Slaughter yield, quality of meat from broiler chickens of different origin and age on diet with extruded or meal soybean

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ABSTRACT
The study aimed to compare meat traits from different ages and origin chickens fed with extruded soybean (ES) instead of soybean meal (SBM). 150 male Ross 308 (R) and 150 male Cobb 500 (C) were used, with 2 replicates (75 birds each). The control groups (1) were fed with SM and experimental groups (2) with ES. After 35 and 42 days of rearing, birds were selected for slaughter (80 in total). The carcass and meat quality were analysed. A lower body and carcass weight was demonstrated in all variants in the experimental groups. The age of the birds affected all the slaughter traits of the chickens, with a benefit for day 42, except for the percentage of leg muscles and carcass remains. The origin of the birds influenced some features, especially fatness in C groups. The effect of the diet varied between age groups and origins, especially in the C group, where lower dressing percentage and muscle weight was shown, but the chemical composition was better for the ES diet. According to the effect of age and origin, feed with ES could be used due to carcass and meat quality results after 42 days, especially for Ross 308.

Introduction
Soybean meal (SBM) is a major source of protein widely used in the diet of broiler chickens (Guo et al. 2020). However, the use of soybean in young chickens is limited and contraindicated because of the content of trypsin inhibitors (Wu et al. 2020). Extrusion has a positive effect on the level of antinutrients (e.g. by reducing the activity of trypsin inhibitors), but also improves the digestibility of protein and starch (Konieczka et al. 2014, 2020). Extrusion is a process in which grains are mixed, cut and heated under high pressure. In the next stage, extruded grains are placed on the nozzle and pressed (Hejdysz et al. 2017). Previous studies investigating the graded inclusion of extruded feed components (other plant species, e.g. lupin or pea) showed that they had a positive effect on the chemical composition of seeds, and body weight gain in broiler chickens (Rutkowski et al. 2016; Hejdysz et al. 2018). Hejdysz et al. (2017) found that the extrusion of peas may increase the use of this component in the diet of broiler chickens. Another study (Hejdysz et al. 2019) investigated the use of extruded peas in the diet of broiler chickens and revealed that extruded seeds had no negative effect on the quality of meat. Similar findings were reported by researchers who tested the use of extruded rape-seed (Stanacev et al. 2012). An important trend in animal production in recent years is focused on the reduction in the use of genetically modified feed components, including SBM (Biesek et al. 2020a). Zhang et al. (2019) found that a balanced feed based on maize and SBM had no negative effect on carcass traits and quality of meat from broiler chickens.

The quality of meat is described by a number of factors determining the suitability of meat for further processing and marketing (Kralik et al. 2018; Qamar et al. 2019). According to Kralik et al. (2018), the quality of meat and its suitability for further processing is determined by pH, meat colour, and its ability to retain water (drip loss, water holding capacity). Apart from diet, the quality of the produced raw meat also depends on many other factors, e.g. the origin of broiler chickens, and their age at slaughter (Potłowicz and Doktor 2012).

The available literature on the use of extruded soybeans in the diet of broiler chickens and its impact on the quality of meat is limited, and therefore the presented study is expected to contribute new information on this subject. Ensuring the quality of poultry meat is a very important element of poultry production at the stage of live birds and raw material (carcasses and meat). Modifying the quality by feeding the chickens is one of the more important and influencing factors. The tested hypothesis is: A complete balanced diet based on extruded soybean depending on age and origin of birds influence carcass traits and the quality of breast and leg muscles in terms of their suitability for further processing. The aim of the study was to evaluate and compare carcass traits and the quality of breast and leg muscles from Ross 308 and Cobb 500 broiler chickens fed a diet based on extruded soybean as an alternative to soybean meal, and slaughtered at the age of 35 or 42 days.
Material and methods

According to Directive no. 2010/63/EU of the European Parliament and of the Council, experimental studies in which animals are kept under similar conditions to those under which commercial farm animals are kept, as presented in this paper, do not require the authorization from an Ethics Committee. The research was carried out on a small farm, and the samples for analysis were collected after slaughtering broiler chickens.

