The effect of partial replacement of milled finisher feed with wheat grains on the production efficiency and meat quality in broiler chickens

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ABSTRACT The study’s aim was to assess the production efficiency, evaluate the carcass and meat quality of chickens fed with wheat grains. 200 Ross 308 chickens were divided into 4 groups (5 replicates with 10 birds in each): control (C) and experimental groups, including W50, where the finisher feed was diluted with wheat grain in 50%, W25−25%, and W10−10%. The production efficiency and chemical composition of the feed were analyzed. After 42 d of rearing, 10 birds from each group were selected, and the tissue composition, pH, color, water-holding capacity, drip loss, the chemical composition of meat, and the apparent protein digestibility, bone, and jejunum strength were investigated. It was proved that ground feed had an unfavorable effect on the body weight (BW) in all groups. Wheat decreased the protein level (P < 0.001) and digestibility (P < 0.001). The body weight gain (BWG) in group W50 was lower than in groups C and W10 (P = 0.009), however, this had no effect on the final feed conversion ratio (FCR) (P = 0.146). Finisher feed costs were reduced in groups W50, W25 compared to group C (P < 0.001). The European Production Efficiency Factor and the European Broiler Index in groups W10 and W25 were similar to group C, whereas in W50 they were reduced (P = 0.035; 0.034). No negative effect on carcass traits was shown in groups W10 and W25, however, 50% feed replacement was unbene-}

Key words: alternative feeding, cereal grain, growth, production economics, raw material quality

INTRODUCTION

Feeding of broiler chickens is the key element of poultry production, and its cost intensity accounts for approximately 70% of the total costs incurred (Abdurofi et al., 2017). For many years, activities have been undertaken to improve the production strategy, which depends on the growth of birds or the feed conversion ratio and its quality (Yadav and Jha, 2019). Apart from factors depending on the chicken producer, poultry farming faces many challenges. In 2020, the outbreak of the pandemic (COVID-19) had a negative impact on the market situation of poultry products (as well as on the entire agri-food sector, HoReCa), which influenced the economics of production (Nurahmi and Zalizar, 2021). Deliveries of poultry products were suspended in many places, and meat processing factories reduced the level of production, which is associated with lower demand in stores, as well as with an increase in prices, including feed prices (Maples et al., 2020). Most of the information is important for large-scale broiler production, however, many small-scale farms rear chickens as this is a more stable income compared to larger livestock. The production cycle is short, and at the same time, farmers offer high-quality food of animal origin (taking into account a very good source of protein) (Hatab et al., 2021). Increasingly, the poultry industry discusses short food supply chains, which is a local and healthy selling method, especially on the aforementioned “family” farms (Aguiar et al., 2018). Combining the fact of the pandemic and the opportunities associated with short supply chains and direct sales of meat products, Hobbs (2021) concluded that small-scale farms have a higher chance of adaptation.
Poultry production may be supported by changing the composition of the feed, by partially replacing complete feeds with cereal grains that can be obtained on the farm, which would reduce the cost-intensity of feeding (El-Deek et al., 2020). In their research, the cited authors undertook issues related to the alternative replacement of ingredients in the finisher feed for broiler chickens Plavnik et al. (2002), described that the use of cereal grains, including wheat, in poultry nutrition reduces production costs, has a positive effect on feed conversion or feed utilization, and the production results are similar to the case when only commercial feeds are used. A similar conclusion was reported by Bennett et al. (2002). The cited authors indicated a higher gizzard weight, which corresponds to the results of the research by Gabriel et al. (2008), in which the effect of using wheat grain on the development of the digestive system of broiler chickens was assessed. Wheat is a widely used grain in poultry nutrition due to its easy availability and metabolizable energy content (Pirgozliev et al., 2003; Ayasan et al., 2020). In the last stage of chicken nutrition, the feed has a reduced protein level and an increased level of metabolic energy. By adding ground wheat grains to the feed, an increased effect can be expected, which may affect the feed conversion ratio and increased abdominal fat in chickens (Chryystal et al., 2020). Nutritional strategy regulates muscle growth, tissue changes, and protein metabolism. However, in the case of meat quality, the postmortem energy changes have a large impact on the end result of production, and should be taken into account (Huang et al., 2020). Adequate nutrition also affects the development and strength of bones and intestines. It should be noted that bone development is relatively late in relation to the development of muscle tissue, which may result in exposure to a lower breaking strength of the femur or tibia bones (Chung et al., 2019). Accordingly, the research hypothesis is as follows: partial replacement of milled finisher feed with ground wheat grains affects the production efficiency and meat quality in broiler chickens.

**MATERIALS AND METHODS**

The experiment was conducted in accordance with the applicable regulations. The slaughter of the birds was carried out in accordance with the applicable regulations on the handling of animals during slaughter, including humane treatment. The methods used in meat quality testing were also employed in accordance with the current and commonly used methodology described in the Materials and Methods section. According to the directive no. 2010/63/EU of 22 September 2010 on the protection of animals used for scientific purposes, the consent of the Ethics Committee was not required. The directive sets out requirements for the protection of animals used for experimental purposes. It states that these rules do not apply to agricultural activities and animal husbandry. The experiment was carried out under conditions similar to the commercial ones, so the farm owners were responsible for the production. In addition, there is a resolution no. 13/2016 (June 17, 2016), which states that collecting material from animals in breeding for genotyping and labeling of these animals is not a procedure. Slaughter for the purpose of collecting tissues and organs from animals, is not a procedure (Act of January 15, 2015 on the protection of animals used for scientific or educational purposes, item 266, Journal of Laws of the Republic of Poland).

