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 unbeneficial compared to group C. Pectoral muscles from the experimental groups were characterized by higher lightness ($P < 0.001$). In group W10 femur bones' strength and in group W25 tibia bones' strength was higher than in group W50 ($P = 0.014$; 0.006). Jejunum tensile strength was higher in group W25 than in W10 ($P = 0.002$). The nutritional strategies based on the dilution of the feed with wheat grain could be applied at the level of 10/25%, but 50% had a negative effect.

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

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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.

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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 metabolic 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 (Chrystal et al., 2020). In addition to the production results in broiler chickens and the broadly understood efficiency, an important aspect, especially for consumers, is the quality of meat, which may depend on the production technology and also on the feeding of chickens (Jiang et al., 2018). 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 ($\mathbf{Ti_2O}$) 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 5983-1:2006), 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 Maciorowski, 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 ($final\ body\ weight\ (g) - initial\ body\ weight(g)$). Feed intake was recorded daily (**FI**). The feed conversion ratio per 1 kg of body weight gain (FCR) was calculated ($\frac{feed\ intake\ (g)}{body\ weight\ gain\ (g)}$). 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: $\frac{viability\ (\%) \times BW\ (kg)}{age\ (days) \times FCR\ \left(\frac{kg\ feed}{kg\ gain}\right)} \times 100$, as well as the European Broiler Index (**EBI**) with the formula: $\frac{viability\ (\%) \times ADG\ \left(\frac{\frac{g}{chick}}{day}\right)}{FCR\ \left(\frac{kg\ feed}{kg\ gain}\right) \times 10}$.

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): $APD\ (\%) = 100 - [100 \times \left(\frac{\%\ TiO2\ in\ feed}{\%\ TiO2\ in\ digesta}\right) \times \left(\frac{\%\ nutrient\ in\ digesta}{\%\ nutrient\ in\ feed}\right)]$. 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 Ziołecki 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 ($\frac{carcass\ weight\ (g)}{live\ body\ weight\ (g)} \times 100$), and the percentage of the individual parts of the carcass ($\frac{weight\ of\ carcass'element\ (g)}{carcass\ weight\ (g)} \times 100$) 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 weighing the carcasses ($pH_{24hours}$). After dissection, the right and left pectoral and leg muscles were collected for further 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 lEclairage; CIE, 1986). The device was calibrated using a calibration plate no. 21033065 and D_{65} $Y_{86\ 1}$ x_0 $y_{0\ 3362}$ scale. The color was determined- L* (lightness), a* (redness), and b* (yellowness). The pectoral muscles were analyzed by drip loss (Honikel, 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: $100 - \left(\frac{M2}{M1}\right) \times 100\%$. Eighty g of pectoral muscles and legs (grounded) were analyzed for the percentage of protein, collagen, salt, intramuscular fat, and water. The analyses were carried out with the use of FoodScan apparatus (FOSS, Hillerød, Denmark) by near-infrared transmission (**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 Biesek 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 intestines were sampled immediately after slaughter. A fragment of the jejunum was dissected from the Meckel's diverticulum to the point of the transition of the jejunum 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 maximum load and force at break (N) and strain in response to compressive force and displacement (mm) were measured. 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. Standardized intestinal samples (5 cm each) were placed between the 2 adapters and stretched. Bowel samples were standardized for Meckel's diverticulum. Measurements were taken at a speed of 500 mm/min.

Statistical Calculation

The obtained data was compiled in a statistical program (Statistica, Statsoft, 13.0, Cracow, Poland). The mean values for each examined trait (dependent variable) 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 variation (**ANOVA**) was used. The verification of statistically 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 significant differences was made between each group. The production efficiency analyses were calculated in 5 replications 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 consistent with the standards for the feeding of broiler chickens. It was shown that the feeds were characterized by DM at the level of over 89%, and CP over 20%. The levels of EE and St were elevated in the grower, and the levels of ADF, NDF, and ADL decreased with increasing time (quantitative differences). The wheat grain used in the experiment was characterized by a similar proportion 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 significantly higher than in other groups, while the CF 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

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	3.59	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
ADL	4.55	3.18	2.84

Abbreviations: ADF, acid detergent fiber; ADL, acid detergent lignin; CA, crude ash; CF, crude fiber; CP, crude protein; DM, dry matter; 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.

*Results are calculated as mean values from 5 samples in 2 replications each; STARTER (1−14 d); GROWER (15−35 d); and WHEAT GRAINS.