Animals and diets

Ross 308 and Cobb 500 broiler chickens were reared on a small farm. One-day-old male chicks were assigned to pens. There were 150 chickens in each group (total 300), with 2 replicates (75 birds each). The living conditions were dictated by the fact that it was a small-scale farm. According to the test assumptions, these were implementation studies, where chickens were kept in conditions similar to commercial ones. Group 1 (control, Ross 308 and Cobb 500) was fed a balanced diet based on soybean meal (Hipro variety). Group 2 (experimental, Ross 308 and Cobb 500) was fed a diet based on extruded soybean produced in Poland. Management conditions for the broiler chickens were consistent with the technology for broiler chicken production (Aviagen 2015). The building was closed. Broilers were kept on wheat straw litter with a housing density of 33 kg/m². The temperature in the building was on average 30°C for the first 3 days, and then it gradually decreased to an average of 20°C (from 29th day). Air humidity averaged 65% and lighting was adjusted to the 24 h cycle for 3 days after insertion and 3 days before slaughter. The remainder of the period was controlled with a maximum 8-hour blackout per day. The concentration of carbon dioxide (CO₂) did not exceed 3000 ppm, and ammonia (NH₃) did not exceed 20 ppm. Birds received complete feeds (commercial), and their composition is presented in Table 1. There were two feeding phases. Chickens were fed a starter diet between days 1 and 14, and then a grower diet between days 15 and 42. The manufacturer of the feeds provided analytical results for the chemical composition of the complete feeds (Table 2). Chickens had access to feed and fresh drinking water ad libitum. Protein and other nutrients in all feeds were balanced through the addition of rapeseed meal (10%), as well as potato protein (4%) in starter diet and 2% in grower diet) in the experimental group. Feed rations for the broiler chickens were developed consistently with nutritional recommendations for poultry feeds (Smulikowska and Rutkowski 2019). Mortality of broiler chickens was lower than 1%, and most deaths were recorded in weak chicks at the beginning of rearing. The mean feed conversion ratio (FCR) in both groups was 1.81–1.82 kg/kg, and the European Broiler Index (EBI) was higher than 270 at the end of the production period.

Slaughter and dissection

Live broiler chickens were weighed individually on the farm on day 35 or 42 of rearing, and 20 chickens from each group were selected (10 birds of the same age in each subgroup). A total of 40 birds were slaughtered on day 35 and 40 birds on day 42. The body weight of the selected birds was close to the mean weight of birds from each pen. Chickens were weighed with an accuracy of ±0.01 g (Radwag scales, Radom, Poland) and marked with a jifty wing band with individual numbers, so that each carcass was the basic experimental sample during the analysis. Chickens were slaughtered by qualified staff in compliance with relevant standards on the slaughtering of broiler chickens. The birds were fasted for 12 h, stunned and then slaughtered by decapitation (rapid dissection of the spinal cord and exsanguination). After slaughter, the carcasses were plucked and eviscerated, the heart, liver (without gallbladder) and gizzard (without digesta) separated, and the shanks cut off. The chilled carcasses, heart, liver and gizzard were weighed (Radwag, Radom, Poland). The carcass was dissected by separating the neck with skin, wings (with skin), breast muscles (pectoralis major muscle and pectoralis minor muscle), leg muscles (boned, thighs and drumsticks), skin with subcutaneous fat (without skin from the neck) and abdominal fat. Carcass remains (trunk and leg bones) were weighed. The total weight of muscles was the sum of breast and leg

| Table 1. Composition of complete feeds for broiler chickens. |
|-----------------------------------------------|
| FED                          | CONTROL (1) | EXPERIMENTAL (2) |
| Ingredients                   | STARTER     | GROWER     | STARTER     | GROWER     |
|                               | (days 0–14) | (days 15–42)| (days 0–14) | (days 15–42)|
| Maize                        | 48.81       | 51.84      | 41.41       | 45.00      |
| Soybean meal (SBM), Hipro    | 31.00       | 28.00      | –           | –          |
| Extruded soybean (ESB)       | –           | –          | 38.00       | 40.00      |
| Rapeseed meal                | 10.00       | 10.00      | 10.00       | 10.00      |
| Potato protein               | –           | –          | 4.00        | 2.00       |
| Soybean oil                  | 6.20        | 6.70       | 2.20        | 3.50       |
| Limestone                    | 0.50        | 0.40       | 0.22        | 0.12       |
| Monocalcium phosphate        | 1.30        | 1.10       | 1.90        | 1.70       |