**Animals and Diets**

One-day-old Ross 308 male broiler chickens were used in the experiment. Their rearing lasted 42 d. The building in which the birds were housed had a fully regulated temperature. For the first 3 d, the average temperature was 30°C (additional heat sources — heaters — were hung above the pens). Then, the temperature was gradually lowered to the level of 20°C. Humidity in the building was on average 60 to 65%. The lighting in the building was continuous (24-h) for the first day, then 23-h lighting was used for 6 d, and next until the 39th day of life of the birds, uninterrupted darkening was provided for a maximum of 6 h a day. The birds had 23 h of light for the last 3 d of their lives. Ventilation was provided for the summer period, so that the content of ammonia did not exceed 20 ppm, carbon dioxide did not exceed 3,000 ppm, and hydrogen sulfide did not exceed 10 ppm. The chickens were randomly divided into four equal groups. The average weight of 1-day-old chicks was 46.67 g. The birds were placed in 1 × 1 m pens, (10 × 5 replications). The feeding of broiler chickens was divided into 3 stages: starter feed (1−14 d), grower (15−35 d), and finisher (36−42 d). The feeds were commercial, in a fine-loose form. The first group was the control group (C). The birds were reared similarly, according to Ross 308 flock management standards. In the experimental groups, in the last feeding stage (36−42 d), the complete feed of the finisher type was diluted with ground wheat grain at different levels. The finisher feed with wheat grain was mixed to obtain a free flowing homogeneous feed. In the second group, a mixture of 50% finisher and 50% wheat (W50) was used, in the third one a mixture of 75% finisher and 25% wheat (W25), and in the fourth group, the mixture contained 90% finisher and 10% wheat (W10). In the last stage of feeding (36−42 d), a marker in the form of 3 g/kg titanium (IV) dioxide (Ti2O) was added to the feed in all groups in order to determine the apparent protein digestibility.

**Feed Composition**

Complete commercial feeds (starter, grower, finisher), finisher-wheat experimental feeds and wheat grains were
analyzed in the laboratory to determine the content of basic ingredients according to the standards of the Polish Committee for Standardization (a body governed by public law). The dry matter (DM) of the feed was determined using the gravimetric method (PN-ISO 6496:2002), crude ash (CA) with the gravimetric method (Commission Regulation (EC) No. 152/2009 of 27.01.2009, Annex III M), crude protein (CP) with the Kjeldahl method (PN-EN ISO 5883-1:2006), crude fiber (CF) with the gravimetric method (PN-ISO 6865:2002), crude fat (EE) with the Soxhlet method (PN ISO 6492:2005), starch (St) with the polarimetric method (PN-R-65785:1994), while acid detergent fiber (ADF), neutral detergent fiber (NDF) and acid detergent lignin (ADL) were determined with the gravimetric method (PN-EN ISO 13906:2009). The methods are described in the research on nutritional value of selected wheat cultivars (Biel and Macirowski, 2021). The analyses were performed on 5 samples from each type of feed, 2 replicates each, and their content was presented as a percentage. According to the manufacturer’s declaration, the feed contained all the necessary additives for broiler chickens, including vitamins and mineral ingredients (macro- and microelements).

**Growth Performance**

Chickens were individually weighed on the first day of rearing, then on 14th, 35th, and on the day of slaughter (42nd). Body weight was recorded (BW), and based on the differences, the body weight gain (BWG) was calculated for each rearing period ($\text{final body weight (g)} - \text{initial body weight (g)}$). Feed intake was recorded daily (FI). The feed conversion ratio per kg of body weight gain (FCR) was calculated ($\frac{\text{feed intake (g)}}{\text{body weight gain (g)}}$). The viability of broiler chickens in each group was monitored. Production efficiency indicators were calculated as follows: the European Production Efficiency Factor (EPEF) with the formula: $\frac{\text{viability (g)} \times \text{BW (kg)}}{\text{age (days)} \times \text{FCR (g/kg day)}} \times 100$, as well as the European Broiler Index (EBI) with the formula: $\frac{\text{viability (g)} \times \text{ADG (g/kg day)}}{\text{FCR (g/kg day)}} \times 10$.

**Feed Costs**

Based on the prices of the feed and wheat (over the experimental period), the quantity of feed consumed by 1 chicken was calculated for each feeding period and for the entire rearing period. In addition, feed costs for the production of 1 kg of live body weight were calculated, as well as the profit on the free market, taking into account only the feed costs incurred, assuming that the sale on July 26, 2021 was PLN 4.75 gross (free market). It was assumed that the feed in the control group accounted for 100% of the price, and from this value the percentage of experimental feed mixtures was calculated in relation to the costs of the standard feed. According to the costs incurred, the starter feed cost PLN 2.08 gross/1 kg, the grower feed cost PLN 2.00 gross/1 kg, and the finisher feed cost PLN 1.83 gross/1 kg. In group W50, the finisher feed cost PLN 1.38 gross/1 kg, in group W25, PLN 1.61 gross/1 kg, and in group W10, PLN 1.75 gross/1 kg.

**Slaughter**

After 42 d of rearing, 2 birds from each replicate (10 chickens from a group, 40 in total) were randomly selected for slaughter. The pre-slaughter starvation lasted 8 h. The slaughter was performed by cutting between the cervical vertebrae and the occipital condyle (rupture of the spinal cord, rapid bleeding), previously having stunned the birds with an electric current. After bleeding out, the carcasses were soaked in water at 65°C for 10 s (for easier feather removal). The carcasses were plucked and gutted, and the feet cut off at the ankle joint. During the gutting process, the edible offals were collected (heart, liver, gizzard). The prepared carcasses were chilled in a refrigerator (Hendi, Poznan, Poland) at 4°C for 24 h (Banaszak et al., 2021).

**Apparent Protein Digestibility**

For the determination of the apparent protein digestibility (APD), intestinal contents (Meckel's diverticulum to the ileal-cecal junction) were collected into sterile containers after slaughter and gutting. The samples were analyzed with the method described in the section on Feed Composition with respect to the determination of the titanium (IV) oxide content in the intestinal contents. The protein content was determined in order to eliminate the error related to the ammonium nitrogen content in the manure. One sample contained intestinal content from two birds due to the low quantity of the digesta. The intestinal contents were lyophilized for 24 h. The content of titanium (IV) oxide was determined according to the method of Short et al. (1996), and the sample preparation procedure was as described by Myers et al. (2004). The APD was calculated according to the formula described by Al-Qazzaz et al. (2021): $\text{APD (g)} = 100 - \left( \frac{\% \text{ TiO}_2 \text{ in feed} \times \% \text{ nutrient in digesta}}{\% \text{ TiO}_2 \text{ in digesta} \times \% \text{ nutrient in feed}} \right) \times 100$. In each group, 5 samples were collected and analyses were done in 2 replicates (in total: 10 results per group).

