



EFFECT OF FOUR FATTENING SYSTEMS ON QUALITY OF WHITE KOŁUDA® GOOSE PRODUCTS*

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Abstract

This study explored the impact of whole grain of oat, barley, wheat, and corn used in the final stage of fattening (14–16 week of age) on the properties of meat and liver of White Kołuda® geese, and variations between the examined tissues. Two identical experiments were conducted to enhance the credibility of the results. Goose livers showed significantly higher protein content than leg muscles and fattening with oats increased protein content in breasts and livers. Each fattening method resulted in the sum of essential amino acids (ΣEAA) exceeding the WHO standard. Barley- and oat-based fattening yielded the most favorable results in terms of protein quality, often resulting in higher essential amino acid index (EAAI) values (161–179) compared to the other two groups (159–166). The White Kołuda® goose livers boasted elevated levels of most elements and demonstrated significant richness in both iron (Fe) (337 mg/kg) and copper (Cu) (304 mg/kg), substantially surpassing daily requirements in a 100 g serving. The products from the oat-fed and barley-fed groups also exhibited elevated levels of several elements, while corn-based products typically displayed some of the lowest levels of most elements. The breast muscles displayed a darker color with a redder hue and less yellowness compared to the legs. Additionally, the leg muscles exhibited the darkest shade when fattened with corn and the yellowest hue when fattened with oats.

Key words: White Kołuda® goose, oat fattening, meat, liver, amino acids, minerals

The National Research Institute of Animal Production in Poland is the owner of the protection rights and the word and graphic trademark registered at the Patent Office of the Republic of Poland for the White Kołuda® geese (Badowski, 2015). The Institute has also developed a goose breeding and feeding system known as “oat fattening”. The White Kołuda® oat-fed goose was officially added to the List of Traditional Products by the Ministry of Agriculture and Rural Development of the Republic of Poland on 10 August 2023 (Ministry of Agriculture and Rural Development, 2023). This method involves providing geese with unlimited access to whole oat grains for 3 weeks before slaughter (Bielińska et al., 2015). This approach results in an increase in muscle mass and fat content while also enhancing the appearance, carcass quality, and meat palatability, as reported by Haraf (2014). However, there are cases in the market where other methods of fattening geese are employed instead of oat fattening but the impact of this approach on the final product remains unknown. To the best of our knowledge, there is a lack of comprehensive research dedicated to the use of four popular types of grains (oats, wheat, barley, and corn) in the feeding of White Kołuda® geese

during the final 3 weeks before slaughter. Therefore, the research presents the effects of using grains other than oats in the final phase of feeding geese on the quality of protein, mineral composition, and some other chemical and technological properties of the meat and liver of White Kołuda® geese.

One of the fundamental parameters determining the quality of meat is the protein content and amino acid (AA) composition. To assess its nutritional value, the content of essential amino acids (EAA) and their mutual proportions in the meat are essential (Okruszek et al., 2013). The evaluation of the nutritional value of protein was first proposed by Block and Mitchell (1946). It involved calculating the amino acid score (AAS), which is the ratio of the content of individual essential amino acids in the evaluated protein to that in a complete protein adopted as a standard (Zwierko-Pastuszevska, 2016). This method has undergone numerous modifications, with the most significant ones related to changes in the selection of reference protein. In 1959, the expression of protein quality was also proposed by determining the geometric mean for all essential amino acids, known as the essential amino acid index (EAAI) (Oser, 1959). The amino acid

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composition in meat depends on many factors, including the genotype of animals (Dalle Zotte et al., 2020; Haraf et al., 2018, 2021) the type of tissue being studied (Boz et al., 2019; Gumulka and Połtowicz, 2020; Okruszek et al., 2013), age, as well as the type and manner of feeding (Wu et al., 2014). Foie gras, a fatty and rich-tasting goose or duck liver, is a traditional delicacy in Europe, primarily in France. Foie gras has been recognized as an integral part of French gastronomy and cultural heritage (Nemati et al., 2020). However, the production of foie gras has faced criticism due to animal welfare concerns, leading to its prohibition in some countries, where such a tradition has never existed before (Guèmenè and Guy, 2004; Kozák, 2021). In Poland, there has been no tradition of fattening geese specifically for the production of fatty livers. The preferred systems are broiler goose production (up to 10–12 weeks of age) and oat fattening, which can be extended to 17 or occasionally 24 weeks of rearing, with both systems involving *ad libitum* feeding (Haraf, 2014). Nevertheless, in Poland, non-fatty (not too greasy) goose livers remain a choice among consumers. Despite this, the quality of protein in this part of the goose carcass has long been overlooked in research, therefore we also took this aspect into account in our own research.