Note: 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; cholecalcifer 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. Analytical composition of complete feeds for broiler chickens. |
|-----------------------------------------------|
| FED                          | CONTROL (1) | EXPERIMENTAL (2) |
| Ingredients                   | STARTER     | GROWER     | STARTER     | GROWER     |
|                               | (days 0–14) | (days 15–42)| (days 0–14) | (days 15–42)|
| Dry matter, g                | 888.00      | 888.00     | 885.00      | 886.00     |
| Energy, MJ ME                | 14.10       | 14.40      | 13.60       | 14.10      |
| Crude protein, g             | 226.00      | 215.00     | 242.00      | 232.00     |
| Crude fat, g                 | 88.90       | 94.50      | 112.00      | 126.00     |
| Fibre, g                     | 45.60       | 44.50      | 43.90       | 44.70      |
| Crude ash, g                 | 57.70       | 53.30      | 59.30       | 56.90      |

Note: 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.
of minced muscles (0.300 g ±5%; M1) were placed on a mincer and analysed for water holding capacity in 10 replicates. Leg muscles from individual groups were disintegrated in a breast and leg muscles was calculated from the difference in weight (g). The proportion of individual elements in the carcass weight was calculated (%), expressed as follows: 

\[
\text{proportion of element} = \left( \frac{\text{weight of element} \times 100}{\text{weight of carcass}} \right)
\]

by eviscerated weight of carcass without giblets (g) divided by preslaughter body weight (g) (Biesek et al. 2020b).

**Physicochemical traits of breast and leg muscles**

Analytical methods followed procedures presented by Kuzniacka et al. (2020a) with minor modifications. The pH value of breast muscles was measured 45 min post-mortem (pH45min). Measurements were taken using a pH-meter with a knife electrode (Elmetron, Zabrze, Poland) inserted at a depth of 2 cm into the pectoralis major muscle. Carcasses were chilled in a refrigerator for 24 h at 4°C. The next day, the pH of breast muscles was measured again (pH24hfour). Each right and left breast muscle and leg muscle was placed on trays with the relevant number and hung in a refrigerated cabinet for 24 h at 4°C. After 24 h the breast and leg muscles were weighed again (M2). Drip loss (%) was calculated based on the difference in muscle weight (((M1 – M2)/M1) × 100%). The left breast and leg muscles from individual groups were disintegrated in a mincer and analysed for water holding capacity in 10 replicates. Samples of minced muscles (0.300 g ±5%; M1) were placed on Whatman 1 filter paper covered with another piece of filter paper and pressed with a 2 kg weight for 5 min. After the specified time, the meat samples were removed from the filter paper, weighed again (M2), and water loss from the breast and leg muscles was calculated from the difference in weight (the formula like in the drip loss analysis). Samples of minced breast and leg muscles (90 g each) were analysed for basic chemical components, as well as the content of protein, collagen, sodium chloride, intramuscular fat, and water (in %). Analyses were performed using FoodScan apparatus (FOSS, Hilleroed, Denmark) and Near Infrared Transmission (NIT) spectrometry.

**Statistical analysis**

The obtained data were processed using Statistica software (Statsoft, Poland). A two-way ANOVA model was used to analyse variance. Three grouping variables were considered in the analysis: Diet with different protein sources, age at slaughter, and origin of the birds (Ross 308, Cobb 500). Differences were verified using Tukey’s test at the significance level p < 0.05. Additionally, Tables 3–5 present the results of the statistical analysis in the form of the significance of differences in terms of age and origin, assuming a p-value < 0.05.

**Results**

**Carcass characteristics**

Comparing broiler chickens fed on a different protein source (1, soybean meal vs. 2, extruded soya), a statistically higher body weight before slaughter and a carcass weight were shown in the chickens from group 1 on days 35 and 42 (P < 0.05), but not statistically significant differences were found in the dressing percentage (P > 0.05). The analysis of individual parts of the carcass revealed that 35-day-old chickens from the control group were characterized by a significantly higher weight of the neck with the skin, as well as the weight of the gizzard (P < 0.05). In the groups of 42-day-old chickens, no statistically significant differences (P > 0.05) were found in terms of carcass elements (Table 3).

