Annals of Animal Science
Volume 27 · pp. 386–403 · DOI: 10.2478/aoas-2027-0010

Annals of Animal Science

Partial to complete replacement of soybean meal with high-protein wheat in broiler diets: Effects on growth and blood parameters

Research Article

Anna Szuba-Trznadel[1], Aleksandra Pliszczak-Król[2], Tomasz Hikawczuk[3], Adrianna Lazar[1], Anna Jama-Rodzeńska[4], Zygmunt Król[5], Bogusław Fuchs[1], Anna Rząsa[2]*

[1] *Department of Animal Nutrition and Feed Science, Faculty of Biology and Animal Science, Wrocław University of Environmental and Life Sciences, Norwida 25, 50-375 Wrocław, Poland*
[2] *Department of Immunology, Pathophysiology and Veterinary Prevention, Wrocław University of Environmental and Life Sciences, Norwida 25, 50-375 Wrocław, Poland*
[3] *Biostatistics Teaching Team, Statistical Analysis Centre, Wrocław Medical University, Karola Marcinkowskiego 2–6, 50-368 Wrocław, Poland*
[4] *Institute of Agroecology and Plant Production, Faculty of Life Sciences and Technology, Wrocław University of Environmental and Life Sciences, Norwida 25, 50-375 Wrocław, Poland*
[5] *Saatbau Poland Sp. z o.o., Żytnia 1, 55-300 Środa Śląska, Poland*

Received 24 February 2026; Accepted 16 July 2026

Abstract: The aim of this study was to evaluate the replacement of soybean meal (SBM) with high-protein wheat (HPW; 163 g kg^{-1} crude protein) in broiler chicken diets. Birds were fed isoenergetic diets with reduced crude protein content, supplemented with crystalline essential amino acids to meet nutritional requirements. Growth performance, selected blood biochemical parameters, and rearing costs were assessed. A total of 196 broilers were randomly assigned to four dietary groups with varying HPW inclusion levels across feeding phases. The control group received the lowest HPW levels and SBM as the primary protein source, while in groups II–IV, SBM concentration was decreased simultaneously with HPW concentration – starting at 50% increments until complete replacement was achieved. No significant differences in body weight or feed conversion ratio were observed between the control group and group II. In contrast, growth performance and the European production efficiency factor were significantly reduced ($P < 0.01$) in groups III and IV, indicating lower profitability at high HPW inclusion levels. Total costs of feeding decreased with increasing HPW inclusion from 3.1% (group II) to 33.7% (group IV). The biochemical parameters fluctuated, although the alterations were relatively minor and statistically significant changes were observed only in certain groups and on selected days. While HPW serves as an effective partial protein substitute, the decline in performance at higher inclusion levels suggests that further research into exogenous enzyme combinations is necessary to unlock the full nutritional potential of high-wheat broiler diets.

Keywords: *Alternative protein sources • Body weight gain • European production efficiency factor • Feed conversion ratio • Hemato-biochemical indices • Poultry nutrition • Triticum aestivum*

1. Introduction

The European Union is increasingly shifting toward reducing the use of genetically modified (GMO) plant-based feed ingredients, particularly soybean meal (SBM), which remains the primary protein source in poultry and pig production (Directive 2015/412/EU; Sieradzki et al., 2021; Pope et al., 2023). The majority of SBM used in the EU is imported and derived from GMO crops. Although non-GMO soybean varieties can provide comparable production results and may exhibit higher crude protein (CP) content under similar agronomic conditions (Di Mauro et al., 2023), their availability is limited. Non-GMO crops, including soybeans and maize, account for only

* *E-mail: anna.rzasa@upwr.edu.pl*

Open Access. © 2027 the author(s), published by National Research Institute of Animal Production
This work is licensed under the Creative Commons Attribution-NonCommercial-NoDerivs 4.0 License.

approximately 10% of global production, which restricts their capacity to meet the growing demand for non-GMO feed materials (Liu et al., 2025). Consequently, interest in alternative protein sources has increased; however, their practical use is often constrained by the presence of anti-nutritional factors, limited availability, and variable nutritional value (Babatunde et al., 2021; Lestingi, 2024).

Wheat (*Triticum aestivum*) is widely used in poultry nutrition due to its high metabolizable energy (ME) content (12.9–15.8 MJ ME·kg^{-1}) and moderate CP content (8–20%) across varieties and processing conditions (Pirgozliev et al., 2024). Nevertheless, its biological value (BV) is relatively low because of deficiencies in essential amino acids (EAAs), particularly lysine (Lys), threonine (Thr), methionine (Met), and tryptophan (Trp), as well as the predominance of glutamine (Gln) and proline (Pro) in wheat protein fractions (Shewry, 2023; Szuba-Trznadel et al., 2024). Wheat can constitute up to 40% of broiler feed mixtures, provided that exogenous enzymes are included to mitigate the effects of non-starch polysaccharides (NSPs) and reduce intestinal viscosity (Smulikowska & Rutkowski, 2018; Lee et al., 2024). Recently, high-protein wheat (HPW) cultivars containing 16–17% CP and improved amino acid profiles have gained attention as potential partial substitutes for SBM (Sułek et al., 2023). However, the replacement of SBM with HPW typically requires supplementation with crystalline amino acids (AAs), which may not only reduce feed costs and nitrogen excretion but can also influence feed conversion ratio (FCR) and body fat deposition (Garcia Neto et al., 2000; Saleh et al., 2021). Additionally, the high starch content of wheat-based diets may affect energy utilization efficiency and carcass composition (Cordero et al., 2025).

The aim of this study was to investigate whether increasing levels of HPW can partially replace SBM in broiler diets without adversely affecting growth performance, FCR, or selected blood and serum biochemical parameters, while simultaneously reducing feed costs. Furthermore, the study aimed to evaluate whether increasing the proportion of locally produced feed components at the expense of imported ingredients could improve economic outcomes. An additional objective was to consider the potential environmental benefits of such dietary strategies, particularly in terms of reducing the carbon footprint associated with feed production and transport. We hypothesized that the partial or complete substitution of SBM with HPW would maintain optimal growth performance and physiological status (reflected by haematological and biochemical parameters) in broiler chickens, while simultaneously improving the economic efficiency of production and potentially reducing its environmental impact.

2. Material and methods

2.1 Animal ethics

All experimental procedures, including the humane euthanasia of birds for blood sampling via CO_2 stunning and decapitation, were reviewed and approved by the Animal Welfare Advisory Team at Wrocław University of Environmental and Life Sciences (Ethical statement no. 04/2023) in compliance with Directive 2010/63/EU.

2.2 Feed component

The study evaluated HPW supplied by Saatbau Poland Sp. z o.o. (Środa Śląska, Poland) as a protein substitute in broiler diets.

The HPW utilized in this study was Activus, a winter wheat cultivar classified in the A quality class, bred by Saatbau Linz GmbH (Austria). This cultivar is characterized by an elevated grain protein content and high baking quality. The batch used in this trial was analysed for its basic nutritional profile, showing a total protein content of 16% (Szuba-Trznadel et al., 2024), making it suitable for high-spec poultry diet formulations.

2.3 Animals and husbandry

The experiment was conducted at the Research and Education Station in Swojczyce, Wrocław University of Environmental and Life Sciences. A total of 196 one-day-old Ross 308 broiler chickens were obtained from ModerHatch hatchery (Magnuszowice, Poland). Upon arrival, broilers were individually weighed and randomly allocated to pens to achieve a uniform initial pen body weight (BW) (46 g ± 1.53 per pen), following a completely randomized design.

Birds were assigned to four experimental groups: group I (control), and groups II, III, and IV. Each group consisted of seven pens with seven birds per pen. Broilers were reared under standard conditions in accordance with Polish animal welfare regulations (Journal of Laws of the Republic of Poland, 2015, item 266, as amended in 2023, item 465) and Ross 308 management guidelines (Ross Broiler Management Handbook, 2018).

The ambient temperature was set at 32°C on day 1, gradually reduced to 24°C by the end of the second week, and maintained at 20–21°C thereafter. Relative humidity ranged from 60 to 73%. The lighting program provided 22 h of light and 2 h of darkness during the first

week, adjusted to 18 h of light and 6 h of darkness from the second week onward. Feed and water were provided *ad libitum*. Each pen was equipped with a hopper feeder and two nipple drinkers with adjustable heights.

2.4 Dietary treatments

Birds were fed starter (days 1–14), grower (days 15–29), and finisher (days 30–49) diets. The finisher phase was extended by 1 week beyond the typical rearing period. Group I served as a wheat-based control (58% inclusion), while groups II–IV received diets with progressively increasing levels of HPW at the expense of SBM. The detailed composition of experimental diets is shown in Tables 1–3. Changes in SBM and HPW inclusion across feeding phases are presented in Table 4, while selected nutritional parameters are shown in Table 5.

All diets were formulated to be isoenergetic. ME was standardized at approximately 12.68 MJ·ME·kg^{-1} (starter), 13.02 MJ ME·kg^{-1} (grower), and 13.18 MJ ME·kg^{-1} (finisher) by adjusting soybean oil inclusion. While the CP content in group I was slightly higher than Polish standard recommendations, the formulation was adjusted in collaboration with the feed manufacturer (Neorol Sp. z o.o.) to align with the specific nutritional requirements of the Ross 308 lineage. Conversely, in groups II–IV, the CP content was intentionally and progressively reduced below reference values as HPW inclusion increased. EAAs requirements were met via crystalline amino acid supplementation according to Polish Nutritional Recommendations for Poultry (Smulikowska & Rutkowski, 2018). To mitigate potential adverse effects of high HPW inclusion, all diets were supplemented with commercial enzyme preparations: xylanase (Ronozyme® WX, DSM Nutritional Products, The Netherlands), containing endo–1,4-β-xylanase (EC 3.2.1.8); guaranteed minimum activity of 1,000 FXU·g^{-1}, included at 0.02%, providing a final activity of 200 FXU·kg^{-1} of feed and phytase (Ronozyme® HiPhos, DSM Nutritional Products, The Netherlands), containing 6-phytase (EC 3.1.3.26); guaranteed minimum activity of 10,000 FYT·g^{-1}, included at 0.02%, providing a final activity of 2,000 FYT·kg^{-1} of feed.