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

	Group[1]					
Item	C	W50	W25	W10	SEM	*P*-value
BW, g						
1st day	46.24	46.32	47.12	46.98	0.23	0.441
14th d	369.42	364.36	380.13	370.90	3.22	0.396
35th d	1,430.55	1,426.42	1,476.40	1,456.30	16.49	0.713
42nd d	1,929.09[a]	1,771.68[b]	1,886.12[ab]	1,949.02[a]	22.21	0.009
BWG, g						
1-14 d	323.18	318.04	333.01	323.92	3.23	0.455
15−35 d	1,061.13	1,062.06	1,096.27	1,085.40	14.32	0.802
36−42 d	498.54[a]	345.26[b]	409.72[b]	492.72[a]	16.67	< 0.001
1-42 d	1,882.85[a]	1,725.36[b]	1,839.00[ab]	1,902.04[a]	22.14	0.009
FI, g						
1-14 d	522.78	447.00	472.00	452.50	17.08	0.408
15−35 d	2,068.60	,141.38	2,152.75	2,078.06	25.32	0.574
36−42 d	967.32[a]	859.16[b]	974.84[a]	1,004.14[a]	15.90	< 0.001
1-42 d	3,619.50	3,447.54	3610.08	3,534.70	43.36	0.499
FCR, kg/kg						
1-14 d	1.63	1.41	1.42	1.40	0.06	0.482
15−35 d	1.96	2.03	1.97	1.92	0.03	0.682
36−42 d	1.96[b]	2.45[a]	2.40[a]	2.04[ab]	0.07	< 0.001
1-42 d	1.92	2.00	1.96	1.86	0.02	0.146

[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. Abbreviations: BW, body weight; BWG, body weight gain; FI, feed intake; FCR, feed conversion ratio.

(16.05%). The analysis of APD showed a statistically significant reduction 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).

Growth Performance and Production Efficiency

On the 42nd day of rearing, a statistically significantly lower BW was demonstrated in group W50 compared to other groups (C, W25 and W10) ($P = 0.009$). When feeding chickens with the finisher feed, a statistically significantly higher BWG was found in groups C and W10, compared to groups W50 and W25 ($P < 0.001$), while BWG on d 1 to 42 was significantly higher in group C than in groups W50 and W10 ($P = 0.009$). At the same time, it was shown that group W50 was characterized by a statistically significantly lower FI compared to other groups during finisher feeding ($P < 0.001$). By converting BWG and FI to FCR, a statistically significantly lower feed consumption ratio per 1 kg body weight gain was demonstrated in group C, compared to groups W50 and W25, where this value was ≥2.40 kg/kg (Table 3). Group W50 showed a statistically significantly lower EPEF and EBI index than group W10 ($P = 0.035$; 0.034, consecutively) (Table 4).

Table 4 also shows feed costs (PLN, gross) depending on the feeding stage. It was shown that in group W50, the costs of finisher feed with a 50% addition of wheat grain were statistically significantly lower, and also in group W25 the aforementioned cost was 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 2. Analytical composition of finisher feed and experimental feeds (finisher with various levels of ground wheat grains) and apparent protein digestibility.

Ingredient [%]	Finisher feed C	Finisher W50 feed	Finisher W25 feed	Finisher W10 feed	SEM	*P*-value
DM	89.53[a]	89.15[c]	89.36[b]	89.43[ab]	0.03	< 0.001
CA	3.90[a]	3.04[d]	3.40[c]	3.69[b]	0.05	< 0.001
CP	18.95[a]	16.05[c]	17.83[b]	18.02[b]	0.17	< 0.001
EE	3.08[a]	2.46[d]	2.82[c]	2.94[b]	0.03	< 0.001
CF	3.58[ab]	3.34[c]	3.48[bc]	3.63[a]	0.03	< 0.001
St	45.65[d]	49.78[a]	47.54[b]	46.60[c]	0.25	< 0.001
ADF	4.21[b]	3.61[c]	4.07[b]	4.50[a]	0.06	< 0.001
NDF	10.59	10.97	10.49	10.24	0.11	0.127
ADL	3.73[a]	2.47[b]	2.52[b]	2.12[c]	0.10	< 0.001
TiO_2	0.003	0.003	0.003	0.003	-	-
APD	71.99[a]	43.14[c]	46.05[c]	53.08[b]	1.69	<0.001

[a,b]Different letters in rows show statistically significant differences between groups, *P*-value <0.05; C, control group; W50, 50% of wheat grains in feed; W25, 25% of wheat grains in feed; W10, 10% of wheat grains in feed.

Abbreviations: ADF, acid detergent fiber; ADL, acid detergent lignin; APD, apparent protein digestibility; CA, crude ash; CF, crude fiber; CP, crude protein; DM, dry matter; EE, crude fat; St, starch; NDF, neutral detergent fiber; TiO_2, titanium dioxide. Results are calculated as mean values from 5 samples in 2 replications each (10 replications in total); FINISHER feeds in each group were given between 36 and 42 d; results of APD are calculated as mean values from 5 samples in 2 replications; the finisher feed was commercial and its chemical composition was assured for analytical purposes; the data is similar to the values declared by the producers.

Table 4. Production efficiency in broiler chickens and feed costs.