In the group of Ross 308 and Cobb 500 chickens, a statistically significantly higher body weight of birds selected for slaughter was demonstrated, as well as the weight of carcasses in the control group, fed on the soybean meal (P < 0.05). However, only the Cobb 500 group showed a significantly higher dressing percentage in group 1 (P = 0.013). The group of Ross 308 chickens fed with the control feed was characterized by a significantly greater weight of the neck with the skin (P = 0.040) and the weight and percentage of gizzard (P = 0.002, 0.026, consecutively), as well as the weight of carcass remains (P = 0.023). On the other hand, Cobb 500 chickens fed on the extruded soya had a significantly higher percentage of wings in the carcass (P = 0.032) (Table 3).

Table 3 shows that age influences the body weight before slaughter and the chicken carcass and the slaughter yield, as well as the weight and percentage of carcasses. Statistically significantly higher weight of all carcass elements and offal was shown, as well as their percentage in the carcass, except for carcass remains. Higher values were found in chickens on day 42 (P < 0.05). In turn, the origin of the chickens influenced several elements. Cobb 500 chickens were significantly heavier than Ross 308 (P = 0.012), and they also showed a significantly higher weight of wings and liver, but a lower percentage of the heart and gizzard in the carcass (P < 0.05).

**Muscles and fatness of chicken’ carcasses**

Comparing the weight of the breast and leg muscles, as well as the fatness of the chicken carcasses (Table 4), a statistically...
### Table 3. Characteristics of broiler chicken carcass and pre-slaughter weight.

| Indicator                        | 35 d | 42 d | P-value   | Ross 308 | Cobb 500 | SEM | P-value   |
|----------------------------------|------|------|-----------|----------|----------|-----|-----------|
| Pre-slaughter body weight (g)    |      |      | <0.001    | 0.007    | <0.001  |      | <0.001    |
| Weight of carcass (g)            |      |      | 1854.35a  | 1748.35b | 1874.45a| 1803.45b| 30.44 |
| Dressing percentage (%)          | 69.96| 69.47| 0.032     | 0.042    | 0.873   | 0.25 | 0.853     |
| Weight and proportion in carcass |      |      | -         |          |         |      | -         |
| Pre-slaughter body weight (g)    |      |      | 1212      | 1180.60b | 1212    | 1208.35b| 3      |
| Weight of carcass (g)            |      |      | 1126.20a  | 1064.35b | 1126.45a| 1064.35b| 5.45  |
| Dressing percentage (%)          | 69.96| 69.47| 0.032     | 0.042    | 0.873   | 0.25 | 0.853     |
| Weight and proportion in carcass |      |      | -         |          |         |      | -         |
| Pre-slaughter body weight (g)    | 1616.60*| 1580.30b| 2112.20a| 2043.50b| <0.001| 0.007| <0.001|
| Weight of carcass (g)            | 1130.99*| 1047.84b| 1517.57a| 1451.35b| 0.003| <0.001| 0.003|
| Dressing percentage (%)          | 69.96| 69.47| 0.032     | 0.042    | 0.873   | 0.25 | 0.853     |
| Weight and proportion in carcass |      |      | -         |          |         |      | -         |

Note: 40 chickens were used in the quality analysis; each value represents the mean of 2 samples (10 chickens/pen) from each group; a, b, … different letters between groups (1 vs. 2 in two terms of slaughter, and 1 vs. 2 for Ross 308 and Cobb 500 chickens) were significantly different (p-value < 0.05); effect of age and origin was checked at significance level p < 0.05; SEM = standard error of the mean.