**Dissection**

The carcasses and offal were weighed. The dissection was performed according to the method of Ziolecki and Doruchowski (1989), separating the neck, wings (with skin), pectoral muscles (e.g., pectoralis major and minor), leg muscles (thigh and drumstick, without bones), skin with subcutaneous fat (combining with the neck skin), fat, and carcass remains (trunk, leg bones). The dressing percentage in broiler chickens ($\frac{\text{carcass weight (g)}}{\text{live body weight (g)}} \times 100$), and
the percentage of the individual parts of the carcass
\[
\left( \frac{\text{weight of carcass element (g)}}{\text{carcass weight (g)}} \right) \times 100
\]
were calculated.

**Meat Quality**

Forty-five min after slaughter, acidification (pH_{45mins})
was measured in the pectoral muscle (m. pectoralis
major) using a pH meter (Elmetron, Zabrze, Poland)
with a dagger electrode. Calibration of the pH-meter
was performed using buffers of known pH (4.00, 7.00,
9.00). The measurement was repeated 24 h after weigh-
ing the carcasses (pH_{24homs}). After dissection, the right
and left pectoral and leg muscles were collected for fur-
ther analysis (Banaszak et al., 2021).

The right muscles were analyzed for color on the outer
side of muscles using a colorimeter (Konica Minolta,
Tokyo, Japan) with the CIE Lab method (Comission
Internationale de Eclairage; CIE, 1986). The device
was calibrated using a calibration plate no. 21033065
and D_{65} Y_{36} x_{0} 0 3362 scale. The color was determined-
L* (lightness), a* (redness), and b* (yellowness). The
pectoral muscles were analyzed by drip loss (Hon-
kel, 1987) to calculate the percentage of water loss. The
method consisted in weighing the pectoral muscle (M1)
and storing it in a string bag with incisions for 24 h in a
refrigerator at a temperature of 4°C. The muscles were
then reweighed (M2). The pectoral and leg muscles
(left) were analyzed for the water-holding capacity
(WHC) (Grau and Hamm, 1952). The muscles were
ground by group in a meat grinder (Hendi, Poznan,
Poland), then, samples of 0.300 g (± 5%) were weighed,
which was the starting weight (M1). The samples were
placed between 2 pieces of Whatmann blotting paper,
and covered with a 2 kg weight for 5 min. After the test
time had elapsed, (M2) was reweighed. Drip loss and
WHC were calculated according to the formula: 100 -
\( \frac{M2 - M1}{M1} \) × 100%. Eighty g of pectoral muscles and legs
(grounded) were analyzed for the percentage of protein,
collagen, salt, intramuscular fat, and water. The analy-
ses were carried out with the use of FoodScan apparatus
(FOSS, Hillerød, Denmark) by near-infrared transmis-
sion (NIT) spectrometry. The method was based on the
Polish Standards (PN-A-82109:2010).

**Bones’ Breaking Strength and Jejunum
Tensile Strength**

The analyses described below were performed using
the methods described by Bieseck et al. (2021). The right
femur and tibia of each chicken leg were used for the
breaking strength analysis. The tensile strength of the
small (jejunum) intestine was also analyzed. The intest-
ines were sampled immediately after slaughter. A frag-
ment of the jejunum was dissected from the Meckel’s
diverticulum to the point of the transition of the jeju-
num to the duodenum. The tensile strength analysis was
performed using the Instron 3345 apparatus (Instron,
Buckinghamshire, UK) integrated with the Bluehill 3
software. Bone strength was analyzed using the Instron
Bend Fixture 10 mm Anvil adapter. The tibia/femur
bones were placed between the clamps, and the maxi-
imum load and force at break (N) and strain in response
to compressive force and displacement (mm) were mea-
sured. Measurements were taken at a speed of
250 mm/min. The tensile strength of the jejunum was
estimated from the measured maximum force at rupture
(N). The load applied to the jejunum was simulated
using the Instron Pneumatic Grip 2kN adapter. Stan-
dardized intestinal samples (5 cm each) were placed
between the 2 adapters and stretched. Bowel samples
were standardized for Meckel’s diverticulum. Measure-
ments were taken at a speed of 500 mm/min.

**Statistical Calculation**

The obtained data was compiled in a statistical pro-
gram (Statistica, Statsoft, 13.0, Cracow, Poland). The
mean values for each examined trait (dependent vari-
able) relative to the group (grouping variable; C, W50,
W25, W10), and the standard error of the mean (SEM)
for all groups were calculated. One-way analysis of vari-
ation (ANOVA) was used. The verification of statisti-
cally significant differences was performed using the
post-hoc test, assuming a significance level of P-value
<0.05 (Tukey’s test). The comparison of statistically sig-
nificant differences was made between each group. The
production efficiency analyses were calculated in 5 repli-
cations and the rest of the analyses were performed in 10
replications.

**RESULTS**

**Feed Composition and Apparent Protein
Digestibility**

By analyzing Table 1, it was shown that the chemical
composition of the starter and grower feed was consist-
tent with the standards for the feeding of broiler chick-
en. It was shown that the feeds were characterized by
DM at the level of over 89%, and CP over 20%. The lev-
els of EE and St were elevated in the grower, and the lev-
els of ADF, NDF, and ADL decreased with increasing
time (quantitative differences). The wheat grain used in
the experiment was characterized by a similar propor-
tion of DM (89.26%), and the CP level was 14.97%. When
statistically comparing the chemical composition of the
finisher feed in the last feeding stage (d 36–42), it was
shown that the feeds containing 50 and 25% wheat
were statistically significantly lower in DM (P < 0.001),
as well as in other feed ingredients, also taking into
account lower levels of CA, CP, EE and ADL in all
experimental groups (W50, W25, W10) (P < 0.001). In
group W50, the content of St was statistically signifi-
cantly higher than in other groups, while the CP level
was similar in the control and W10 groups, and at the
same time significantly higher than in groups W50 and
W25 (P < 0.001). The significantly lowest CP level was
found in the feed where 50% wheat grain was added
The feeds (starter and grower) were commercial and their chemical composition was assured for analytical purposes; the data is similar to the values declared by the producers.