2.5 Performance measurement and sampling

The experimental period was extended to 49 days based on the specific nature of the dietary treatments (high to

Table 1. Composition of feed mixtures for broiler chickens (starter)

Ingredient, g·kg^{-1}	Groups			
	I	II	III	IV
Wheat (Activus cv.)	580.1	711.1	776.1	840.6
Soybean meal (CP 48%)	256.5	128.0	64.0	—
Feed wheat flour	85.0	85.0	85.0	85.0
Soybean oil	35.0	17.8	9.3	1.0
Choline chloride 60%	2.8	2.8	2.8	2.8
Sodium bicarbonate ($NaHCO_3$)	1.5	1.5	1.5	1.5
1-Ca phosphate	7.4	8.5	9.0	9.5
Chalk	12.8	13.2	13.5	14.1
Premix (Broiler Starter Green Line)[1]	2.0	2.0	2.0	2.0
DL-methionine (99%)[2]	4.1	5.3	5.9	6.5
L-arginine (97%)[2]	1.7	5.5	7.3	9.2
L-lysine HCl (78.9%)[2]	4.8	8.8	10.8	12.8
L-threonine (99%)[2]	2.0	3.8	4.7	5.6
L-tryptophan (98%)[2]	—	0.6	0.9	1.1
L-valine (96.5%)[2]	0.4	2.6	3.6	4.7
Sodium sulphate	1.0	1.0	1.0	1.0
Salt	1.1	1.0	0.9	0.9
Sacox 120 microGranulate[3]	1.3	1.3	1.3	1.3
Enzyme phytase[4]	0.2	0.2	0.2	0.2
Enzyme xylanase[5]	0.2	0.2	0.2	0.2

[1]Each 1 kg of premix contained (Broiler Starter Green Line): Vitamins: A 6000000.00 IU, D_3 1250000.00 IU, 25-hydroxycholecalciferol 18750.00 mcg, E 50000.00 mg, K_3 2000.00 mg, B_1 1750.00 mg, B_2 4500.00 mg, Ca pantothenate 7499.94 mg, B_6 2500.00 mg, B_{12} 15000.00 mcg, niacin 32500.00 mg, folic acid 1000.00 mg, biotin 100000.00 mcg. Minerals: Ca 14.53%, Mg 0.01%, Na 1.76%. Fe 10000.00 mg, Cu 8000.00 mg, Mn 60000.00 mg, Zn 55000.00 mg, I 625.00 mg, Se 150.00 mg. Enzymes: 6-phytase 750000.00 FYT, endo–1,4-beta-xylanase 100000.00 FXU. Others: citric acid 12.00 mg, butylhydroxytoluene 48.19 mg. propyl gallate 3.96 mg, clinoptilolite of sedimentary origin 20000.00 mg·kg^{-1}. [2]Amino acids bought from DSM Company, The Netherlands. [3]Sacox 120 microGranulate – salinomycin sodium salt 120 g: salinomycin sodium: 114–132 g; silicon dioxide: 10–100 g·kg^{-1}; calcium carbonate: 500–700 g. [4]Enzyme phytase – Ronozyme® HiPhos (DSM Company, The Netherlands). [5]Enzyme xylanase – Ronozyme WX (DSM Company, The Netherlands). *Digestible amino acid – according to nutritional recommendations for poultry (Smulikowska & Rutkowski, 2018) – crystalline AAs are completely absorbed in the small intestine and their availability is assumed to be 100%.

Table 2. Composition of feed mixtures for broiler chickens (grower)

Ingredient, g·kg^{-1}	Groups			
	I	II	III	IV
Wheat (Activus cv.)	669.3	777.7	831.1	884.5
Soybean meal (CP 48%)	211.4	105.0	52.5	—
Feed wheat flour	49.9	50.0	50.0	50.0
Soybean oil	30.5	16.3	9.3	2.3
Choline chloride 60%	2.7	2.7	2.7	2.7
Sodium bicarbonate ($NaHCO_3$)	1.5	1.5	1.5	1.5
1-Ca phosphate	5.9	6.8	7.2	7.7
Chalk	11.2	11.5	11.7	11.8
Premix (Broiler Grower Green Line)[1]	2.0	2.0	2.0	2.0
DL-methionine (99%)[2]	3.9	4.9	5.4	5.9
L-arginine (97%)[2]	4.5	7.8	9.5	11.1
L-lysine HCl (79.8%)[2]	1.6	3.1	3.8	4.6
L-threonine (99%)[2]	—	0.4	0.7	0.9
L-tryptophan (98%)[2]	0.2	1.9	2.8	3.7
L-valine (96.5%)[2]	1.0	1.0	1.0	1.0
Sodium sulphate	1.0	0.9	0.9	0.8
Sacox 120 microGranulate[3]	1.3	1.3	1.3	1.3
Enzyme phytase[4]	0.2	0.2	0.2	0.2
Enzyme xylanase[5]	0.2	0.2	0.2	0.2

[1]Each 1 kg of premix contained (Broiler Grower Green Line): Vitamins: A 5000000.00 IU, D_3 2000000.00 IU, E 50000.00 mg, K_3 2000.00 mg, B_1 1500.00 mg, B_2 4000.00 mg, Ca pantothenate 7499.94 mg, B_6 2500.00 mg, B_{12} 15000.00 mcg, niacin 32500.00 mg, folic acid 1000.00 mg, biotin 125000.00 mcg. Minerals: Ca 14.59%, Mg 0.01%, Na 1.76%. Fe 10000.00 mg, Cu 8000.00 mg, Mn 60000.00 mg, Zn 55000.00 mg, I 625.00 mg, Se 150.00 mg. Enzymes: 6-phytase 750000.00 FYT, endo–1,4-beta-xylanase 100000.00 FXU. Others: citric acid 12.00 mg, butylhydroxytoluene 48.19 mg, propyl gallate 3.96 mg, clinopptilolite of sedimentary origin 20000.00 mg. [2]Amino acids bought from DSM Company, The Netherlands. [3]Sacox 120 microGranulate – salinomycin sodium salt 120 g·kg^{-1}: salinomycin sodium: 114–132 g·kg^{-1}; silicon dioxide: 10–100 g·kg^{-1}; calcium carbonate: 500–700 g·kg^{-1}. [4]Enzyme phytase – Ronozyme® HiPhos (DSM Company, The Netherlands). [5]Enzyme xylanase – Ronozyme WX (DSM Company, The Netherlands). *Digestible amino acid – according to nutritional recommendations for poultry (Smulikowska & Rutkowski, 2018) – crystalline AAs are completely absorbed in the small intestine and their availability is assumed to be 100%.

Table 3. Composition of feed mixtures for broiler chickens (finisher)

Ingredient, g·kg^{-1}	Groups			
	I	II	III	IV
Wheat (Activus cv.)	726.6	810.4	851.7	891.9
Soybean meal (CP 48%)	161.9	80.0	40.0	—
Feed wheat flour	50.0	50.0	49.7	50.0
Soybean oil	28.5	17.5	12.0	6.8
Choline chloride 60%	2.7	2.7	2.7	2.7
Sodium bicarbonate ($NaHCO_3$)	1.1	1.1	1.1	1.1
1-Ca phosphate	4.5	5.2	5.5	5.9
Chalk	10.4	10.4	10.3	10.7
Premix (Broiler Finisher Green Line)[1]	2.0	2.0	2.0	2.0
DL-methionine (99%)[2]	3.2	4.0	4.4	4.7
L-arginine (97%)[2]	1.6	4.0	5.2	6.3
L-lysine HCl (79.8%)[2]	4.3	6.9	8.2	9.4
L-threonine (99%)[2]	1.3	2.4	3.0	3.5
L-tryptophan (98%)[2]	—	0.2	0.4	0.6
L-valine (96.5%)[2]	—	1.4	2.0	2.7
Sodium sulphate	1.0	1.0	1.0	1.0
Salt	0.5	0.4	0.4	0.3
Enzyme phytase[3]	0.2	0.2	0.2	0.2
Enzyme xylanase[4]	0.2	0.2	0.2	0.2

[1]Each 1 kg of premix contained (Broiler Finisher Green Line): Vitamins: A 5000000.00 IU, D_3 2000000.00 IU, E 40000.00 mg, K_3 1500.00 mg, B_1 1000.00 mg, B_2 3500.00 mg, Ca pantothenate 6250.44 mg, B_6 2000.00 mg, B_{12} 10000.00 mcg, niacin 25000.00 mg, folic acid 1000.00 mg, biotin 100000.00 mcg. Minerals: Ca 15.83%, Mg 0.01%, Na 1.76%. Fe 10000.00 mg, Cu 8000.00 mg, Mn 60000.00 mg, Zn 55000.00 mg, I 625.00 mg, Se 150.00 mg. Enzymes: 6-phytase 750000.00 FYT, endo–1,4-beta-xylanase 100000.00 FXU. Others: citric acid 12.00 mg·kg^{-1}, butylhydroxytoluene 48.19 mg·kg^{-1}, propyl gallate 3.96 mg·kg^{-1}, clinoptilolite of sedimentary origin 20000.00 mg·kg^{-1}. [2]Amino acids bought from DSM Company, The Netherlands. [3]Enzyme phytase – Ronozyme® HiPhos (DSM Company, The Netherlands). [4]Enzyme xylanase – Ronozyme WX (DSM Company, The Netherlands). *Digestible amino acid – according to nutritional recommendations for poultry (Smulikowska & Rutkowski, 2018) – crystalline AAs are completely absorbed in the small intestine and their availability is assumed to be 100%.

complete replacement of SBM with HPW). This extension enabled the assessment of altered growth trajectories and compensatory growth, as well as the physiological maturity and quality of the carcass.

