences in other traits between male and female ducks (Table 4). Despite the lack of significant effects of the diet and sex of birds on the pre-slaughter body weight and the weight of carcass remains, the analysis revealed an interaction between these 2 variables (Diet × Sex) ($P < 0.05$).

The weight of leg muscles and the total proportion of muscles in carcass were significantly higher in group 2 compared to group 1 ($P = 0.042$, $O = 0.020$, respectively). The weight of other carcass elements and their proportion in carcass presented in Table 5 did not differ significantly between the nutrition groups. The weight of breast muscles was significantly greater in female ducks ($P = 0.041$), as were the values of traits describing carcass fatness (weight and proportion of skin with subcutaneous fat, abdominal fat, and total fat) compared to males ($P < 0.05$). There was no interaction between the variables (Diet × Sex) in terms of muscle or fat content in carcass ($P > 0.05$).

Physicochemical Traits of Breast and Leg Muscles

The physicochemical traits of breast and leg muscles are presented in Table 6. The diet based on extruded

Table 3. Growth performance of broiler ducks (whole groups).

Group[1]	Control (1)		Treatment (2)			*P* value		
N = 50 per group	Males	Female	Male	Female	SEM	Diet	Sex	Diet × Sex
Body weight gain, g	3429.30	3375.46	3420.87	3258.07	0.25	0.602	0.105	0.092
Feed intake, g	7514.80	8045.73	7164.75	7467.36	24.01	0.065	0.232	0.059
Feed conversion ratio, kg/kg	2.19	2.38	2.09	2.29	0.08	0.113	0.083	0.141

Notes: No statistically significant differences were found.

[1]The mean values were the result of each subgroup that was represented by 50 birds arranged in 5 replicates with 10 birds in each (total number of ducks in each dietary group, 100).

Table 4. Duck carcass characteristics.

Indicator N = 10 per group	Diet[1]		Sex		SEM	P value		
	1	2	Male	Female		Diet	Sex	Diet × Sex
Preslaughter body weight (g)	3390.00	3441.50	3442.50	3389.00	17.05	0.099	0.087	0.012[x]
Weight of carcass (g)	2273.46[b]	2343.58[a]	2289.67	2327.36	15.44	0.019	0.193	0.152
Dressing percentage (%)	67.08[b]	68.08[a]	66.51[b]	68.66[a]	0.28	0.023	0.000	0.409
Weight and proportion in carcass								
Neck with skin (g)	279.97	284.34	288.41	275.90	4.10	0.594	0.131	0.288
Neck with skin (%)	12.14	12.32	12.59[a]	11.86[b]	0.17	0.574	0.026	0.069
Wings (g)	286.07[b]	304.00[a]	297.13	292.94	4.19	0.035	0.611	0.773
Wings (%)	12.59	12.99	12.99	12.59	0.18	0.258	0.271	0.345
Heart (g)	15.83	17.09	16.62	16.31	0.33	0.052	0.624	0.080
Liver (g)	66.15	66.12	66.10	66.17	1.86	0.995	0.987	0.891
Stomach (g)	91.69	94.30	102.33[a]	83.65[b]	2.25	0.444	0.000	0.138
Carcass remains (g)	590.26	587.42	600.06	577.62	9.34	0.876	0.220	0.038[x]

Notes: 10 ducks were used in the quality analysis; each value represents the mean of 5 samples (2 ducks/pen) from each group.
[ab]Differences between groups marked with letters (1 vs. 2, and male vs. female) were significant ($P < 0.05$).
[x]Significant interaction between two variables: diet × sex.
[1]Diet 1 = soybean meal; Diet 2 = extruded soybean.

soybean (group 2) had a significant effect on improved water-holding capacity of breast muscles from ducks. The study demonstrated that water-holding capacity in group 2 was significantly lower compared with group 1 ($P = 0.000$). On the other hand, the analysis of the chemical composition showed a significantly lower protein content, and a greater content of collagen and intramuscular fat in the breast muscles from group 2 ($P < 0.05$). In males, pH_{45min} was significantly lower ($P = 0.028$), and loss of water was significantly higher ($P < 0.001$). Between dietary groups no significant differences in pH_{45min} and $pH_{24hours}$ values were noticed ($P > 0.05$). Values were at the level 6.33−6.43 and 5.86−5.92, respectively). Similar values were also obtained between dietary and sex groups in colour of breast and leg muscles ($P > 0.05$). The content of protein in breast muscles was significantly lower in males ($P = 0.000$), and the contents of collagen, salt and intramuscular fat were significantly higher ($P < 0\ .05$). An interaction between two variables, Diet × Sex, was found for physicochemical traits (breast muscles: water-holding capacity, protein, collagen, and fat content; leg muscles: protein, fat, and water content). Both variables had a significant effect on water-holding capacity ($P = 0.000$), as well as on the contents of protein, collagen and intramuscular fat in breast muscles ($P < 0.05$).