Table 1. Analytical composition of complete feed (starter, grower) and ground wheat grains.

| Ingredient [%] | Starter feed | Grower feed | Wheat grains |
|---------------|--------------|-------------|--------------|
| DM            | 89.23        | 89.20       | 89.26        |
| CA            | 4.67         | 4.67        | 2.20         |
| CP            | 20.23        | 20.18       | 14.97        |
| EE            | 3.03         | 3.39        | 1.88         |
| CF            | 3.50         | 3.52        | 2.51         |
| St            | 40.62        | 42.70       | 55.01        |
| ADF           | 5.32         | 4.24        | 3.18         |
| NDF           | 11.90        | 10.85       | 10.43        |
| ADF           | 4.55         | 3.18        | 2.84         |

Abbreviations: ADF, acid detergent fiber; ADL, acid detergent lignin; CA, crude ash; EE, crude fat; NDF, neutral detergent fiber; St, starch.

The feeds (starter and grower) were commercial and their chemical composition was assured for analytical purposes; the data is similar to the values declared by the producers.

Table 2. Analytical composition of complete feed (starter, grower) and ground wheat grains.

| Ingredient [%] | Starter feed | Grower feed | Wheat grains |
|---------------|--------------|-------------|--------------|
| DM            | 89.53        | 89.15       | 89.36        |
| CA            | 3.90         | 3.04        | 3.40         |
| CP            | 18.95        | 16.05       | 17.83        |
| EE            | 3.08         | 2.46        | 2.82         |
| CF            | 3.58         | 3.34        | 3.45         |
| St            | 45.65        | 49.78       | 47.54        |
| ADF           | 4.21         | 3.61        | 4.07         |
| NDF           | 10.50        | 10.97       | 10.49        |
| ADF           | 3.73         | 2.47        | 2.52         |
| TiO₂          | 0.003        | 0.003       | 0.003        |
| APD           | 71.90        | 43.14       | 46.05        |

Abbreviations: ADF, acid detergent fiber; ADL, acid detergent lignin; APD, apparent protein digestibility; CA, crude ash; EE, crude fat; NDF, neutral detergent fiber; TiO₂, titanium dioxide. Results are calculated as mean values from 5 samples in 2 replications.

Table 3. Growth performance in broiler chickens and feed consumption traits.

| Item          | C   | W50 | W25 | W10 | SEM  | P-value |
|---------------|-----|-----|-----|-----|------|---------|
| BW, g         |     |     |     |     |      |         |
| 1st day       |     |     |     |     |      |         |
| 2nd day       |     |     |     |     |      |         |
| 10th day      |     |     |     |     |      |         |
| 30th day      |     |     |     |     |      |         |
| 42nd day      |     |     |     |     |      |         |
| FI, g         |     |     |     |     |      |         |
| 1st day       |     |     |     |     |      |         |
| 2nd day       |     |     |     |     |      |         |
| 10th day      |     |     |     |     |      |         |
| 30th day      |     |     |     |     |      |         |
| 42nd day      |     |     |     |     |      |         |
| FCR, kg/kg    |     |     |     |     |      |         |
| 1st day       |     |     |     |     |      |         |
| 2nd day       |     |     |     |     |      |         |
| 10th day      |     |     |     |     |      |         |
| 30th day      |     |     |     |     |      |         |
| 42nd day      |     |     |     |     |      |         |
| APD           |     |     |     |     |      |         |

Abbreviations: ADL, acid detergent lignin; APD, apparent protein digestibility; CA, crude ash; EE, crude fat; NDF, neutral detergent fiber; TiO₂, titanium dioxide.

Growth Performance and Production Efficiency

On the 42nd day of rearing, a statistically significantly lower BW was demonstrated in group W10, as well as highly significantly lower values in groups W25 and W50, compared to the control group (P < 0.001; Table 2).

Table 4 also shows feed costs (PLN, gross) depending on the feeding stage. It was shown that in group W50, compared to other groups, the costs of feed finisher with a 50% addition of wheat grains were statistically significantly lower than in groups C and W10 (P < 0.001). When analyzing feed costs per 1 kg of produced live body weight and profit on the free market per 1 kg of live body weight, taking into account feed costs, no statistical differences were found between the groups (P > 0.05).
Table 4. Production efficiency in broiler chickens and feed costs.

| Item                                                      | Group¹              | SEM  | P-value |
|-----------------------------------------------------------|---------------------|------|---------|
| **Efficiency in broiler production**                      |                     |      |         |
| Viability, %                                              | 98                  | 100  | 0.69    | 0.585   |
| EPEF                                                      | 235.53ab            | 211.34ab | 224.42ab | 290.00a |
| EBI                                                       | 229.80ab            | 205.82ab | 218.81ab | 243.98ab |
| Feed costs per chicken, PLN (gross)                       |                     |      |         |
| 1-14 d                                                    | 1.09                | 0.93  | 0.94    | 0.04    | 0.408   |
| 15–35 d                                                   | 4.22                | 4.28  | 4.31    | 4.16    | 0.05    | 0.574   |
| 36–42 d                                                   | 1.77ab              | 1.19a | 1.57    | 1.76a   | 0.06    | <0.001  |
| 1-42 d                                                    | 7.15                | 6.43  | 6.93    | 6.90    | 0.10    | 0.056   |
| **Experimental feed costs compared to the control feeding,** % | 100                 | 90.35 | 97.39 | 97.04 | 1.51    | 0.127   |
| **Profit on the free market per 1 kg of live weight including feed costs** | 0.95                | 1.02  | 0.98    | 1.12    | 0.04    | 0.541   |

¹ Different letters in rows show statistically significant differences between groups, P-value < 0.05.