2.5.1 Production performance

BW was recorded individually every week. Body weight gain (BWG) was calculated as the difference between initial and final BW over defined periods. Feed intake

Table 4. Wheat and soybean meal content in experimental mixtures (%)

	Group I	Group II	Group III	Group IV
SBM	30	15	7.5	0100
HPW	60	75	82.5	100

SBM, soybean meal; HPW, high-protein wheat.

(FI) was measured daily per pen as the difference between feed offered and feed refusals. FCR is calculated as follows:

$$FCR(kg\ kg^{-1}) = FI(kg) \cdot BWG(kg)^{-1}$$

2.5.2 Rearing efficiency indicators

Crude protein intake (CPI) and protein efficiency ratio (PER) are calculated for each phase:

$$CPI\ (g\ day^{-1}) = DFI\ (g) \cdot CP\ content\ (\%) \cdot 100^{-1}$$

$$PER = BWG\ (g) \cdot (CPI(g))^{-1}$$

The cost of feeding (CostF) was calculated for each experimental group and feeding phase based on the cumulative FI and the price per kilogram of the respective diet (*P*), according to the following formula:

$$CostF\ (EUR\ per\ FI\ cumulatively\ in\ kg) = total\ FI\ (kg) \cdot P(EUR)$$

The total feeding cost (TCostF) over the entire rearing period was determined as the sum of the costs incurred during the starter (S), grower (G), and finisher (F) phases:

$$TCostF(EUR\ per\ total\ FI\ cumulatively\ in\ kg) = CostF(S) + CostF(G) + CostF(F)$$

The European production efficiency factor (EPEF) is evaluated for the final phase:

$$EPEF = \frac{Viability\ (\%) \cdot Body\ weight\ (kg)}{Age\ (days) \cdot FCR} \cdot 100$$

2.5.3 Blood sample collection and analysis

The number of birds per pen decreased progressively due to scheduled sampling (one bird per pen at each time point), and bird-days were accounted for in all performance calculations. Blood was collected once from each bird by the same well-trained operator, and the collected volume was divided into two sample aliquots. All analytical procedures for the determination of haematological and biochemical parameters were performed in technical duplicate. The duplicate measurements were averaged prior to statistical analysis.

Table 5. Nutritional value (in kg of feed mixture) of diets for broiler chickens

Groups	I	II	III	IV	I	II	III	IV	I	II	III	IV
	Starter phase (1–14)				Grower phase (15–29)				Finisher phase (30–49)			
CA, g	59.8	48.6	42.5	56.8	46.7	46.6	42.8	30.4	41.7	39.4	23.3	31.7
CP, g	236.4	217.6	214.5	196.8	225.0	215.1	206.2	199.5	207.0	196.1	187.4	176.8
EE, g	36.6	22.8	23.2	23.8	40.4	34.1	27.1	19.3	38.5	28.2	22.3	19.7
CF, g	26.4	21.6	18.4	16.0	21.0	18.5	18.5	25.7	26.0	24.2	23.1	20.4
Ca, g	9.80	9.12	9.53	9.45	8.50	8.93	8.56	9.18	8.59	8.79	8.54	7.77
P, g	6.42	6.60	6.71	6.15	6.17	6.33	6.18	6.67	6.47	6.49	6.32	6.67
Na, g	2.09	2.02	2.06	2.01	1.60	2.09	1.47	1.45	1.69	1.25	1.53	1.43
Lys, g	17.96	18.70	18.19	18.03	13.24	13.20	13.27	13.04	11.68	11.27	11.64	11.93
Met + Cys, g	9.64	9.11	9.04	9.30	9.52	9.17	8.93	8.72	9.12	9.25	9.67	9.82
Thr, g	9.93	9.48	9.46	9.41	8.54	8.77	8.68	9.26	6.71	6.73	6.18	7.10
Trp, g	2.58	2.40	2.39	2.30	1.68	1.48	1.49	1.43	1.35	1.29	1.33	1.15
Arg, g	14.80	15.01	14.89	14.93	12.83	13.35	13.91	13.24	10.13	10.03	10.31	10.35
Val, g	10.06	9.93	10.18	10.10	8.17	8.18	8.77	8.68	8.17	8.14	8.40	8.73

CA, crude ash; CP, crude protein; EE, ether extract (crude fat); CF, crude fibre; Ca, calcium; P, phosphorus; Na, sodium; Lys, lysine; Met + Cys, methionine + cystine; Thr, threonine; Trp, tryptophan; Arg, arginine; Val, valine.

Because individual haematological and biochemical parameters may exhibit age-dependent variation, the age-appropriate normal ranges were defined as the interval between the 2.5th and 97.5th percentiles of the distribution of values obtained from birds in the control group (group I).

2.5.3.1 Assessment of haematological parameters

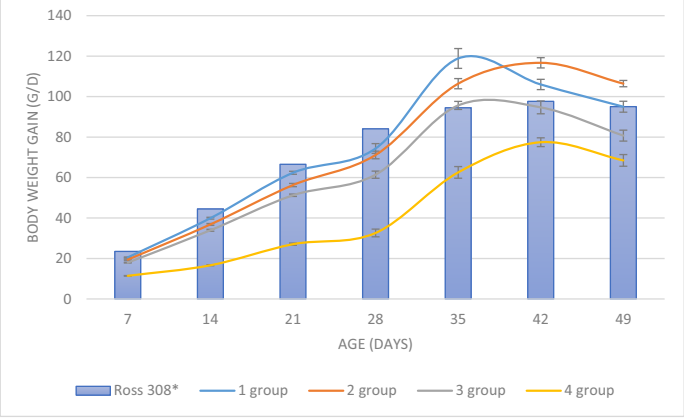
Blood was collected into tubes containing K_2EDTA (PROFILAB, No 324, Poland) as an anticoagulant. Quantitative assessments of erythrocytes (red blood cell (RBC)) and leukocytes (white blood cell (WBC)) were performed manually using a Bürker haemocytometer and Natt–Herrick solution in dilution 1:200 (self-made according to the recipe found in Thrall et al., 2006).

2.5.3.2 Assessment of biochemical parameters

Blood samples were collected into plastic tubes without anticoagulant and allowed to clot to obtain serum. Biochemical parameters were determined using kinetic methods for alanine aminotransferase – ALT (Alpha Diagnostics, No A6425–125, Poland), aspartate aminotransferase – AST (Alpha Diagnostic, No A6461–125, Poland), alkaline phosphatase – ALP (Alpha Diagnostics, No A6406-075, Poland), and creatinine – Cr (Pointe Scientific, No C7539–100, USA), and colorimetric methods for total protein – TP (Pointe Scientific, No C7528–100, USA), albumin – Alb (Alpha Diagnostics, No A6502–100, Poland), total cholesterol – TCh (CHOD–PAP method, Pointe Scientific, No C7510–100, USA), and phosphorus – *P* (Alpha Diagnostics, No A6516–100, Poland) using appropriate commercial kits. For enzymatic assays, the rate of increase in absorbance was directly proportional to the enzyme activity. In colorimetric methods, the colour intensity of the sample corresponded to the concentration of the parameter. All parameters were measured using the biochemical analyser Pointe 180 (Pointe Scientific, Poland). Reagents were reconstituted, and the appropriate wavelengths were selected following the manufacturer's guidelines.

2.6 Data analysis

Data were organized using Microsoft Excel (Microsoft Corp., Redmond, WA, USA, 2019). Statistical analyses were performed with Statistica 13 (Tibco Software Inc., Palo Alto, CA, USA, 2017). Data distribution was checked separately within each group using the Shapiro–Wilk test. Homogeneity of



Rearing period (days)	Groups I	II	III	IV	P - value
1–7	A	ABa	Bb	C	<0.001
7–14	Aa	ABb	Bc	C	<0.001
14–21	A	Ba	Bb	C	<0.001
21–28	Aa	A	Ab	B	<0.001
28–35	Aa	A	Ab	B	<0.001
35–42	AB	A	B	C	<0.001
42–49	AB	A	B	C	<0.001

[a-c] means within a row with different superscripts differ ($P < 0.05$).
[A-C] means within a row with different superscripts differ ($P < 0.01$).

Figure 1. Average body weight gain (BWG) of broiler chickens fed with different high-protein wheat (HPW) contents (mean value ± SEM, $n = 7$).

variance between groups was assessed with Levene's test. One-way analysis of variance (ANOVA) was used for statistical comparison, followed by Tukey's honestly significant difference test to determine significant differences between group means. Statistical significance was set at $P < 0.05$ and $P < 0.01$. Obtained results are presented in tables and figures. Results in tables are presented as arithmetic means with the standard error of the mean (SEM). The SEM values presented in the tables represent pooled SEMs calculated from the residual mean square error obtained from the ANOVA/generalized linear model. Figures 1 and 2 show means with error bars. Significant differences between groups (indicated by different superscript letters) and corresponding *P*-values are presented in tables below each figure.