The analysis in leg muscles revealed a lower content of protein ($P = 0.000$) and higher content of intramuscular fat ($P = 0.000$) in ducks fed a diet based on extruded soybean (group 2). Considering the effect of sex, the contents of protein and water were significantly higher in males ($P = 0.000$), but the contents of collagen, salt and intramuscular fat were higher in leg muscles of females ($P < 0.05$). Different sources of protein in the diet (different diets) and sex of birds had a significant effect on the contents of protein, intramuscular fat and water content in leg muscles. Analysis of these traits revealed an interaction between Diet and Sex ($P < 0.05$).

DISCUSSION

Many years ago, White et al. (1967) investigated the effect of extruded soybean as a substitute for raw soybean on the growth performance of chickens. The researchers also analysed the effect of diets with the

Table 5. Muscles and fatness of duck carcasses.

Indicator N = 10 per group	Diet[1]		Sex		SEM	P-value		
	1	2	Male	Female		Diet	Sex	Diet × Sex
Breast muscles (g)	389.79	418.08	388.13[b]	419.74[a]	7.98	0.065	0.041	0.361
Breast muscles (%)	17.11	17.84	16.95	18.00	0.30	0.222	0.083	0.619
Leg muscles (g)	323.78[b]	343.04[a]	336.21	330.61	4.67	0.042	0.543	0.738
Leg muscles (%)	14.23	14.65	14.68	14.20	0.18	0.247	0.181	0.734
Total muscles (g)	713.57[b]	761.57[a]	724.33	750.35	10.39	0.020	0.189	0.392
Total muscles (%)	31.35	32.49	31.63	32.20	0.36	0.119	0.433	0.810
Skin with subcutaneous fat (g)	385.51	387.51	366.12[b]	406.90[a]	8.00	0.986	0.011	0.948
Skin with subcutaneous fat (%)	21.07	20.55	19.99[b]	21.62[a]	0.33	0.408	0.013	0.411
Abdominal fat (g)	18.09	19.21	13.64[b]	23.66[a]	1.47	0.655	0.000	0.142
Abdominal fat (%)	0.80	0.81	0.59[b]	1.02[a]	0.06	0.873	0.000	0.092
Total fat (g)	496.64	501.90	472.06[b]	526.38[a]	9.56	0.763	0.004	0.723
Total fat (%)	21.86	21.36	20.58[b]	22.64[a]	0.37	0.457	0.004	0.303

Notes: 10 ducks were used in the quality analysis; each value represents the mean of 5 samples (2 ducks/pen) from each group.
[ab]Differences between groups marked with letters (1 vs. 2, and male vs. female) were significant ($P < 0.05$).
[1]Diet 1 = soybean meal; Diet 2 = extruded soybean.

Table 6. Physicochemical parameters of breast and leg muscles from ducks.

	Diet[1]		Sex			*P* value		
Indicator[2] N = 10 per group	1	2	Male	Female	SEM	Diet	Sex	Diet × Sex
Breast muscles								
pH_{45min}	6.43	6.33	6.33[b]	6.43[a]	0.48	0.279	0.028	0.122
$pH_{24hours}$	5.86	5.92	5.85	5.85	0.03	0.375	0.223	0.572
Colour								
L*	46.44	46.00	46.01	46.43	0.30	0.478	0.497	0.350
a*	11.30	11.91	11.89	11.32	0.25	0.212	0.240	0.112
b*	4.72	4.35	4.83	4.24	0.21	0.381	0.159	0.549
Water-holding capacity (%)	42.21[a]	37.35[b]	43.18[a]	36.38[b]	0.99	0.000	0.000	0.000[x]
Drip loss (%)	1.00	1.22	0.94	1.28	0.11	0.312	0.118	0.176
Protein (%)	21.08[a]	20.93[b]	20.90[b]	21.10[a]	0.04	0.000	0.000	0.000[x]
Collagen (%)	1.04[b]	1.20[a]	1.26[a]	0.98[b]	0.05	0.036	0.001	0.006[x]
Salt (%)	0.24	0.25	0.29[a]	0.21[b]	0.01	0.381	0.000	0.160
Fat (%)	2.04[b]	2.61[a]	2.43[a]	2.22[b]	0.07	0.000	0.000	0.000[x]
Water (%)	80.16	77.16	77.24	80.09	0.86	0.074	0.088	0.267
Leg muscles								
Color								
L*	42.89	44.24	44.58	42.55	0.65	0.298	0.121	0.535
a*	9.98	9.85	9.99	9.84	0.32	0.842	0.819	0.727
b*	3.03	3.02	3.37	2.68	0.25	0.971	0.180	0.659
Water-holding capacity (%)	32.15	34.63	34.87	31.91	0.93	0.179	0.111	0.578
Protein (%)	19.75[a]	19.29[b]	19.95[a]	19.09[b]	0.09	0.000	0.000	0.012[x]
Collagen (%)	1.13[b]	1.20[a]	1.09[b]	1.24[a]	0.02	0.047	0.000	0.484
Salt (%)	0.20	0.49	0.48[b]	0.51[a]	0.01	0.079	0.004	0.798
Fat (%)	4.67[b]	4.98[a]	4.21[b]	5.43[a]	0.11	0.000	0.000	0.000[x]
Water (%)	74.75	74.77	75.10[a]	74.42[b]	0.08	0.413	0.000	0.000[x]