However, it was quantitatively indicated that in groups W10 and W50 the costs were PLN 0.16 to 0.04 lower than in groups C and W25. As a percentage of the cost of experimental feeds in relation to the control finisher feed, it was shown that the cost intensity was reduced by almost 10% in group W50, and almost 3% in groups W25 and W10 (P = 0.127).

**Carcass Traits**

The live body weight of the selected birds was significantly higher in group W10 than in groups C and W50 (P = 0.008), and the carcass weight in groups W25 and W10 was significantly higher than in group W50 (P = 0.009). On the other hand, the dressing percentage did not differ statistically significantly between groups (P = 0.738). Analyzing other features presented in Table 5, a statistically significantly higher weight of the gizzard was shown in group W50 than in group C (P = 0.036), while its percentage was significantly lower in all groups compared to group W50 (P = 0.003). Group W10 showed a statistically significantly higher weight and percentage of pectoral muscles in the carcass compared to group W50 (P = 0.007; 0.032, consecutively), while the leg muscle weight was significantly higher in group W25 than in group W50 (P = 0.040). The aforementioned statistically significant differences influenced the significantly higher total muscle weight in group W10 compared to group W50 (P = 0.006). The results concerning fat characteristics of the carcass of broiler chickens were similar (P > 0.05; Table 6).

**Meat Quality**

Table 7 presents qualitative physicochemical features of the pectoral and leg muscles of broiler chickens. A statistically significantly higher lightness (L*) was found in the experimental groups than in group C (P < 0.001). On the other hand, a highly significant water loss (expressed as water-holding capacity) was shown in groups C and W50, and a lower one in W25 than in group W10 (P < 0.001). In the control group there was a

Table 5. Features of broiler chicken carcasses.

| Item                                      | Group¹              | SEM  | P-value |
|-------------------------------------------|---------------------|------|---------|
| Pre-slaughter body weight, g               | 2,039.90b           | 2,044.70b | 2,174.90ab | 2,199.50a |
| Carcass weight, g                         | 1,488.55ab          | 1,466.87ab | 1,583.38a  | 1,586.33a  |
| Carcass weight with offal, g              | 1,568.08ab          | 1,551.33ab | 1,668.72a  | 1,665.78ab |
| Dressing percentage, %                    | 72.98               | 71.77  | 73.00    | 72.09     | 0.47      | 0.738    |
| Neck, g                                   | 58.67               | 59.96  | 67.73    | 58.17     | 1.56      | 0.101    |
| Neck, %                                   | 3.94                | 4.10   | 4.26     | 3.69      | 0.10      | 0.186    |
| Wings, g                                  | 158.73              | 156.05 | 164.63   | 168.52    | 2.20      | 0.178    |
| Heart, g                                  | 11.27               | 9.93   | 12.02    | 11.99     | 0.31      | 0.051    |
| Heart, %                                  | 0.07                | 0.17   | 0.11     | 0.08      | 0.02      | 0.314    |
| Liver, g                                  | 48.79               | 51.28  | 52.48    | 47.70     | 1.09      | 0.399    |
| Liver, %                                  | 3.12                | 3.31   | 3.15     | 2.87      | 0.07      | 0.177    |
| Gizzard, g                                | 19.35ab             | 20.35b | 20.84ab  | 19.70ab   | 0.03      | 0.003    |
| Carcass remains, g                        | 376.87              | 406.60 | 432.55   | 408.52    | 9.01      | 0.187    |
| Carcass remains, %                        | 25.35               | 27.80  | 27.19    | 25.70     | 0.47      | 0.200    |

¹ Different letters in rows show statistically significant differences between groups, P-value < 0.05.

Table 6 presents qualitative physicochemical features of the pectoral and leg muscles of broiler chickens. A statistically significantly higher lightness (L*) was found in the experimental groups than in group C (P < 0.001). On the other hand, a highly significant water loss (expressed as water-holding capacity) was shown in groups C and W50, and a lower one in W25 than in group W10 (P < 0.001). In the control group there was a
significantly higher protein content in breast muscles than in the experimental groups ($P < 0.001$), a significantly higher collagen content in groups C and W50 than in group W25 ($P = 0.002$), and a significantly higher salt content in group W10 than in group C ($P = 0.006$), intramuscular fat in group W10 significantly higher than in the other groups ($P < 0.001$), and a significantly higher water content in group W25 than in groups C, W50 and W10 ($P < 0.001$). In leg muscles, yellowness ($b^*$) was significantly higher in group W10 than in group W25 ($P = 0.021$). As in pectoral muscles, the protein content in leg muscles was statistically significantly higher in group C compared to the experimental groups ($P < 0.001$). Collagen content was found to be significantly higher in group W25, and at the same time significantly lower in groups W10, W50 and C (decreasingly sequentially) ($P < 0.001$). Group W10 was characterized by a significantly higher content of salt and intramuscular fat in the leg muscles ($P < 0.001$), while the water content was significantly the lowest, and in group C it was the highest ($P < 0.001$).

### Bones’ Breaking Strength and Jejunum Tensile Strength

Femur bones of broiler chickens from group W10 were characterized by a statistically significantly higher breaking strength compared to group W50 ($P = 0.014$), while in the case of tibia bones, a significantly higher breaking strength was found in group W25 than in group W50 ($P = 0.006$). Similarly, group W25 was characterized by a statistically significantly higher tensile strength of jejunum than in group W10 ($P = 0.002$; Table 8).