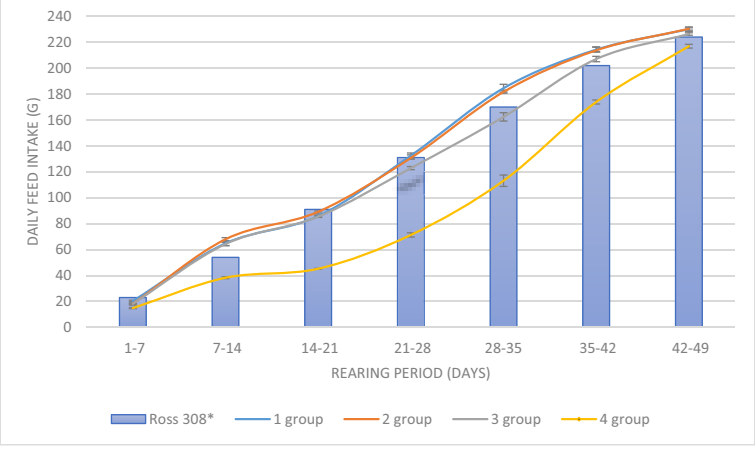
3. Results

3.1 Performance

Weekly BW values of broiler chickens are presented in Table 6. No significant differences among groups were observed during the first week of life. However, from day 7 onward, birds in group I (58% HPW) and group II (71.1% HPW) exhibited significantly higher BW ($P < 0.01$) compared with groups III (77.6% HPW) and IV (84.1% HPW). On day 14, groups I and II remained heavier ($P < 0.01$) than group IV, while group III showed a significant reduction in BW compared to both the control group and group II ($P < 0.05$).

By day 21, BW decreased linearly as HPW inclusion increased ($P < 0.01$), with the highest BW recorded in the control group. This linear pattern persisted through days 28 and 35 ($P < 0.01$). By day 42, no significant difference was observed between groups I and II; however, both were significantly heavier than groups III and IV ($P < 0.01$). At the end of the experiment (day 49), groups I and II exhibited comparable BW, whereas groups III and IV remained significantly lighter ($P < 0.01$). Overall, group II maintained a BW similar to the control group, while higher HPW inclusion levels resulted in BW reductions of approximately 16% and 42% in groups III and IV, respectively.

Daily BWG is illustrated in Figure 1. Notably, group II showed an upward trend in BWG during the later stages of rearing, approaching or even exceeding control values.



Rearing period (days)	Groups I	II	III	IV	P - value
1–7	A	AB	AB	B	0.006
7–14	A	A	A	B	<0.001
14–21	A	A	A	B	<0.001
21–28	A	A	A	B	<0.001
28–35	A	A	B	C	<0.001
35–42	A	A	A	B	<0.001
42–49	A	A	A	B	<0.001

$^{A-C}$ means within a row with different superscripts differ ($P < 0.01$).

Figure 2. Average daily feed intake (FI) of broiler chickens fed with different high-protein wheat (HPW) contents (mean value ± SEM, $n = 7$).

Table 6. Average BW (g day^{-1}) in broiler chickens fed with different HPW contents

Day of life	Groups				SEM	*P*-value
	I	II	III	IV		
1	45.82	46.10	45.09	46.52	0.576	0.373
7	189.52^{A}	182.13^{A}	170.86^{B}	126.50^{C}	3.282	<0.001
14	468.92^{Aa}	439.98^{ABa}	408.45^{Bb}	243.01^{Cc}	7.919	<0.001
21	905.40^{A}	834.02^{B}	767.17^{C}	432.50^{D}	15.933	<0.001
28	1425.92^{A}	1332.11^{B}	1197.09^{C}	660.78^{D}	37.237	<0.001
35	2257.85^{A}	2076.82^{B}	1866.56^{C}	1098.59^{D}	45.116	<0.001
42	2999.80^{A}	2893.71^{A}	2529.28^{B}	1640.79^{C}	61.439	<0.001
49	3664.80^{A}	3638.71^{A}	3094.28^{B}	2120.07^{C}	39.016	<0.001

Abbreviations: BW – body weight, HPW – high-protein wheat.
SEM = pooled standard error of the mean derived from ANOVA model (based on n = 7 replicate pens per treatment group).
$^{a–c}$ Means within a row with different superscripts differ (P < 0.05). $^{A–D}$ Means within a row with different superscripts differ (P < 0.01).

FI across the rearing phases is summarized in Figure 2. During the starter phase, group IV consumed significantly less feed (14.85 g·day^{-1}·bird^{-1}) than the control group (20.35 g·day^{-1}·bird^{-1}; P < 0.01). Between days 7 and 14, FI was comparable among groups with HPW inclusion up to 77.6% (64.29–67.96 g·day^{-1}·bird^{-1}) but remained significantly lower in group IV (38.28 g·day^{-1}·bird^{-1}; P < 0.01). This reduction in FI associated with higher HPW inclusion persisted throughout the duration of the experiment.

FCR results are presented in Table 7. During the first week, FCR averaged 0.75 kg·kg^{-1}, with no significant differences among groups. From the second week onward, group IV consistently exhibited the poorest (highest) FCR (P < 0.05 to P < 0.01), whereas groups I and II remained comparable. This trend persisted throughout the entire experimental period.

Regarding mortality, no bird losses or health complications were observed during the entire 49-day experimental period. Because there was no mortality, no adjustments for missing bird-days due to the death were required in the final FCR and EPEF calculations.

3.2 Rearing efficiency indicators

3.2.1 Protein utilization indicators

Average CPI during each feeding phase is shown in Table 8. In the starter phase, CPI was the highest in the control group (P < 0.01) and decreased progressively as HPW inclusion increased, with the most substantial reduction observed in group IV. During the grower phase, significant differences (P < 0.01) were observed between the control group, group II, and the remaining experimental groups. Cumulative CPI up to day 49 was highest in the control group, with all groups differing significantly from one another (P < 0.01). Compared with the control group, cumulative CPI was reduced by 8.9%, 17.3%, and 36.3% in groups II, III, and IV, respectively.

Protein efficiency ratio values are presented in Table 9. During the starter phase, groups II and III exhibited the highest PER values (P < 0.05), while the lowest PER was recorded in group IV. Although group IV did not differ significantly from the control group, PER was 10.6% and 12.5%

Table 7. Average FCR (kg kg^{-1}) in broiler chickens fed with different HPW contents

Rearing period (days)	Groups				SEM	*P*-value
	I	II	III	IV		
1–7	0.75	0.70	0.75	0.82	0.044	0.290
7–14	1.04^{Bb}	1.10^{Bb}	1.14A^{Bb}	1.25^{Aa}	0.029	<0.001
14–21	1.20^{Bb}	1.33^{a}	1.38^{Aa}	1.44^{Aa}	0.027	<0.001
21–28	1.42^{Bb}	1.52^{AB}	1.61^{a}	1.71^{A}	0.047	0.002
28–35	1.42^{B}	1.53^{AB}	1.58^{A}	1.67^{A}	0.030	<0.001
35–42	1.54^{B}	1.58^{BC}	1.70^{AC}	1.73^{A}	0.026	<0.001
42–49	1.69^{C}	1.69^{C}	1.88^{B}	2.02^{A}	0.021	<0.001
1–49	1.71^{C}	1.71^{C}	1.91^{B}	2.06^{A}	0.022	<0.001

Abbreviations: FCR – feed conversion ratio, HPW – high-protein wheat.
SEM = pooled standard error of the mean derived from ANOVA model (based on n = 7 replicate pens per treatment group).
$^{a–b}$ Means within a row with different superscripts differ (P < 0.05). $^{A–C}$ Means within a row with different superscripts differ (P < 0.01).

Table 8. Average CPI (g per rearing period per head) of broiler chickens fed with different HPW contents

Rearing period	Groups				SEM	*P*-value
	I	II	III	IV		
Starter	115.85^{A}	103.51^{B}	94.43^{C}	57.09^{D}	1.836	<0.001
Grower	344.50^{A}	309.00^{Ba}	283.87^{Bb}	150.55^{C}	5.657	<0.001
Finisher (to day 35)	258.48^{A}	221.22^{B}	192.51^{C}	119.35^{D}	4.053	<0.001
Finisher (to day 42)	549.54^{A}	495.68^{B}	441.75^{C}	297.34^{D}	8.824	<0.001
Finisher (to day 49)	878.95^{A}	791.47^{B}	728.37^{C}	558.64^{D}	10.219	<0.001

Abbreviations: CPI – crude protein intake, HPW – high-protein wheat.
SEM = pooled standard error of the mean derived from ANOVA model (based on n = 7 replicate pens per treatment group).
$^{a-b}$ Means within a row with different superscripts differ (P < 0.05). $^{A-D}$ Means within a row with different superscripts differ (P < 0.01).

Table 9. Average PER (g g^{-1}) of broiler chickens fed with different HPW contents

Rearing period	Groups				SEM	*P*-value
	I	II	III	IV		
Starter	3.66^{ab}	3.81^{a}	3.85^{a}	3.45^{b}	0.099	0.036
Grower	2.79	2.89	2.77	2.77	0.117	0.874
Finisher (to day 35)	3.22	3.37	3.35	3.38	0.183	0.920
Finisher (to day 42)	2.86^{b}	3.15^{ab}	3.02^{ab}	3.29^{a}	0.101	0.034
Finisher (to day 49)	2.49^{B}	2.96^{A}	2.61^{B}	2.61^{B}	0.044	<0.001

Abbreviations: PER – protein efficiency ratio, HPW – high-protein wheat.
SEM = pooled standard error of the mean derived from ANOVA model (based on n = 7 replicate pens per treatment group).
$^{a–b}$ Means within a row with different superscripts differ (P < 0.05). $^{A–B}$ Means within a row with different superscripts differ (P < 0.01).

lower than in groups II and III, respectively. No significant differences among groups were observed during the grower and early finisher phases (up to day 35). However, during the final two weeks, birds from group II exhibited significantly higher PER value compared with those fed the control diet, whereas no differences were observed between the remaining groups (P < 0.05–0.01).