Notes: 10 ducks were used in the quality analysis; each value represents the mean of 5 samples (2 ducks/pen) from each group.
[ab]Differences between groups marked with letters (1 vs. 2 and male vs. female) were significant ($P < 0.05$).
[x]Significant interaction between two variables: Diet × Sex.
[1]Diet 1 = soybean meal; Diet 2 = extruded soybean.
[2]pH_{45} – 45 min postmortem, pH_{24} – 24 h postmortem L* - lightness, a* - redness, b* - yellowness.

inclusion of infrared-cooked and autoclaved soybean. The study demonstrated a positive effect of extruded soybean on the performance of chickens. Another study found that soya extrusion can improve the nutritional value of seeds, and be the substitution for commonly used soybean meal in feed for broiler chickens by reducing the level of crude protein to 9% without a negative effect on the dressing percentage of chickens (Jahanian and Rasouli, 2016). In our study the weight of duck carcass was between 2273.46 and 2343.48 g. Similar weight of carcass was reported by Banaszak et al. (2020) and Kowalska et al. (2020). The similarity may be attributed to the fact that all these experimental studies were carried out on Cherry Valley ducks. As reported by Kokoszyński et al. (2020), the genotype and origin in interaction with the sex of birds influences the parameters of duck carcasses. The dressing percentage in our study was in the range of 66.51 to 68.66% (depending on the diet and sex), and was much higher than that reported by Kokoszyński et al. 2019, who used different Pekin-type ducks but also slaughtered them at the age of 49 d, as in our study. The difference may be associated with the use of different feeds and a potential positive effect of extruded soybean or even the origin of ducks, as mentioned above.

Kowalska et al. (2020) demonstrated significantly greater stomach weight as well as fatness (weight of skin with subcutaneous fat and abdominal fat) in female ducks compared to males, which partially corresponds with results obtained in the present study. The weight of stomach obtained in the present work was lower in females than in males (83.65 vs. 102.33 g, respectively). Results reported by Stęczny et al. (2017) indicate that the proportion of the neck with skin as significantly greater values were found in male ducks in both studies. Markam et al. (2017) indicated that female Pekin ducks were characterized by a higher proportion of breast muscles in the carcass. In our study, the weight of breast muscles from female birds was significantly greater than in males ($P = 0.041$). Higher carcass fatness in females may be due to the secretion of oestrogen in the ovary (Kaewtapee et al., 2018). Additionally, it could be associated with a higher FI and feed conversion ratio (numerically, without statistical differences), which were presented in Table 3.

The decrease in pH measured 24 h postmortem compared to pH measured 45 min postmortem indicates normal biochemical changes in breast muscles, and also affects the ability of meat to retain water (water-holding capacity) (Tanganyika and Webb, 2019). This relationship was observed in our study when analysing breast muscles from ducks. Significant differences in the pH of muscles between individual groups may result from different physical activity of animals before slaughter (Grześkowiak et al., 2003), as well as the level of preslaughter stress (Debut et al., 2003). Our study demonstrated that drip loss expressed by water-holding capacity was significantly higher in males.