Item	Group[1] C	W50	W25	W10	SEM	*P*-value
Efficiency in broiler production						
Viability, %	98	100	98	100	0.69	0.585
EPEF	235.53[ab]	211.34[b]	224.42[ab]	250.00[a]	5.12	0.035
EBI	229.89[ab]	205.82[b]	218.81[ab]	243.98[a]	5.04	0.034
Feed costs per chicken, PLN (gross)						
1-14 d	1.09	0.93	0.98	0.94	0.04	0.408
15−35 d	4.22	4.28	4.31	4.16	0.05	0.574
36−42 d	1.77[a]	1.19[c]	1.57[b]	1.76[a]	0.06	< 0.001
1-42 d	7.15	6.43	6.93	6.90	0.10	0.056
Feed costs per 1 kg of live weight	3.79	3.73	3.77	3.63	0.04	0.541
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

[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. Abbreviations: EPEF, European Production Efficiency Factor; EBI, European Broiler Index. Feeding stages − starter (1−14 d); grower (15−35 d); finisher (36−42 d); Average selling price on the free market in Poland on July, 26 2021 = PLN 4.40 net + 8% VAT = PLN 4.75 gross (www.cenyrolnicze.pl); Profit on the free market was checked only for the feeding costs.

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	Group[1] C	W50	W25	W10	SEM	*P*-value
Pre-slaughter body weight, g	2,039.90[b]	2,044.70[b]	2,174.90[ab]	2,199.50[a]	22.22	0.008
Carcass weight, g	1,488.55[ab]	1,466.87[b]	1,583.38[a]	1,586.33[a]	16.57	0.009
Carcass weight with offal, g	1,568.08[ab]	1,551.33[b]	1,668.72[a]	1,665.78[ab]	16.83	0.011
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
Wings, %	10.66	10.67	10.42	10.64	0.14	0.908
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	19.47[b]	23.25[a]	20.84[ab]	19.76[ab]	0.52	0.036
Gizzard, %	1.24[b]	1.50[a]	1.25[b]	1.19[b]	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

[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 6. Muscle and fatness in broiler chickens.

Item	Group[1] C	W50	W25	W10	SEM	P-value
Pectoral muscle, g	404.37[ab]	373.13[b]	406.18[ab]	443.23[a]	7.45	0.007
Pectoral muscle, %	27.17[ab]	25.35[b]	25.74[ab]	27.92[a]	0.36	0.032
Leg muscle, g	315.08[ab]	304.95[b]	338.74[a]	331.02[ab]	4.69	0.040
Leg muscle, %	21.16	20.77	21.42	20.89	0.21	0.713
Total muscle, g	719.45[ab]	678.08[b]	744.92[ab]	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	23.21	23.77	24.19	23.10	1.07	0.984
Abdominal fat, %	1.56	1.62	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.

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 significant 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 7. Physicochemical features of broiler chickens' pectoral and leg muscle.

Item		Group[1] C	W50	W25	W10	SEM	P-value
Pectoral muscle							
pH45mins		6.23	6.21	6.17	6.10	0.02	0.068
pH24h		6.04	5.98	5.92	5.93	0.02	0.189
Color	L*	55.60[b]	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	1.29	2.07	1.46	0.12	0.115
WHC, %		36.76[c]	37.50[c]	40.86[b]	44.86[a]	0.58	< 0.001
Protein, %		22.50[a]	21.96[b]	21.95[b]	21.69[c]	0.05	< 0.001
Collagen, %		1.03[a]	1.08[a]	0.91[b]	1.01[ab]	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[b]	2.21[c]	1.90[d]	2.30[a]	0.03	< 0.001
Water, %		75.28[d]	75.74[c]	76.17[a]	75.97[b]	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[ab]	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[c]	18.20[d]	0.12	< 0.001
Collagen, %		1.31[d]	1.47[c]	1.63[a]	1.53[b]	0.02	< 0.001
Salt, %		0.30[c]	0.37[b]	0.42[b]	0.46[a]	0.01	< 0.001
Intramuscular fat, %		4.97[d]	6.76[c]	7.94[b]	8.44[a]	0.21	< 0.001
Water, %		74.47[a]	73.35[b]	72.50[c]	72.27[d]	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[1]				SEM	P-value
	C	W50	W25	W10		
Bones' breaking strength						
Femur bone						
Maximum load [N/mm]	207.71[ab]	161.33[b]	177.42[ab]	222.03[a]	7.58	0.014
Compressive deformation (dislocation) gauge length [mm]	74.42	73.72	73.89	74.07	0.32	0.898
Tibia bone						
Maximum load [N/mm]	298.24[ab]	232.19[b]	329.58[a]	303.17[ab]	10.40	0.006
Compressive deformation (dislocation) gauge length [mm]	73.91	73.74	73.73	73.31	0.21	0.787
Jejunum tensile strength						
Maximum load [N]	2.61[ab]	2.80[ab]	3.18[a]	2.17[b]	0.10	0.002
Dislocation during stretching [mm]	36.19	37.31	36.50	32.67	1.54	0.735

[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.

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 Abdolllahi 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 (Zaefarian 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 arabinoxylans, and Β-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-Łojewska et al., 2017). In the study of Munyaka et al. (2016), the addition of xylanase and Β-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 intercellular spaces facilitates the release of water from the meat (Nasir et al., 2017). According to Petraci 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 (Zaefarian 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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