3.2.2 Feed cost and EPEF

The economic analysis (Table 10) revealed that both the price of feed mixtures and the cumulative cost of feeding were significantly affected by the dietary inclusion of HPW. A consistent downward trend in feed prices per tonne was observed as the proportion of HPW increased across all feeding phases. Specifically, the total cost of feeding over the 49-day rearing period was reduced by 3.1%, 8.8%, and 33.7% in groups II, III, and IV, respectively, compared to the control group (P < 0.01).

The EPEF values are presented in Table 11. During the early finisher phase (up to day 35), the control group showed significantly higher EPEF values (P < 0.01) than groups II and III, and all three groups significantly outperformed group IV. By days 42 and 49, groups I and II maintained significantly higher EPEF values than groups III and IV (P < 0.01), indicating that moderate HPW inclusion does not adversely affect overall production efficiency.

3.3 Blood parameters

The effects of dietary HPW inclusion on selected haematological and biochemical blood parameters are presented in Tables 12–15.

3.3.1 Haematological parameters

Dietary HPW inclusion did not significantly affect RBC. In contrast, WBC varied both among groups within the same age interval and across successive sampling points. Compared to the control group, similar trends were observed on days 14 and 49, characterized by a decrease in WBC in groups II and III and an increase in group IV. An opposite trend was noted on days 21 and 35. On day 42, an increase in WBC was observed across all groups. Although these fluctuations were noticeable, the values only slightly exceeded the established normal limits. On day 21, WBC counts in groups II and IV were below the lower limit of the normal range (with a maximum deviation of

Table 10. Price of the diet and the cost of feeding broiler chickens (EUR per tonne) fed with different HPW contents

Item	Groups				SEM	*P*-value
	I	II	III	IV		
Price for a ton [EUR per ton]						
Starter	349.29	339.15	335.61	332.55		
Grower	323.58	317.92	315.33	312.50		
Finisher	302.59	295.28	292.92	291.04		
Cost of feeding (EUR per FI cumulatively in kg)						
Starter	0.17^{Aa}	0.17^{A}	0.16^{Ab}	0.10^{B}	0.003	<0.001
Grower	0.50^{A}	0.49^{A}	0.46^{A}	0.25^{B}	0.010	<0.001
Finisher (to day 35)	0.36^{A}	0.34^{AB}	0.30^{B}	0.21^{C}	0.011	<0.001
Finisher (to day 42)	0.79^{A}	0.75^{AB}	0.69^{B}	0.50^{C}	0.017	<0.001
Finisher (to day 49)	1.26^{A}	1.21^{ABa}	1.14^{Bb}	0.92^{C}	0.019	<0.001
Total cost of feeding (EUR per total FI cumulatively in kg)						
To day 35	1.03^{A}	1.00^{AB}	0.92^{B}	0.56^{C}	0.022	<0.001
To day 42	1.46^{A}	1.41^{AB}	1.31^{B}	0.85^{C}	0.027	<0.001
To day 49	1.93^{A}	1.87^{A}	1.76^{B}	1.28^{C}	0.029	<0.001

Abbreviations: HPW – high-protein wheat.
SEM = pooled standard error of the mean derived from ANOVA model (based on n = 7 replicate pens per treatment group).
$^{a–b}$ Means within a row with different superscripts differ ($P < 0.05$). $^{A–C}$ Means within a row with different superscripts differ ($P < 0.01$).

Table 11. Average EPEF of broiler chickens fed with different HPW contents during the last feeding phase

Rearing period	Groups				SEM	*P*-value
	I	II	III	IV		
Finisher (to day 35)	454.48^{A}	387.22^{B}	337.96^{C}	189.55^{D}	7.803	<0.001
Finisher (to day 42)	463.37^{A}	435.49^{A}	355.88^{B}	227.68^{C}	8.174	<0.001
Finisher (to day 49)	443.13^{A}	440.34^{A}	336.18^{B}	214.49^{C}	7.913	<0.001

Abbreviations: EPEF – European production efficiency factor, HPW – high-protein wheat.
SEM = pooled standard error of the mean derived from ANOVA model (based on n = 7 replicate pens per treatment group).
$^{A–D}$ Means within a row with different superscripts differ ($P < 0.01$).

approximately 11% in group IV). On day 35, values exceeded the upper limit in group II (approximately 5%), and a similar trend was observed in group IV on day 49.

3.3.2 Biochemical parameters

Biochemical parameters exhibited more pronounced fluctuations in response to feed composition and bird age (Table 9). On day 42, all experimental groups showed higher ALT activity compared to the control group ($P = 0.072$), with group III reaching the highest level (approximately 17.8% above the upper normal limit). Slightly elevated ALT was also observed in group III on days 35 and 49.

From day 35, the activity of AST differed significantly from the control group. On days 35 and 42, AST was higher ($P < 0.01$) in group II, while it was markedly lower in group IV (by 25.5% below the lower limit of the normal range) on day 35. By day 49, AST was reduced in all experimental groups, with the lowest activity recorded in group IV (3.4% reduction below the lower limit of the normal range), but the statistical significance of the difference was not confirmed.

The activity of ALP alternately decreased and increased relative to the control group across all groups. Reductions below the lower reference limit were recorded in group II on day 35 (by 12.2%) and 49. Conversely, ALP exceeded the upper normal level in group IV on day 49 (by 16.9%).

Table 12. Hematological parameters in the serum of broiler chickens fed with different HPW contents

Day	Normal range*	Groups				SEM	*P*-value
		I	II	III	IV		
RBC, 10^6 µL^{-1}							
14th	1.4–2.4	1.98	2.20	2.24	1.88	0.148	0.2685
21st	2.1–3.2	2.47	2.42	2.30	2.17	0.153	0.5118
35th	1.6–3.2	2.33	2.22	2.32	2.32	0.146	0.9314
42nd	2.1–2.7	2.41	2.74	2.61	2.36	0.129	0.1503
49th	2.2–2.9	2.52	2.56	2.36	2.49	0.124	0.7077
WBC, 10^3 µL^{-1}							
14th	26–47	33.87	32.48	28.39	38.00	4.990	0.6014
21st	42–68	54.67	41.68	46.89	37.37	4.791	0.0914
35th	19–39	27.68	34.48	28.64	29.52	2.307	0.1896
42nd	24–66	38.77	43.30	45.52	43.17	4.749	0.8529
49th	34–66	45.65	44.48	42.03	55.46	1.294	0.1165

Abbreviations: RBC – red blood cells, WBC – white blood cells.
SEM = pooled standard error of the mean derived from ANOVA model (based on n = 7 replicate pens per treatment group).
*Normal range was defined as the range between the 2.5th and 97.5th percentiles of the distribution of values obtained from birds in the control group (group I).

Table 13. Serum enzyme profile in broiler chickens fed with different HPW contents

Day	Normal range*	Groups				SEM	*P*-value
		I	II	III	IV		
ALT, U L^{-1}							
14th	7.2–14.8	10.09	10.06	8.83	11.59	1.076	0.368
21st	6.0 –9.8	8.09	8.64	8.84	8.39	0.796	0.916
35th	8.1–11.9	9.67	11.03	12.10	10.34	1.256	0.572
42nd	4.6–8.1	5.86	9.00	9.54	8.17	0.999	0.072
49th	5.2–9.7	7.26	7.87	9.14	8.16	1.089	0.672
AST, U L^{-1}							
14th	177–214	199.31	207.66	191.06	186.94	7.559	0.246
21st	165–240	197.81	189.47	170.36	174.94	7.561	0.060
35th	250–586	376.37^{B}	470.64^{A}	342.49^{B}	186.33^{C}	50.181	0.005
42nd	224–537	348.44^{B}	490.84^{A}	385.97^{B}	224.04^{C}	37.745	0.001
49th	408–838	625.39	492.04	567.89	393.96	74.611	0.174
ALP, U L^{-1}							
14th	1000–4236	2712.57	2351.42	1950.85	1752.28	35.179	0.246
21st	385–2796	1088.28	1878.85	1216.00	1248.57	33.189	0.353
35th	302–597	417.71	265.14	363.42	396.57	7.619	0.512
42nd	212–559	351.42	471.42	283.42	452.57	8.762	0.403
49th	150–223	186.85^{A}	149.71^{A}	178.28^{A}	257.71^{B}	1.802	0.002

Abbreviations: ALT – alanine aminotransferase, AST – aspartate aminotransferase, ALP – alkaline phosphatase, HPW – high-protein wheat.
SEM = pooled standard error of the mean derived from ANOVA model (based on n = 7 replicate pens per treatment group).
$^{A–C}$ Means within a row with different superscripts differ ($P < 0.01$). *Normal range was defined as the range between the 2.5th and 97.5th percentiles of the distribution of values obtained from birds in the control group (group I).

Table 14. Protein and lipid metabolism in the serum of broiler chickens fed with different HPW contents

Day	Normal range*	Groups				SEM	*P*-value
		I	II	III	IV		
TP, g dL^{-1}							
14th	2.1–3.2	2.59^{ab}	2.81^{ab}	2.87^{a}	2.11^{b}	0.188	0.035
21st	2.1–3.1	2.73	2.67	2.63	2.33	0.110	0.073
35th	2.2–3.3	2.84	3.01	2.76	2.71	0.219	0.078
42nd	2.4–3.4	2.79	3.07	3.19	2.61	0.159	0.068
49th	2.9–3.7	3.12	3.34	3.10	3.17	0.131	0.617
Alb, g dL^{-1}							
14th	1.2–1.6	1.37^{A}	1.44^{A}	1.37^{A}	1.05^{B}	0.044	<0.001
21st	1.2–1.5	1.4^{a}	1.38^{ab}	1.38^{ab}	1.21^{b}	0.046	0.027
35th	1.4–1.7	1.58	1.54	1.62	1.56	0.318	0.834
42nd	1.6–2.2	1.81^{a}	1.82^{a}	1.82^{a}	1.57^{b}	0.328	0.034
49th	1.4–2.0	1.64	1.78	1.61	1.66	0.086	0.516
TCh, mg dL^{-1}							
14th	95–149	121.16	140.73	124.43	124.70	8.217	0.350
21st	104–124	115.59	119.23	121.46	120.02	5.283	0.875
35th	122–175	143.80	120.39	131.16	126.24	7.330	0.166
42nd	102–148	124.81^{A}	90.37^{B}	86.11^{B}	87.91^{B}	5.710	<0.001
49th	64–102	85.63	84.69	77.80	90.60	3.941	0.176

Abbreviations: TP – total protein, Alb – albumin, TCh – total cholesterol concentration, HPW – high-protein wheat.
Pooled SEM = pooled standard error of the mean derived from ANOVA model (based on n = 7 replicate pens per treatment group).
$^{a–b}$ Means within a row with different superscripts differ ($P < 0.05$). $^{A–C}$ Means within a row with different superscripts differ ($P < 0.01$).
*Normal range was defined as the range between the 2.5th and 97.5th percentiles of the distribution of values obtained from birds in the control group (group I).