Other studies investigating the effect of extruded fodder plant seeds on the physicochemical characteristics of poultry meat were carried out on different plant species and with the use of broiler chickens, not ducks. The partial replacement of SBM with extruded rapeseed meal in the diet of chickens influenced the quality of carcass as well as the chemical composition of breast muscles, but differences were not statistically significant (Stanavec et al., 2014). Similar findings were reported by Diaz et al. (2006), who analysed the effect of extruded peas, faba bean and lupin seeds on the growth performance of chickens. The study revealed that the proportion of breast muscles in carcasses was higher in chickens fed a diet based on extruded faba beans, but no significant differences and no negative impact were found in the performance parameters. Hejdysz et al. (2019) demonstrated that a diet based on extruded faba beans had no negative effect on the pH and water-holding capacity of breast and leg muscles from broiler chickens. In our study carcass weight and dressing percentage were higher in ducks fed a diet based on extruded soybean, which may be related to higher digestibility of protein from the feed (Dahlin and Lorenz, 1993). Water-holding capacity of breast muscles was better in ducks fed a diet based on extruded soybean. This value was expressed by the amount of drip loss. According to Ali et al. (2008), the water-holding capacity of meat is influenced by the temperature during slaughter and storage, which is associated with the denaturation of sarcoplasmic proteins. Laudadio and Tufarelli (2010) argued that water-holding capacity is affected by the diet. In our study, breast muscles from group 2 (extruded soybean) were more suitable for potential further processing, and the better water-holding capacity would not reduce the juiciness of meat. In leg muscles no significant differences of water-holding capacity were found. The mechanism of water-holding capacity in the muscles of the breast and legs may differ, as the levels of individual chemical components (especially protein) are different in both types of muscles. It may be related to biochemical processes (denaturation, protein stability) taking place in the muscle tissue (Lesiak et al., 1996). As described by Yu et al. (2005) the breast muscles have more white muscle fibers, and the muscles of the legs – red ones. Fiber types differ in their ability shrinkage, so the more muscle fibers shrinks, the larger the leakage of water from the muscle tissue would be obtained. Contents of protein, fat and water in duck meat measured in our study were similar to those presented by Mazanowski et al. (2003), which indicates that the chemical composition of meat is comparable in ducks of different origins (A44, A55, or Cherry Valley), with slightly higher values in Cherry Valley ducks, which may be related to the different origin of the birds and improved breeding technology (Witak, 2008).

The use of different feeds with a different structure, content of individual components or chemical composition may be absorbed at different levels by birds, which may also be sex-dependent (Giurguis, 1976). The mentioned author paid special attention to differences in fat in terms of diet and sex interaction. Interactions may also be caused by the fact that males are characterized by a different degree of protein digestibility and weight gain (muscle tissue) compared to females, as well as carcass fatness (Shahin and Adb El Azeem, 2006; 2008). In the author's own research, despite the lack of differences between the groups, an interaction of diets × sex in the body weight of birds was shown, however, such results were not shown in the weight of individual muscle tissues or fat. This may indicate that nutrition and gender were important in the mass of the residues, which were largely composed of leg bones or the body, as demonstrated in our own research. The interactions demonstrated in the physicochemical characteristics of the quality of the pectoral muscles and legs may also be related to the structure of tissues and their ability to maintain water, and the relationship between nutrition and sex was also demonstrated in the studies by Adamski et al. (2011). In Pekin ducks, sexual dimorphism is not very visible (similar gains in muscle weight or body gain), which makes it difficult to breed separately (Farhat and Chavez, 2000; Marie-Etancelin et al., 2008).

The proposed diet for Cherry Valley ducks based on non-GMO extruded soya (37.17–29.00% inclusion in the feed) as a substitute for commonly used soybean meal had no adverse effect on the carcass characteristics and the quality of breast and leg muscles. The study demonstrated a positive effect of the alternative feed on the weight and dressing percentage of duck carcasses, as well as the weight of the wings and leg muscles, and slightly on the total proportion of muscles in carcass. Importantly, the proposed diet improved the water-holding capacity of breast muscles from ducks, which supports the conclusion on the good quality of meat and its suitability for further processing, and this trait is essential for food producers and potential consumers. The higher content of fat in muscles can also be regarded as a positive trait, since intramuscular fat is a flavour carrier in processed food of animal origin. Differences in carcass traits and meat quality between males and females, especially the higher fatness of female carcasses, are mainly attributed to natural differences resulting from sexual dimorphism. The interaction between the sex of birds and the proposed diet based on extruded soybean influenced the live body weight of ducks, the weight of carcass remains, water-holding capacity of breast muscles, the contents of protein, collagen and fat in breast muscles, and the contents of protein, fat and water in leg muscles. The identified interaction could suggest that the proposed feed could be used for rearing Cherry Valley ducks in separate groups of male and female birds. However, the lack of significant interactions of diet and sex in carcass weight and slaughter yield or muscle weight does not indicate this.

ACKNOWLEDGMENTS

The study was carried out under the measure "Qualitative assessment of animal raw materials produced based on domestic sources of vegetable protein" of the Multiannual Programme "Increased use of domestic feed protein to produce high-quality animal products under

the conditions of sustainable development" [Resolution No. 222/2015].

DISCLOSURES

The authors assure that there is no conflict of interest related to the research and submitted manuscript entitled "Characteristics of carcass and physicochemical traits of meat from male and female ducks fed a diet based on extruded soybean" to the journal Poultry Science.

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