### Table 4. Muscles and fatness of broiler chicken carcasses.

| Indicator                        | 35 d | 42 d | P-value   | Ross 308 | Cobb 500 | SEM | P-value   |
|----------------------------------|------|------|-----------|----------|----------|-----|-----------|
| Pre-slaughter body weight (g)    |      |      | <0.001    | 0.007    | <0.001  |      | <0.001    |
| Weight of carcass (g)            |      |      | 1854.35a  | 1748.35b | 1874.45a| 1803.45b| 30.44 |
| Dressing percentage (%)          | 69.96| 69.47| 0.032     | 0.042    | 0.873   | 0.25 | 0.853     |
| Weight and proportion in carcass |      |      | -         |          |         |      | -         |
| Pre-slaughter body weight (g)    | 1616.60*| 1580.30b| 2112.20a| 2043.50b| <0.001| 0.007| <0.001|
| Weight of carcass (g)            | 1130.99*| 1047.84b| 1517.57a| 1451.35b| 0.003| <0.001| 0.003|
| Dressing percentage (%)          | 69.96| 69.47| 0.032     | 0.042    | 0.873   | 0.25 | 0.853     |
| Weight and proportion in carcass |      |      | -         |          |         |      | -         |
| Pre-slaughter body weight (g)    |      |      | <0.001    | 0.007    | <0.001  |      | <0.001    |
| Weight of carcass (g)            |      |      | 1854.35a  | 1748.35b | 1874.45a| 1803.45b| 30.44 |
| Dressing percentage (%)          | 69.96| 69.47| 0.032     | 0.042    | 0.873   | 0.25 | 0.853     |
| Weight and proportion in carcass |      |      | -         |          |         |      | -         |

Note: 40 chickens were used in the quality analysis; each value represents the mean of 2 samples (10 chickens/pen) from each group; a, b, … different letters between groups (1 vs. 2 in two terms of slaughter, and 1 vs. 2 for Ross 308 and Cobb 500 chickens) were significantly different (p-value < 0.05); effect of age and origin was checked at significance level p < 0.05; *total fat consists of skin with subcutaneous fat, abdominal fat and skin from the neck.
Table 5. Physicochemical parameters of breast and leg muscles from broiler chickens.

| Indicator | 35 d | 42 d | P-value | Ross 308 | Cobb 500 | SEM | P-value |
|----------|------|------|---------|----------|----------|-----|---------|
| pH<sub>45 min</sub> | 6.65 | 6.51 | 6.31 | 6.39 | 0.075 | 0.384 | <0.001 | 6.68 | 6.67 | 6.54 | 6.50 | 0.03 | 0.997 | 0.914 | 0.005 |
| pH<sub>24 h</sub> | 6.58 | 6.53 | 6.41 | 6.38 | 0.757 | 0.905 | <0.001 | 6.41 | 6.40 | 6.31 | 6.25 | 0.03 | 0.987 | 0.545 | <0.001 |
| Colour | **L**<sup>*</sup> | 51.52 | 51.32 | 52.09 | 51.02 | 0.997 | 0.679 | 0.842 | 52.38 | 52.28 | 51.24 | 50.06 | 0.37 | 0.999 | 0.613 | **0.016** |
| a<sup>*</sup> | 3.35 | 3.41 | 3.55 | 2.56 | 0.999 | 0.235 | 0.380 | 3.51 | 3.34 | 3.38 | 2.82 | 0.18 | 0.890 | 0.708 | 0.338 |
| b<sup>*</sup> | 3.81 | 3.38 | 3.48 | 2.83 | 0.999 | 0.245 | 0.234 | 3.92 | 3.32 | 3.37 | 2.89 | 0.18 | 0.206 | 0.797 | 0.185 |
| Water holding capacity (%) | 35.99 | 32.08 | 30.93 | 30.89 | 0.111 | 0.999 | <0.001 | 33.32 | 32.13 | 33.59 | 30.84 | 0.50 | 0.764 | 0.119 | 0.559 |
| Drip loss (%) | 1.44 | 1.75 | 1.35 | 0.75 | 0.356 | 0.999 | <0.001 | 1.44 | 1.02 | 1.35 | 1.47 | 0.09 | 0.122 | 0.903 | 0.158 |
| Protein (%) | 23.10 | 23.05 | 23.18 | 23.18 | 0.999 | 0.105 | <0.001 | 23.18 | 23.45 | 23.09 | 23.34 | 0.04 | <0.001 | <0.001 | <0.001 |
| Collagen (%) | 1.37 | 1.25 | 1.31 | 1.07 | 0.991 | 0.803 | <0.001 | 21.36 | 29.66 | 35.89 | 36.07 | 0.61 | 0.507 | 0.999 | <0.001 |
| Salt (%) | 0.27 | 0.26 | 0.23 | 0.21 | 0.985 | 0.841 | <0.001 | 0.30 | 0.27 | 0.20 | 0.20 | 0.01 | 0.455 | 0.991 | <0.001 |
| Fat (%) | 5.45 | 4.74 | 4.98 | 5.26 | 0.001 | 0.001 | <0.001 | 1.77 | 1.79 | 0.02 | <0.001 | 0.98 | <0.001 | <0.001 |
| Water (%) | 75.57 | 75.41 | 76.63 | 78.80 | 0.999 | 0.242 | 0.008 | 75.33 | 75.17 | 76.87 | 79.04 | 0.47 | 0.999 | 0.243 | 0.002 |