Significant differences between group IV and three others were stated on day 49 ($P < 0.01$).

Fluctuations in plasma protein concentrations (TP as well as Alb) and Cr observed in the experimental chickens were minor. Although statistical analysis revealed significant differences in Alb concentrations between groups, the variations were minimal. The slight decreases below the lower normal limit were observed in group IV on day 14 (by 12.5%) and 42 (by 1.9%). Cr exceeded the upper normal level in all groups on day 35 (maximum by 23.7% in group III). The observed differences were minor, but they were statistically significant ($P < 0.05$). Small decreases below the normal level were noted on day 21 in groups III and IV, by 4.7% and 9.7%, respectively.

Dietary HPW content did not significantly affect TCh or *P* concentrations. Although statistically significant ($P < 0.01$) small decreases of TCh, relative to both group I and the lower limit of the normal range were observed in all experimental groups (groups II, III, and IV) on day 42, with the greatest decrease (by approximately 15.6%) noted in group III. TCh lowered below the normal level (approximately 1.3%) was also in group II on day 35. Lowered *P* was observed in all groups on day 14 and in group IV (by approximately 23% below normal level) on day 42.

4. Discussion

Previous studies have demonstrated that the complete replacement of genetically modified SBM in monogastric animal diets remains challenging (Soisontes et al., 2024). One of the main limitations of alternative protein sources is the presence of anti-nutritional factors, which may impair nutrient utilization and animal performance. Nevertheless, these constraints can be partially or fully mitigated through appropriate processing methods or by optimizing the inclusion levels of such feed ingredients (Marchal et al., 2024). Another strategy to reduce SBM use involves lowering dietary CP levels by approximately

Table 15. Renal function and mineral status in the serum of broiler chickens fed with different HPW contents

Day	Normal range*	Groups				SEM	*P*-value
		I	II	III	IV		
	Cr, mg dL^{-1}						
14th	0.3–0.3	0.301	0.300	0.300	0.300	0.001	0.998
21st	0.3–0.4	0.314	0.343	0.286	0.271	0.020	0.087
35th	0.2–0.3	0.286^{b}	0.329^{ab}	0.371^{a}	0.314^{ab}	0.020	0.039
42nd	0.3–0.4	0.314	0.300	0.300	0.300	0.007	0.410
49th	0.3–0.4	0.314	0.314	0.314	0.314	0.014	0.998
	P, mg dL^{-1}						
14th	6.0–37.0	15.476	11.011	12.536	12.304	3.268	0.802
21st	6.3–18.0	8.511	8.511	9.126	8.725	0.772	0.934
35th	7.4–12.7	9.246	9.246	10.690	11.927	1.337	0.438
42nd	7.1–10.6	9.169	9.169	8.184	5.496	1.194	0.125
49th	6.6–11.6	8.310	8.310	7.519	8.006	0.622	0.782

Abbreviations: Cr – creatinine, *P* – phosphorus, HPW – high-protein wheat.
SEM = pooled standard error of the mean derived from ANOVA model (based on $n = 7$ replicate pens per treatment group).
$^{a–b}$ Means within a row with different superscripts differ ($P < 0.05$). *Normal range was defined as the range between the 2.5th and 97.5th percentiles of the distribution of values obtained from birds in the control group (group I).

2–3 percentage points relative to standard nutritional recommendations. This approach is feasible through supplementation with crystalline AAs, which enhances the BV of dietary protein and supports efficient protein synthesis in broilers (Maynard et al., 2022).

4.1 Production performance

The progressive reduction in bird numbers per pen during the experiment may have influenced FI and contributed to increased variability in performance parameters, particularly during the final phase. Previous studies have shown that a reduction in stocking density below certain thresholds can affect FI and growth performance. Moreover, it has been reported that low stocking density can increase the coefficient of variation in BW (Feddes et al., 2002). While this reduction was a necessary consequence of the longitudinal sampling design, it should be considered when interpreting the finisher phase data.

In the present study, high inclusion levels of HPW, particularly above 77%, were associated with reduced BW. The pronounced reduction in BW observed in group IV (–42% vs. group I at day 49) appears to be driven primarily by markedly reduced FI, which directly limited the energy and amino acid supply necessary for growth. This is supported by the substantially lower FI recorded in this group, suggesting that reduced nutrient intake, rather than the diet composition *per se*, was the primary constraint on performance. A strong relationship between FI and growth rate in broilers has been consistently demonstrated in previous studies (Selle et al., 2023). In addition, several secondary mechanisms may have contributed to this growth depression. High inclusion levels of wheat are associated with increased NSP content, which may elevate digesta viscosity and impair nutrient digestibility (Selle et al., 2023). Although xylanase was included in the present study, its efficacy depends on the enzyme dose, substrate characteristics, and gut conditions. Consequently, it may not have been sufficient to fully counteract NSP-related effects at such extreme wheat inclusion levels (84%). Therefore, the growth failure in group IV is best characterized as a multi-factorial response, in which reduced FI acted as the primary driver, while NSP-related effects on digestibility likely contributed additively. This interpretation aligns with previous reports, indicating that excessive wheat inclusion, particularly under reduced CP conditions, can impair performance through the combined effects of diminished intake, impaired digestibility, and reduced metabolic efficiency (Choct et al., 2004; Selle et al., 2023). Comparable results were reported by Steenfeldt (2001), who observed decreased BW in broilers fed diets containing 81.5% wheat derived from 16 cultivars (112–127 $g \cdot kg^{-1}$ CP), compared with diets containing 65%

wheat. Choct et al. (2004) reported improvements in daily BWG, FCR, and excreta moisture content in broilers fed xylanase-supplemented wheat-based diets under low-energy conditions, suggesting that enzyme supplementation may partially alleviate the negative effects of high wheat inclusion. Furthermore, it has also been suggested that higher xylanase inclusion rates, the incorporation of 1–3% insoluble fibre, or the use of coarser wheat particle size may further mitigate the adverse effects of arabinoxylans on gut function (Hikawczuk et al., 2023; Naeem et al., 2024).

The absence of significant differences in BW between group I (control) and group II during both the starter (71.1% HPW) and grower (77.8% HPW) phases, combined with the relatively high CP content of the HPW used (163 g·kg^{-1}), indicates that partial replacement of SBM with HPW is feasible during early rearing. The lack of significant differences in FCR among groups during the first week of life is likely attributable to residual yolk sac reserves providing a buffer for nutritional requirements.

Biesek et al. (2022) demonstrated that partial substitution of ground wheat with whole wheat grain (10% of the diet) improved BW and FI without affecting FCR. Similarly, Yin et al. (2020) observed no significant differences in BW and FI between broilers fed high CP (215 g·kg^{-1}) and low-CP (165 g·kg^{-1}) wheat-based diets, although FCR was slightly higher in the low-CP group (1.58 vs. 1.49 kg·kg^{-1}). Interestingly, mortality was numerically lower in birds fed whole wheat, without detrimental effects on performance.

Reducing CP levels in wheat-based broiler diets remains a significant challenge, as it is frequently associated with impaired growth performance, characterized by reduced BWG and increased FCR (Selle et al., 2023). In the present study, feed efficiency during later rearing phases was most favourable in groups I and II, whereas higher HPW inclusion levels (groups III and IV) were associated with increased FI per kilogram of BWG. Similar findings were reported by Wang et al. (2024), who observed increased FI and FCR when wheat inclusion reached 55.77% during the grower phase and 62.38% during the finisher phase, despite enzyme supplementation. Chrystal et al. (2021) reported that reducing dietary CP to 193 g·kg^{-1} in wheat-based diets (63.7% wheat inclusion) between days 7–35 resulted in only a 0.42% reduction in daily BWG and a 3.9% increase in FCR compared with maize-based diets. Likewise, Greenhalgh et al. (2022) reported a 3.39% reduction in BWG and a 3.47% increase in FCR when dietary CP was reduced to 180 g·kg^{-1} in wheat-based diets during days 21–35.

4.2 Rearing efficiency indicators

4.2.1 Protein indicators

The reduction in CPI observed during the first 2 weeks of rearing in the present study may indicate limited protein availability for optimal protein synthesis and growth at higher HPW inclusion levels. Cheng et al. (2023), comparing alternative protein sources with SBM, reported increased CPI in non-SBM formulations but found no significant differences in the PER when diets were balanced with crystalline amino acids to match SBM profiles. These findings emphasize the importance of precise amino acid balancing when SBM is partially or fully replaced to ensure that the lower CP levels do not become the limiting factor for muscle development.

4.2.2 Feeding cost and EPEF

The EPEF values calculated in the present study confirmed the absence of significant differences between groups I and II throughout the rearing period. Minor deviations were observed only during the first week of the finisher phase (up to day 35), which were not maintained in later stages (days 42 and 49). In contrast, significantly lower EPEF values were recorded in groups III and IV, reflecting the poor growth performance and feed efficiency noted earlier.