### Table 6. Muscle and fatness in broiler chickens.

| Item                                | Group$^1$       | SEM  | $P$-value |
|-------------------------------------|-----------------|------|-----------|
|                                    | C   | W50 | W25 | W10      |
| Pectoral muscle, g                  | 404.37$^{a,b}$  | 373.13$^b$ | 406.18$^{a,b}$ | 443.23$^a$ | 7.45 | 0.007 |
| Pectoral muscle, %                  | 27.17$^{a,b}$   | 25.35$^b$ | 25.74$^{a,b}$ | 27.92$^a$ | 0.36 | 0.032 |
| Leg muscle, g                       | 315.08$^{a,b}$  | 303.92$^b$ | 338.74$^{a,b}$ | 331.02$^a$ | 4.69 | 0.040 |
| Leg muscle, %                       | 21.16          | 20.77 | 21.42 | 20.89 | 0.21 | 0.713 |
| Total muscle, g                     | 719.45$^{a,b}$  | 678.08$^b$ | 744.92$^{a,b}$ | 774.25$^a$ | 10.45 | 0.006 |
| Total muscle, %                     | 48.33          | 46.12 | 47.16 | 48.80 | 0.41 | 0.086 |
| Skin with subcutaneous fat, g       | 151.62         | 142.41 | 149.36 | 153.77 | 3.22 | 0.640 |
| Skin with subcutaneous fat, %       | 10.16          | 9.69  | 9.45  | 9.71  | 0.19 | 0.605 |
| Abdominal fat, g                    | 25.21          | 23.77 | 24.19 | 23.10 | 1.07 | 0.984 |
| Abdominal fat, %                    | 1.56           | 1.65  | 1.53  | 1.46  | 0.07 | 0.884 |
| Total fat, g                        | 174.83         | 166.18 | 173.55 | 176.87 | 3.54 | 0.744 |
| Total fat, %                        | 11.72          | 11.31  | 10.98  | 11.17  | 0.20 | 0.631 |

$^a,b$Different letters in rows show statistically significant differences between groups, $P$-value < 0.05.

$^1$Group: C, control; W50, feed with 50% of wheat in finisher; W25, feed with 25% of wheat in finisher; W10, feed with 10% of wheat in finisher.

### Table 7. Physicochemical features of broiler chickens’ pectoral and leg muscle.

| Item                                    | Group$^1$       | SEM  | $P$-value |
|-----------------------------------------|-----------------|------|-----------|
|                                        | C   | W50 | W25 | W10      |
| pH45mins                                | 6.23 | 6.21 | 6.17 | 6.10 | 0.02 | 0.608 |
| pH24h                                   | 6.04 | 5.98 | 5.92 | 5.93 | 0.02 | 0.189 |
| Color $L^*$                             | 55.60$^a$      | 56.65$^a$ | 56.65$^a$ | 55.84$^a$ | 0.43 | < 0.001 |
| a*                                      | 2.90 | 2.44 | 3.19 | 2.81 | 0.16 | 0.437 |
| b*                                      | 4.83 | 4.55 | 4.29 | 5.16 | 0.21 | 0.521 |
| Drip loss, %                            | 1.47 | 1.20 | 2.07 | 1.46 | 0.12 | 0.115 |
| WHC, %                                  | 36.76$^b$      | 37.50$^a$ | 40.86$^a$ | 44.86$^a$ | 0.58 | < 0.001 |
| Protein, %                              | 22.50$^a$      | 21.96$^b$ | 21.95$^a$ | 21.69$^a$ | 0.05 | < 0.001 |
| Collagen, %                             | 1.03$^a$       | 1.08$^b$ | 0.91$^b$ | 1.01$^b$ | 0.02 | 0.002 |
| Salt, %                                 | 0.27$^b$       | 0.30$^{ab}$ | 0.32$^{ab}$ | 0.36$^a$ | 0.01 | 0.006 |
| Intramuscular fat, %                    | 2.25$^{ab}$   | 2.21$^b$ | 1.90$^{ab}$ | 2.30$^a$ | 0.03 | < 0.001 |
| Water, %                                | 75.28$^{a,b}$  | 75.74$^b$ | 76.17$^{a,b}$ | 75.97$^a$ | 0.06 | < 0.001 |
| Leg muscle                              |               |      |      |       |
| Color $L^*$                             | 51.12          | 53.41 | 53.60 | 53.49 | 0.50 | 0.235 |
| a*                                      | 4.63           | 4.66  | 4.26  | 5.11  | 0.30 | 0.816 |
| b*                                      | 3.32           | 3.37$^{ab}$ | 2.18$^{b}$ | 4.10$^a$ | 0.23 | 0.021 |
| WHC, %                                  | 36.70          | 36.18 | 35.74 | 37.00 | 0.45 | 0.779 |
| Protein, %                              | 20.17$^a$      | 19.09$^{b}$ | 18.50$^a$ | 18.20$^a$ | 0.12 | < 0.001 |
| Collagen, %                             | 1.31$^{a,b}$   | 1.47$^b$ | 1.63$^a$ | 1.53$^a$ | 0.02 | < 0.001 |
| Salt, %                                 | 0.47$^{ab}$    | 0.57$^b$ | 0.92$^{ab}$ | 0.46$^a$ | 0.01 | < 0.001 |
| Intramuscular fat, %                    | 4.97$^{ab}$    | 6.76$^b$ | 7.94$^{a,b}$ | 8.44$^a$ | 0.21 | < 0.001 |
| Water, %                                | 74.47$^{a,b}$  | 73.35$^b$ | 72.50$^{a,b}$ | 72.27$^a$ | 0.14 | < 0.001 |

$^a,b$Different letters in rows show statistically significant differences between groups, $P$-value < 0.05.

$^1$Group: C, control; W50, feed with 50% of wheat in finisher; W25, feed with 25% of wheat in finisher; W10, feed with 10% of wheat in finisher. $L^*$ - lightness; a*, redness; b*, yellowness; WHC, water-holding capacity.