Note: 40 chickens were used in the quality analysis; each value represents the mean of 2 samples (10 chickens/pen) from each group; a, b . . . different letters between groups (1 vs. 2 in two terms of slaughter, and 1 vs. 2 for Ross 308 and Cobb 500 chickens) were significantly different (p-value < 0.05); effect of age and origin was checked at significance level p < 0.05; Diet 1 = soybean meal; Diet 2 = extruded soybean; SEM – standard error of the mean; pH<sub>15</sub> – 15 min post-mortem, pH<sub>24 h</sub> – 24 h post-mortem; L<sup>*</sup> – lightness, a<sup>*</sup> – redness, b<sup>*</sup> – yellowness.
significantly higher weight of the muscles of the legs and total muscles (breast and leg muscles) was shown in 42-day-old chickens fed on the basis of soybean meal (1) compared to a group of chickens with extruded soya (2) \((P < 0.05)\). In the remaining presented traits of 35- and 42-day-old chickens, no significant differences were found between the feeding groups \((P > 0.05)\).

In the group of Cobb 500 chickens fed with the experimental feed, a significantly lower mass of breast and leg muscles and total muscles was demonstrated \((P = 0.05)\). On the other hand, no statistically significant differences \((P > 0.05)\) were found in the other examined traits in terms of feeding and different origins of chickens \((Table 4)\). The weight of breast, leg muscles and total muscle, skin with subcutaneous fat, abdominal fat and total fat was significantly higher in the 6-week-old chickens compared to 5-week-old chickens, however, the percentage of skin with subcutaneous fat and the percentage of total fat were significantly higher in the group of chickens after 35 days of rearing \((P < 0.05)\). There were no significant differences in the percentage of leg muscles in the carcass depending on the age of slaughter \((P > .05)\), but the percentage of total muscles was different due to the age, and abdominal fat was influenced by age and origin \((P < 0.05)\). Cobb 500 chickens were characterized by significantly higher weight and percentage of abdominal fat \((P < 0.05)\), as well as total fat mass \((P = 0.030)\) compared to Ross 308 chickens \((Table 4)\).

**Physiochemical traits of breast and leg muscles**

In the group of 35-day-old chickens fed with a feed based on soybean meal, a significantly higher share of collagen in the breast muscles was shown compared to group 2 \((P < 0.05)\). In turn, on day 42, the breast muscles of the chickens from group 1 were characterized by a lower water retention capacity, expressed as drip loss, a lower proportion of protein, and a higher proportion of collagen and intramuscular fat \((P < 0.05)\) \((Table 5)\). In the leg muscles of group 1, after 35 days of rearing, a significantly higher content of collagen, intramuscular fat and lower water was demonstrated, while after 42 days, significantly lower intramuscular fat and higher collagen and water were shown compared to group 2 \((P < 0.05)\).

In the group of Ross 308 and Cobb 500 chickens, it was shown that feeding with extruded soybean had an effect on higher protein content in the breast muscles and lower collagen content \((P < 0.001)\). In the group of Ross 308 chickens fed with feed based on ESB, a statistically significantly lower content of intramuscular fat in the breast muscles was demonstrated \((P < 0.001)\). On the other hand, the analysis of the physicochemical characteristics of the leg muscles in relation to diet and origin indicates that in the Cobb 500 group of chickens, the yellowness in the control group was significantly higher \((P < 0.001)\), as well as a higher content of collagen, salt, fat and water \((P < 0.05)\). In the Ross 308 group fed with the control diet, it was shown that the content of collagen, fat in leg muscle was significantly higher, and water content was lower \((P < 0.001)\) \((Table 5)\). No statistically significant differences were found in the other examined features \((P > 0.05)\). The breast muscles of chickens after 35 days of rearing were characterized by significantly higher pH at 45 min and 24 h after slaughter, as well as higher water loss measured by water-holding capacity and drip loss \((P < 0.05)\), compared to older chickens. Analysing the chemical composition of the breast muscles, significantly higher protein, fat and water contents were shown in the group of 42-day-old chickens, and lower content of collagen and salt than in the chickens at 35 days of age \((P < 0.05)\). In turn, the leg muscles of younger chickens were characterized by significantly higher redness \((a^*)\), higher drip loss, collagen and water content, and lower water-holding capacity, protein and fat content than the 42-days-old chickens \((P < 0.05)\) \((Table 5)\).