Kiczorowska et al. (2015) reported EPEF values ranging from 233 in broilers fed diets containing more than 47% irradiated pea seeds to 337 in the control group, with a profitability threshold in Poland defined at EPEF = 259. In the present study, all EPEF values in group IV fell below this profitability threshold, rendering high HPW inclusion economically unviable. The highest profitability was observed on day 42 in group I and on day 49 in group II. Similarly, Biesek et al. (2022) reported improved EPEF values in 42-day-old broilers fed wheat-based diets containing 10% whole wheat, suggesting that the physical form and inclusion level of wheat are critical determinants of economic outcome.

4.2.3 Blood parameters

The analysis of haematological and biochemical parameters confirmed that the inclusion of HPW, despite the intentional reduction in CP levels, maintained homeostatic balance and did not adversely affect the metabolic health of the broilers. These results suggest that HPW-based diets were physiologically well tolerated during the rapid

growth phase, with key blood markers remaining within established normal ranges.

Alterations in WBC, involved in immunological defence and regulatory pathways, only marginally exceed established age-specific reference intervals. In the absence of concomitant changes in RBC, it may be reasonably concluded that the dietary modification exerted only a limited effect on circulating blood cell populations. The observed systemic response was therefore most likely adaptive rather than indicative of relevant stress or inflammatory activations and suggests the absence of additional exposure to deleterious environmental or management-related factors.

Plasma TP and Alb concentrations reflect digestive efficiency, amino acid absorption, and subsequent utilization to meet the high energetic demands of growth (Macelline et al., 2021). These levels also depend on hepatic synthetic capacity and the incorporation of amino acids into muscle tissue (Rajman et al., 2006). HPW supplementation did not significantly alter TP or Alb concentration, aligning with reports by Lee et al. (2010), El-Katcha et al. (2014), and Seyedoshohadaei et al. (2024). These results indicate that the modified diet did not substantially impair overall protein metabolism and protein synthesis in the liver. However, due to the lack of data regarding gastrointestinal morphology and digestive enzyme activity, it is difficult to reliably assess digestive efficiency as well as amino acid and protein absorption.

Fluctuations in the activities of ALT and AST suggest that HPW may influence the liver status (El-Katcha et al., 2014); however, the stability of TP and Alb indicates that hepatic protein synthetic capacity remained preserved. Additionally, these enzymatic patterns may be age dependent. While some studies show no age correlation for ALT, AST typically increases with age (Rajman et al., 2006; Senanayake et al., 2015). The activity of alkaline phosphatase showed slight variability and reflects presumably the natural age-related decline observed in poultry (Rajman et al., 2006).

Creatinine is a limited diagnostic marker in birds because they primarily excrete uric acid as the end-product of nitrogen metabolism. Increase in Cr is interpreted as an indicator of muscle damage or renal dysfunction (Macelline et al., 2021; Rajman et al., 2006). In this study, Cr concentrations, although statistically different, were relatively slight, suggesting the absence of adverse effects on muscles and renal function, maintenance of systemic protein and amino acid metabolism, and adequacy of the dietary amino acid profile (Seyedoshohadaei et al., 2024). The concurrent decrease in AST further suggests a lack of muscle membrane disruption, as elevated AST is often linked to muscle injury (Rajman et al., 2006).

Serum *P* concentrations remained stable throughout the experiment, suggesting that wheat-derived *P* effectively met nutritional requirements without increasing environmental load. A transient decrease in *P* at 14 days may be attributed to temporary shifts in intestinal absorption during early development. Regarding lipid metabolism, HPW supplementation did not exert a sustained effect on TCh. A minor, transient decrease in TCh below reference limits at 42 days normalized quickly, indicating a marginal impact on systemic lipid metabolism (Zarghi & Golian, 2009; Seyedoshohadaei et al., 2024). The lack of significant changes in TCh and TP further supports the conclusion that HPW did not induce a systemic stress response, which typically elevates these markers (Rajman et al., 2006).

5. Conclusion

This study demonstrates that HPW can effectively replace SBM protein when included at moderate levels (approximately 71–77% of the diet, as in group II) and supplemented with appropriate exogenous enzymes. Under these conditions, growth performance and EPEF values remained comparable to those of the control group. In contrast, higher HPW inclusion levels (groups III and IV) resulted in significantly impaired growth and a substantial reduction in production efficiency.

Although feed costs decreased progressively with increasing HPW inclusion, only group II dietary protocol achieved a meaningful reduction in total feeding costs (approximately 2.8–3.1%) while maintaining production standards. These findings indicate that moderate HPW inclusion represents a viable and economically sound strategy for partial SBM replacement in broiler diets.

Further research is warranted to define the safe upper limits of HPW inclusion across different feeding phases and to assess the potential benefits of partially replacing ground wheat with whole grain, particularly during the grower and finisher periods. Importantly, reducing reliance on imported protein sources through the use of locally produced HPW may potentially contribute to improved environmental sustainability by lowering the estimated carbon footprint of poultry feed formulations, primarily by reducing transport-related emissions.

Acknowledgments

The authors are indebted to Saatbau Poland Sp. z o.o. for kindly providing the HPW grains used in this study. The

authors are also indebted to Neorol Sp z o.o. for preparing feed mixtures used in the presented study.

Funding information

This research was supported by the Wroclaw University of Environmental and Life Sciences (Poland) as part of the Ph.D. research program “MISTRZ”, No N090/0011/22. The APC is co-financed by Wrocław University of Environmental and Life Sciences and Saatbau Poland Sp. z o.o.

Author contributions

Conceptualization, A.S.-T., A.P.-K., and A.Rz.; data curation, A.S.-T., A.P.-K., T.H., and A.Rz.; formal analysis, A.S.-T., A.P.-K., T.H., and A.Rz.; funding acquisition, A.S.-T.; investigation, A.S.-T., A.P.-K., A.L., A.J.-R., and A.Rz.; methodology, A.S.-T., A.P.-K., and A.Rz.; project administration, A.S.-T.; software, A.S.-T., A.P.-K., T.H., and A.Rz.; supervision, A.S.-T. and A.Rz.; validation, Z.K. and B.F.; visualization, T.H.; writing – original draft, A.S.-T., A.P.-K., and A.Rz.; writing – review and editing, A.S.-T., A.P.-K., T.H., A.L., A.J.-R., Z.K., B.F., and A.Rz.

Conflict of interest statement

The authors declared no conflicts of interest.

References

Babatunde, O. O., Park, C. S., & Adeola, O. (2021). Nutritional potentials of atypical feed ingredients for broiler chickens and pigs. *Animals*, *11*, 1196. https://doi.org/10.3390/ani11051196

Biesek, J., Banaszak, M., Wlaźlak, S., & Adamski, M. (2022). The effect of partial replacement of milled finisher feed with wheat grains on the production efficiency and meat quality in broiler chicken. *Poultry Science*, *101*, 101817. https://doi.org/10.1016/j.psj.2022.101817

Cheng, V., Shoveller, A. K., Huber, L. A., & Kiarie, E. G. (2023). Comparative protein quality in black fly larvae meal vs. soybean meal and fish meal using classical protein efficiency ratio (PER) chick growth assay model. *Poultry Science*, *102*, 102255. https://doi.org/10.1016/j.psj.2022.102255

Choct, M., Kocher, A., Waters, D. L. E., Petterson, D., & Ross, G. (2004). A comparison of three xylanases on the nutritive value of two wheats for broiler chickens. *British Journal of Nutrition*, *92*(1), 53–61. https://doi.org/10.1079/BJN20041166

Chrystal, P. V., Greenhalgh, S., McInerney, B. V., McQuade, L. R., Akter, Y., De Paula Dorigam, J. C., Selle, P. H., & Liu, S. Y. (2021). Maize-based diets are more conducive to crude protein reductions than wheat-based diets for broiler chickens. *Animal Feed Science and Technology*, *275*, 114867. https://doi.org/10.1016/j.anifeedsci.2021.114867

Cordero, P., Ramírez-Toloza, G., Dufflocq, P., Herrera-Alcaíno, S., & Guzmán-Pino, S. A. (2025). Reduced dietary protein and essential amino acids impair growth performance and increase lysine sensitivity in broiler chickens. *Animals*, *15*(7), 1027. https://doi.org/10.3390/ani15071027

Di Mauro, G., Schwalbert, R., Alvarez Prado, S., Saks, M.G., Ramirez, H., Costanzi, J., & Parra, G. (2023). Exploring practical nutrition options for maximizing seed yield and protein concentration in soybean. *European Journal of Agronomy*, *146*, 126794. https://doi.org/10.1016/j.eja.2023.126794

Directive 2010/63/EU of 22 September 2010 on the protection of animals used for scientific purposes. Official Journal of the European Union, *L276*, 33–79.

Directive 2015/412/EU of 11 March 2015 amending Directive 2001/18/EC as regards the possibility for the Member States to restrict or prohibit the cultivation of genetically modified organisms (GMOs) in their territory. Official Journal of the European Union, L68: 1–8.