**Table 8.** Bones’ breaking strength and jejunum tensile strength in broiler chickens.

| Item                                      | Group       | SEM  | P-value |
|-------------------------------------------|-------------|------|---------|
| Maximum load [N/mm]                       | C           | W50  | W25     | W10     |
| Femur bone                                | 207.71<sub>ab</sub> | 161.33<sup>b</sup> | 177.42<sup>ab</sup> | 222.03<sup>a</sup> | 7.58 | 0.014 |
| Tibia bone                                | 74.42       | 73.72 | 73.89   | 74.07   | 0.32 | 0.898 |
| Maximum load [N/mm]                       | 292.24<sup>ab</sup> | 232.19<sup>b</sup> | 329.58<sup>a</sup> | 303.17<sup>ab</sup> | 10.40 | 0.006 |
| Tibia bone                                | 73.91       | 73.74 | 73.73   | 73.31   | 0.21 | 0.787 |
| Jejunum tensile strength                  | 2.61<sup>ab</sup> | 2.80<sup>b</sup> | 3.18<sup>a</sup> | 2.17<sup>b</sup> | 0.10 | 0.002 |
| Dislocation during stretching [mm]         | 36.19       | 37.31 | 36.50   | 32.67   | 1.54 | 0.725 |

<sup>a,b</sup>Different letters in rows show statistically significant differences between groups, *P*-value < 0.05.

<sup>1</sup>Group: C, control; W50, feed with 50% of wheat in finisher; W25, feed with 25% of wheat in finisher; W10, feed with 10% of wheat in finisher.

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**DISCUSSION**

At the beginning, the discussion should address issues of low production performance in the presented study. The complete feed used in the control group and in all experimental feeds had a very fine form (loose). As a result, the birds did not consume the appropriate amount of feed, which resulted in a low body weight. However, this did not cause the FCR to deviate. As described in the studies of Abdollahi et al. (2018), the structure of the feed affects the level of digestion of feed nutrients, the functioning of proventriculus and gizzard, and thus their mechanical work and secretion of digestive enzymes. The authors indicate that larger (whole grain) forms of feed have a beneficial effect on the functioning of birds. These elements influence weight gain and feed consumption. Our research did not show any abnormal deviations between the control group and the experimental groups, so it suggests that the low production rates were caused by the too fine structure of the feed Khalil et al. (2021). found that mash feed may make it difficult to assess the apparent metabolic energy, and granulation increases its level in cereal grains. However, this did not affect the correct conduct of our research, and thus the indications of the desirability of providing information for small-scale production of broiler chickens. The size of feed particles affects the development of individual sections of the digestive tract and health of chickens. Mash diets are believed to increase the availability of digestive enzymes to feed ingredients and to stimulate digestion and absorption. The use of crushed wheat grains in the nutrition of chickens allows for achieving a larger relative weight of the gastrointestinal tract, for example, proventriculus or small intestine, compared to feeding with granulated grains (Zaeferian et al., 2016).

In our research, the weight of chickens on the day of slaughter (BW) was higher in groups C and W10, compared to the group with the highest share of wheat (W50). Similarly to BW, BWG over the experimental feeding period was higher in groups C and W10 compared to other groups. In the study of Husveth et al. (2015), whole wheat grains were used, which were granulated in the feed at the 5, 10, and 15% levels (grower I, grower II, finisher). There was no effect on BW and a significantly lower FCR (*P* = 0.01) compared to the group with a higher wheat content (5, 20, 30%) and to the control group. Partial replacement of the complete feed with wheat dilutes it and changes the percentage of nutrients in the feed (Ravindran et al., 2006). Potentially, this could be one of the reasons for the lower BW, BWG, and a higher FCR in the wheat groups at 25 and 50% levels. In our study, the level of protein in the abovementioned groups was reduced, which is related to the replacement of part of the complete feed with wheat, which is characterized by a much lower level of protein (below 15%). It could be suggested that the reduced protein content and the too milled form (loose) of the feed resulted in the reduced apparent protein digestibility. Furthermore, broiler rearing effectiveness and nutrient availability are dependent on the wheat variety (Gutierrez del Alamo et al., 2008). When wheat is used in a crushed form, the high content of gluten in the grains may stick the beak, which makes it difficult for the birds to swallow the feed (Abdollahi et al., 2018). Gluten could significantly affect FI in the group fed with ground wheat at 50% level in the finisher feed. There are also non-starch polysaccharides (NSPs) in wheat grains, mainly arabinoxyloans, and B-glucans, which will reduce the nutritional value of the feed. NSPs lower the viscosity of the intestinal contents, which inhibits the absorption and use of feed ingredients (Bednarska-Lojewska et al., 2017). In the study of Munyaka et al. (2016), the addition of xylanase and B-glucanase enzymes to high wheat feed increased the BWG (*P* < 0.001) of chickens. The addition of feed enzymes can effectively reduce the negative impact of NSP on the bird’s organism. Also, there was found a beneficial effect of feed enzymes (phytase) on the production results of birds fed with the wheat-based feed (Ingelmann et al., 2018).

According to Movramati et al. (2018), the production of broiler chickens is profitable when the EPEF is above 260.00. Other studies found that EPEF should not be less than 300.00 to 310.00 to maintain farm profitability. Additionally, the EPEF value is a determinant of a high technical condition (Szollosi and Szucs, 2014). The value of production efficiency indicators also depends on the genotype of chickens. Cobb 500 chickens can obtain higher EPEF and EBI compared to Ross 308.
(Marcu et al., 2013). The highest EPEF and EIB were found in the W10 group. Nevertheless, the value of EPEF was 250.00, which, according to the authors mentioned above, indicates unprofitable production. However, it may be due to the relatively lower BW and higher FCR. The beneficial effect of replacing maize with barley and triticale at the level of 30% in broiler chicken nutrition was demonstrated by Pogosyan et al. (2020). This treatment allowed reducing the cost of feed for the production of 1 kg of meat by even 2.8 to 3.9%. The reduction of feeding costs was also demonstrated by replacing maize with triticale at the level of 20%, which was found in the production of Hy-Line Brown laying hens. After cost conversion, up to $17/t of feed was noticed (Lim et al., 2021).