**Table 5** also shows statistically significant differences in terms of the origin of the chickens. Significantly higher pH was found 45 min and 24 h after slaughter in the Ross 308 group, as well as higher lightness \((L^*)\), protein and salt content, and lower intramuscular fat and water content in the breast muscle \((P < 0.05)\) compared to Cobb 500. There was no effect on the collagen content \((P > 0.05)\). In turn, the leg muscles of Ross 308 chickens were characterized by lower water-holding capacity and drip loss, as well as the content of collagen, salt, intramuscular fat and water, and higher protein content compared to Cobb 500 \((P < 0.05)\).

**Discussion**

Research on the effect of extrusion of feed components on the growth performance and meat quality of broiler chickens and other farm animals has been conducted for many fodder plant species \((Konieczka et al. 2014; Hejdy sz et al. 2016; Rutkowski et al. 2016; Hejdy sz et al. 2017, 2018; Konieczka et al. 2020; Vadopalas et al. 2020)\), but publications related to the quality of meat from broiler chickens fed a diet based on extruded soybean are scarce.

Many years ago Hull et al. \((1968)\) concluded that extruded soybean promoted the growth of broiler chickens. Jansons et al. \((2020)\) investigated the effect of a local variety of extruded soybean as an alternative to imported soybean on the growth performance of porkers and the quality of pork. The researchers found no negative impact of the diet based on extruded soybean on the growth performance, carcass characteristics or quality of meat. The use of extruded sesame seeds in the production of broiler chickens did not affect the weight and proportion of individual elements in the carcass \((Owosibo et al. 2017)\). In our study, differences were found in the live body weight, the weight of carcass in both ages and for Ross 308 and Cobb 500 chickens. This may indicate that the chicks were of a different body weight, but their growth was uniform in every feeding group. There was no effect on the dressing percentage. Excluding Cobb 500 chickens fed with different diets.

A study by Hejdy sz et al. \((2019)\) demonstrated no differences in pH and water holding capacity of breast and leg muscles between broiler chickens fed raw or extruded faba beans. Similar to our research, they found no differences in these traits depending on the diet used. Meat from broiler chickens is prone to a rapid decrease in pH, which may result in poorer water holding capacity of muscles, but the mechanism regulating this process in chicken meat has been little
investigated (Bowker and Zhuang 2015). Studies on the use of extruded rapeseed and maize grain in the diet of Ross 308 chickens showed that the partial replacement of soybean meal (SBM) with the alternative feed had no significant effect on the quality traits of the carcass or the quality of breast muscles (Stanacev et al. 2012). In our study, most of the analysed traits of carcass, breast muscles and leg muscles did not differ between the groups. Minor differences between various studies may result from the use of different species of extruded fodder plants (diet) or the origin of the broiler chickens (Mikulski et al. 2011; Kuźniacka et al. 2014). In our study, the body weight of 42-day-old Ross 308 chickens was similar to that reported by Kokoszyński et al. (2017), who also conducted research on Ross 308 chickens. The chemical composition of breast and leg muscles in our study was similar to that reported by Luadadio et al. (2011), Biesek et al. (2020a), and Kuźniacka et al. (2020b), who used chickens fed an SBM-diet as controls. Importantly, the protein level measured in all of the above-mentioned studies and in our experiment was about 22–29% in breast muscles and 18–21% in leg muscles.