El-Katcha, M. I., Soltan, M. A., El-Kaney, H. F., & Karwarie, E. S. (2014). Growth performance, blood parameters, immune response and carcass traits of broiler chicks fed on graded levels of wheat instead of corn without or with enzyme supplementation. *Alexandria Journal of Veterinary Sciences*, *40*(1), 95. https://www.researchgate.net/publication/312163059

Feddes, J., Emmanuel, E., & Zuidhoft, M. (2002). Broiler performance, body weight variance, feed and water intake, and carcass quality at different stocking densities. *Poultry Science*, *81*(6), 774–779. https://doi.org/10.1093/ps/81.6.774

Garcia Neto, M., Pesti, G. M., & Bakalli, R. I. (2000). Influence of dietary protein level on the broiler chicken’s response to methionine and betaine supplements. *Poultry Science*, *79*(10), 1478–1484. https://doi.org/10.1093/ps/79.10.1478

Greenhalgh, S., Lemme, A., Dorigam, J. C. D. P., Chrystal, P. V., Macelline, S. P., Liu, S. Y., & Selle, P. H. (2022). Dietary crude protein concentrations, feed grains, and whey protein interactively influence apparent digestibility coefficients of amino acids, protein, starch, and performance of broiler chickens. *Poultry Science*, *101*(11), 102131. https://doi.org/10.1016/j.psj.2022.102131

Hikawczuk, T., Szuba-Trznadel, A., Wróblewska, P., & Wiliczkiewicz, A. (2023). Oat hull as a source of lignin-cellulose complex in diets containing wheat or barley and its effect on performance and morphometric measurements of gastrointestinal tract in broiler chickens. *Agriculture*, *13*(4), 896. https://doi.org/10.3390/agriculture13040896

Kiczorowska, B., Samolińska, W., Grela, E. R., & Andrejko, D. (2015). Effect of infrared-irradiated pea seeds in mixtures for broilers on the health status and selected performance indicators of the birds (in Polish). *Medycyna Weterynaryjna*, *71*, 583–588. http://www.medycynawet.edu.pl/archives/summary/455-summary-2015/358-summary-2015-09/5365-summary-med-weter-71-9-583-588-2015

Lee, S. R., Khan, D. R., Park, J. Y., Kaczmarek, S., & Choi, E. J. (2024). Novel thermal stability enhanced xylanase improves the performance and digestibility parameters in broilers. *Poultry Science*, *103*(12), 104447. https://doi.org/10.1016/j.psj.2024.104447

Lee, S. Y., Kim, J. S., Kim, J. M., An, B. K., & Kang, C. W. (2010). Effects of multiple enzyme (Rovabio® max) containing carbohydrolases and phytase on growth performance and intestinal viscosity in broiler chicks fed corn-wheat-soybean meal based diets. *Asian-Australasian Journal of Animal Sciences*, *23*(9), 1198–1204. https://doi.org/10.5713/ajas.2010.90592

Lestingi, A. (2024). Alternative and sustainable protein sources in pig diet: A review. *Animals*, *14*(2), 310. https://doi.org/10.3390/ani14020310

Liu, C., Wang, Y., Tang, Q., Li, N., Wang, Z., Tan, T., & Wang, X. (2025). Analysis of international coexistence management of genetically modified and non-genetically modified crops. *Plants*, *14*(6), 895. https://doi.org/10.3390/plants14060895

Macelline, S. P., Chrystal, P. V., Liu, S. Y., & Selle, P. H. (2021). The dynamic conversion of dietary protein and amino acids into chicken-meat protein. *Animals*, *11*(8), 2288. https://doi.org/10.3390/ani11082288

Marchal, L., Bello, A., Archer, G., Sobotik, E. B., & Dersjant-Li, Y. (2024). Total replacement of soybean meal with alternative plant-based ingredients and a combination of feed additives in broiler diets from 1 day of age during the whole growing period. *Poultry Science*, *103*(7), 103854. https://doi.org/10.1016/j.psj.2024.103854

Maynard, C. W., Kidd, M. T., Chrystal, P. V., McQuade, L. R., McInerney, B. V., Selle, P. H., & Liu, S. Y. (2022). Assessment of limiting dietary amino acids in broiler chickens offered reduced crude protein diets. *Animal Nutrition*, *10*, 1–11. https://doi.org/10.1016/j.aninu.2021.11.010

Naeem, M., Burton, E. J., Scholey, D. V., Alkhtib, A., & Broadberry, S. (2024). Use of wheat dilution to improve digestive function in broilers: Application in low protein diets. *British Poultry Science*, *65*(2), 144–153. https://doi.org/10.1080/00071668.2023.2291487

Pirgozliev, V. R., Hammandy, M. H., Mansbridge, S. C., Whiting, I. M., & Rose, S. P. (2024). Efficiency of utilization of metabolizable energy for carcass energy retention in broiler chickens fed maize, wheat or a mixture. *Poultry*, *3*(2), 85–94. https://doi.org/10.3390/poultry3020008

Pope, M., Borg, B., Boyd, R. D., Holzgraefe, D., Rush, C., & Sifri, M. (2023). Quantifying the value of soybean meal in poultry and swine diets. *Journal of Applied Poultry Research*, *32*(2), 100337. https://doi.org/10.1016/j.japr.2023.100337

Rajman, M., Juráni, M., Lamošová, D., Máčajová, M., Sedlačková, M., Košťál, Ľ., Ježová, D., & Výboh, P. (2006). The effects of feed restriction on plasma biochemistry in growing meat type chickens (Gallus gallus). *Comparative Biochemistry and Physiology Part A: Molecular & Integrative Physiology*, *145*(3), 363–371. https://doi.org/10.1016/j.cbpa.2006.07.004

Ross Broiler Management Handbook. (2018). Provision of Feed and Water. https://aviagen.com/assets/Tech_Center/Ross_Broiler/Ross-BroilerHandbook2018-EN.pdf.

Saleh, A. A., Amber, K. A., Soliman, M. M., Soliman, M. Y., Morsy, W. A., Shukry, M., & Alzawqari, M. H. (2021). Effect of low protein diets with amino acids supplementation on growth performance, carcass traits, blood parameters and muscle amino acids profile in broiler chickens under high ambient temperature. *Agriculture*, *11*(2), 185. https://doi.org/10.3390/agriculture11020185

Selle, P. H., Macelline, S. P., Chrystal, P. V., & Liu, S. Y. (2023). The challenge to reduce crude protein contents of wheat-based broiler diets. *Animal Production Science*, *63*(18), 1899–1910. https://doi.org/10.1071/AN22419

Senanayake, S. S. H. M. M. L., Ranasinghe, J. G. S., Waduge, R., Nizanantha, K., & Alexander, P. A. B. D. (2015). Changes in the serum enzyme levels and liver

lesions of broiler birds reared under different management conditions. *Tropical Agricultural Research*, *26*(4), 584. https://doi.org/10.4038/tar.v26i4.8121

Seyedoshohadaei, S., Torki, M., Yaghoubfar, A., & Abdolmohammadi, A. (2024). Interactions of wheat cultivars and supplemental enzyme in diet of broiler chickens on growth performance, carcass characteristics, intestinal morphometric features, and blood parameters. *Journal of Agriculture and Food Research*, *18*, 101291. https://doi.org/10.1016/j.jafr.2024.101291

Shewry, P. (2023). Wheat grain proteins: Past, present, and future. *Cereal Chemistry*, *100*(1), 9–22. https://doi.org/10.1002/cche.10585

Sieradzki, Z., Mazur, M., Król, B., & Kwiatek, K. (2021). Prevalence of genetically modified soybean in animal feedingstuffs in Poland. *Journal of Veterinary Research*, *65*(1), 93–99. https://doi.org/10.2478/jvetres-2021-0012

Smulikowska, S., & Rutkowski, A. (2018). Polish Requirements of Poultry Nutrition, 5th ed. (in Polish). The Kielanowski Institute of Animal Physiology and Nutrition, Polish Academy of Sciences, Jabłonna, Poland.

Soisontes S., Freund F., & Laquai V. (2024). The future of protein feed: a case study of sustainable substitutes in the German livestock industry. *Environment, Development and Sustainability*, *26*(10), 25199–25226. https://doi.org/10.1007/s10668-023-03676-1

Steenfeldt, S. (2001). The dietary effect of different wheat cultivars for broiler chickens. *British Poultry Science*, *42*(5), 595–609. https://doi.org/10.1080/00071660120088416

Sułek, A., Cacak-Pietrzak, G., Różewicz, M., Nieróbca, A., Grabiński, J., Studnicki, M., Sujka, K., & Dziki, D. (2023). Effect of production technology intensity on the grain yield, protein content and amino acid profile in common and durum wheat grain. *Plants*, *12*(2), 364. https://doi.org/10.3390/plants12020364

Szuba-Trznadel, A., Gałka, B., Kamińska, J., Jama-Rodzeńska, A., Król, Z., Jarki, D., & Fuchs, B. (2024). Diversity of chemical composition and nutritional value in grain from selected winter wheat cultivars grown in south-western Poland. *Scientific Reports*, *14*(1), 2630. https://doi.org/10.1038/s41598-024-53094-0

Thrall, M. A., Baker, D. C., Campell, T. W., DeNicola, D., Fettman, M. J., Duane Lassen, E., Rebar, A., & Weiser, G. (2006). *Veterinary hematology and clinical chemistry* (p. 231). Blackwell Publishing.

Wang, X., Li, D., Xu, Y., Ding, X., Liang, S., Xie, L., Wang, Y., & Zhan, X. (2024). Xylanase supplement enhances the growth performance of broiler by modulating serum metabolism, intestinal health, short-chain fatty acid composition, and microbiota. *Animals*, *14*(8), 1182. https://doi.org/10.3390/ani14081182

Yin, D., Chrystal, P. V., Moss, A. F., Yun Liu, S., Yuan, J., & Selle, P. H. (2020). Effects of reducing dietary crude protein and whole grain feeding on performance and amino acid metabolism in broiler chickens offered wheat-based diets. *Animal Feed Science and Technology*, *260*, 114386. https://doi.org/10.1016/j.anifeedsci.2019.114386

Zarghi H., & Golian A. (2009). Effect of triticale replacement and enzyme supplementation on performance and blood chemistry of broiler chickens. *Journal of Animal and Veterinary Advances*, *8*(7), 1316–1321. https://www.researchgate.net/publication/202542972