Singh et al. (2014) stated that, in the studies of many authors, the inclusion of whole wheat grains affects the digestive tract of birds in particular, it increases gizzard’s weight. Partial replacement with whole grains of crushed wheat (100 g/kg and 200 g/kg feed) increases the weight of birds’ gizzards (Ravindran et al., 2006). According to Gabriel et al., (2008), gizzard weight of the birds fed with whole wheat grains is 26% higher, compared to the birds fed with crushed wheat at the level of 400 g/kg of feed. The gizzard is stimulated to work more to properly grind the grains, which facilitates further digestion of the nutrients. In our research, a higher gizzard weight was found in birds fed with a 50% share of wheat in the finisher feed, despite the fact that it was fed in a crushed form. In the literature, it was described that wheat in feed, both in the form of ground (490–500 g/kg feed) and whole grains (100–200 g/kg feed), increases the weight of pectoral muscles in birds (Amerah and Ravindran, 2008).

In the research of Aghazadeh and Yazdi (2012), a positive effect of the addition of butyric acid and wheat administration was found on the weight of chicken’s pectoral muscles. The birds in the group with the aforementioned additive obtained a higher weight of pectoral muscles. Disparate effects of wheat on pectoral muscles also occur with the addition of feed enzymes to the feed (Wu and Ravindran, 2004; Selle et al., 2003). Pectoral muscles of W50 chickens with a high L* value have a lower WHC. This relationship is also confirmed by Bowker and Zhang (2015). High WHC of meat affects the juiciness, firmness and technological usefulness of the meat. Most of the muscle tissue water is in the intracellular spaces between myofibrillar fibers (actin and myosin). WHC can be determined by the intensity of post-mortem biochemical changes in muscles. Increased water loss results from the formation of actinomyosin complexes and the influence of magnesium and calcium cations on the negatively charged protein chains. Reducing the intracellular spaces facilitates the release of water from the meat (Nasir et al., 2017). According to Petracci et al. (2015), low WHC is associated with the denaturation of muscle proteins as a result of lowering the pH value and increasing meat temperature. In the study by Kokoszyński et al. (2017), partial replacement of the complete mixture with wheat at the level of 15% in the last 2 wk of rearing SM3 Heavy ducks, resulted in a significant reduction in the lightness of the muscles. The high content of intramuscular fat in pectoral and leg muscles in group W10 (P < 0.001) could be an added value, due to the fact that intramuscular fat acts as a flavor carrier in meat and also affects its tenderness (Leng et al., 2016). The physicochemical properties of chicken pectoral muscles (protein, fat, water) are also influenced by the chemical composition of the feed, in particular the CP or EE content (Marcu et al., 2013). Differences in the percentage of protein, fat and water in pectoral and leg muscles between the groups may have occurred as a result of diluting the complete feed with wheat grain, which changed the chemical composition of the feed. Collagen is one determinant of meat texture, and its content may be dependent on myofibrillar degradation, meat tenderness, and muscle sarcomere length (Starkey et al., 2017). According to the higher loss of water and lower collagen content in the muscles of the experimental group W25, their relationship in terms of texture is apparent. The salt content limits protein extraction and alters the thermal patterns of protein denaturation and aggregation of major muscle proteins, which can affect texture and WHC properties of meat products (Li et al., 2015). All these elements are interrelated, and the chemical composition of meat depends on chicken nutrition and on the nutrients in the feed (Kaloev et al., 2020). The highest necessary load for a femoral break was found in group W10, and in the case of the tibia bone in group W25. This may indicate better bone mineralization (Salaam et al., 2016). This is important because the high bone strength helps to avoid fractures during rearing (Grupioni et al., 2015), and this has an impact on the suitability for further technological processing of the carcasses. In turn, a high jejunum tensile strength was demonstrated in group W25. This may confirm a higher integrity of the cells that build the intestinal wall and their high elasticity (Cowieson et al., 2016). Feeding chickens with granulated wheat may increase the relative jejunum weight (g/kg body weight) by 3.2% compared to the use of loose feed (Zafarian et al., 2016). The authors also state that the size of wheat grain particles influenced the weight of individual sections of the gastrointestinal tract. The inclusion of coarsely ground maize in the feed (50%) had a positive effect on the intestinal strength compared to the group without the addition of this grain (Xu et al., 2015). The other authors found no effect of wheat particle size and insoluble fiber in feed on jejunum strength (Abdollahi et al., 2019). The tensile strength of the intestines may depend on the structure of the feed, which is related to the work done and the development of the intestines. This may be related to the activity of the muscles (peristalsis), the amount of time the feed remains in the gut, as well as the villus length, crypt depth, and epithelial thickness in the jejunum (Xu et al., 2015). However, the histomorphometric analyses of intestines were not the subject of this study. The strength of the intestines is significant from the point of view of technological processing and hygiene of the production of poultry carcasses.

In conclusion, this study showed that the use of loose feed is not a good solution, because in all groups,
regardless of the proposed nutritional strategy, the body weight gain was reduced. From an economic point of view, the finisher feed with 50% wheat content was the cheapest. It did not have any statistical significance in terms of the profit per 1 kg of live body weight. However, the difference between PLN 0.95 and PLN 1.12 per 1 kg is significant in practice, especially on small-scale farms (theoretically: 200 chickens with an average body weight of 3 kg for PLN 0.95 gives the result of PLN 570, and at the price of PLN 1.12 per 1 kg the sum increases to PLN 672). When producing for local direct sales it is an even more important indicator that could help small farms at a time when feed prices are rising. Taking into account quality of the obtained meat, the most favorable nutritional strategy, compared to the control group, was the one using 90/75% of the finisher feed and 10/25% of wheat grains, while the 50% proposal, despite the 10% reduction in feeding costs, did not have a beneficial effect on the characteristics of the carcasses and meat, which was associated with a highly significant reduction in the protein content in the feed and its digestibility.

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DISCLOSURES

The authors declare that they have no conflicts of interest of which they would be aware.

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