Carcass characteristics and meat quality depend on the age of chickens at slaughter (Hussein et al. 2019). In our study, the pH of breast muscles was lower in 42-day-old chickens, whereas the findings by Bieginiewska et al. (2016) showed higher values. The pH values in both nutritional experiments may indicate a slight anomaly suggesting the DFD (dark, firm, dry) meat defect, although this is not substantiated because of the light colour of the muscles. Mehaffey et al. (2006) found higher values of drip loss in younger chickens (6-weeks-old) compared to older birds (7-weeks). A similar relationship was found in our study in feeding groups (P < 0.05). The water-holding capacity was higher in breast muscles from younger chickens, and in leg muscles from older chickens (p < 0.05). Higher water-holding capacity indicates a higher loss of water and thus lower suitability of meat for further processing. Other researchers also demonstrated higher drip loss for breast muscles from younger chickens (38 days) compared to older birds (49 days) (Fisinin et al. 2018). If carcasses are not properly chilled, myosin is denatured quickly, which causes increased loss of water and paleness of meat, and consequently PSE (pale, soft, exudative) meat defects (Dransfield and Sosnicki 1999). Zdanowska-Siądedek et al. (2013) reported that the age of broiler chickens has a significant effect on the quality of meat. Chickens reared for 6 weeks are characterized by a high yield of breast muscles, and in birds at the age of about 42 days, the level of collagen maturity makes the meat tender, which is important from the point of view of consumers. The tenderness of meat from older birds is lower. The juiciness of meat decreases in a similar fashion, especially in chickens older than 9 weeks. The age of birds was also indicated as an important factor influencing the quality of poultry carcasses in a study by Adamski et al. (2016) where goose meat was described. In our study, it was noticed that breast muscle weight was much higher from the 35th day to 42nd day, which is beneficial for producers of broiler chicken meat. The content of total fat in chicken carcasses in our study was determined by the age of birds. Older broilers had more fat than the younger. Similarly, Mikulski et al. (2011) found that slower-growing chickens had higher fat content in carcasses than faster-growing chickens which is related to the digestibility of nutrients from feed. In our study, some differences between Ross 308 and Cobb 500 were found. As Tougan et al. (2013) described, the genotype and origin could affect the meat quality traits, e.g. pH value. It was also noticed in our research, on the 35th day. Chemical composition was also determined by origin (genotype) and the slaughter age of birds, also in interaction with the use of different diets. Meat quality traits change as the birds get older (Tougen et al. 2013), e.g. higher collagen content which affects the texture of the meat. The use of different feeds could modulate the growth of muscles as well as the fatness of carcasses. Comparing Ross 308 and Cobb 500 chickens, better meat quality traits in Ross 308 groups were found, but it doesn’t correspond with other findings, where authors stated slightly higher values of economic efficiency of Cobb 500 chickens (Marcu et al. 2013). Cobb 500 chickens showed lower muscle weight compared to Ross 308 chickens fed with ESB. This may indicate that it is more advantageous to use ESB in the rearing of Ross 308.

Conclusions

The proposed balanced feed with a 38–40% inclusion of extruded soybean did not influence the most traits of carcass, excluding leg muscles weight, but the dressing percentage was similar. There was a beneficial effect of extruded soya on the drip loss, which is important for consumers and for further technological processing. Despite differences in body and carcass weight, no significant changes were found in the dressing percentage in 35 and 42 days old chickens and in the Ross 308 group, which is important for poultry producers. Analysing obtained results, it was stated that the age of slaughter is important, and it is preferable to rear for 42 days, due to the dressing percentage. The origin of birds has an impact on the tested traits. The Ross 308 chickens showed better carcass traits and meat quality, and the Cobb 500 chickened less placement, which may be genotype dependent, but indicates that Ross 308 fed on the proposed extruded soybean feed had better results. Almost all of the traits tested differed when the 35-day-old and 42-day-old chickens were analysed. It is related to the physiology of the birds and the growth characteristic of this species. These results indicate that the correct rearing of chickens should take into account their origin and age, and the feed should be adjusted to these factors.

Animal welfare statement

The authors confirm that the ethical policies of the journal, as noted on the journal’s author guidelines page, have been adhered to. The authors confirm that they have followed EU standards for the protection of animals used for scientific purposes. According to Directive no. 2010/63/EU of the European Parliament and of the Council, experimental studies in which animals are kept under similar conditions to those under which commercial farm animals are kept, as presented in this paper, do not require the authorization from an Ethics Committee. The research was carried out on a small farm, and the
samples for analysis were collected after slaughtering broiler chickens. Resolution 13/2016 of the National Ethics Committee for Animal Experiments of June 17, 2016, where: Collecting material from animals in breeding for genotyping and marking these animals are not procedures within the meaning of the Act on the protection of animals used for scientific or educational purposes and there is no need to obtain the consent of the Local Ethics Committee.

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