The proper functioning of any living organism also requires the supply of micro- and macronutrients in appropriate quantities. There are still relatively few publications concerning the mineral content in the meat of White Kołuda® geese. Even fewer studies are available that present the mineral content in the livers of geese raised in *ad libitum* feeding systems. As noted by Geldenhuys et al. (2015), various factors, including genetic, physiological, and environmental factors, can influence the mineral composition of meat. An important environmental factor is the diet of the animals. Modern farming relies on feeds supplemented with various additives as sources of different minerals such as calcium (Ca), sodium (Na), iron (Fe), manganese (Mn), copper (Cu), zinc (Zn), iodine (I), cobalt (Co) and selenium (Se) (Goluch et al., 2021). Agricultural fertilizers used in farming also play a significant role, potentially providing nitrogen (N), phosphorus (P), potassium (K), and sometimes other elements like Cu, Fe, Mn, boron (B) (Goluch et al., 2021). Additionally, green forages are another source of minerals. The full grains of cereals fed during the final fattening phase also contribute to the mineral supply. Moreover, we must not overlook the water provided to geese during the rearing period, as it also contains micro- and macroelements (Goluch and Haraf, 2018). All these factors can significantly modify the mineral composition of the meat. Therefore, available publications show a considerable variation in the content of individual minerals in goose meat. Of particular note are the high mineral contents in raw meat from White Kołuda® goose breasts, as presented by Goluch et al. (2021).

This study aimed to explore the impact of whole oat (control group), wheat, barley, and corn grains used in the final stage of fattening on the physicochemical properties of the breast and thigh meat and liver of White Kołuda®

geese. Two identical experiments were conducted in consecutive years to enhance the credibility of the research results, confirming their reproducibility, a factor that is recently increasingly emphasized (Freedman et al., 2015).

Material and methods

Animal experiment

The research included two identical experiments: Experiment I (1st year) and Experiment II (2nd year). The experimental material consisted of a total of 64 male White Kołuda® geese of genotype W33, raised for 16 weeks according to the fattening technology system used at the Experimental Station in Kołuda Wielka of the National Research Institute of Animal Production (Bielińska et al., 2015). The birds were fed in the same way until they were 13 weeks old. During this time, they were provided with complete feed mixtures KB-1 (starter), KB-2 (grower), KB-3 (finisher), green fodder, and had limited access to pasture (Table 1). At the beginning of the 14th week of life, 8 male geese were randomly assigned each year to four dietary groups, resulting in a total of 32 male geese per year, of which the first group was fattened with whole oats, the second group with whole wheat, the third group with whole barley, and the fourth group with whole corn grain.

The *ad libitum* fattening period lasted 21 days in total. The entire rearing period lasted 16 weeks. The same cereal varieties were used in both experiments. After breeding, the birds were slaughtered by decapitation. Feeding experiments on animals and slaughter analysis were conducted at the Experimental Station of the National Research Institute of Animal Production in Kołuda Wielka. The analyses were performed at the Central Laboratory of the National Research Institute of Animal Production in Aleksandrowice, which has implemented a quality system in accordance with the ISO/IEC 17025:2017. The material for analysis consisted of the breast (pectoralis major and pectoralis minor muscle) and thigh muscle (leg), both without skin, and the liver.

Analysis of feed mixtures

The determination of dry matter (DM), crude protein (CP), crude fiber (CF), crude fat (CFat), ash, and amino acids was performed in accordance with Commission Regulation (EC) No 152/2009. To calculate the total protein from nitrogen content, the coefficient of 6.25 was used. Macro- and microelements were determined by the method using atomic absorption spectrometry (ISO 6869:2000). The phosphorus content was determined spectrophotometrically by the molybdenum blue method, based on ISO 10540-1:2003. The measurement was performed at a wavelength of 700 nm using a Shimadzu UV-1202 spectrophotometer (Shimadzu, Japan). Starch and sucrose were determined by polarimetric and titrimetric methods, respectively (Commission Regulation (EC) No 152/2009). Table 1 presents the nutritional ingredients of the complete feed mixtures used in the experiments.

Table 1. Nutrient contents of feed

	Experiment I							Experiment II								
	starter (KB-1)	grower (KB-2)	finisher (KB-3)	green fodder	oat grain	wheat grain	barley grain	corn grain	starter (KB-1)	grower (KB-2)	finisher (KB-3)	green fodder	oat grain	wheat grain	barley grain	corn grain
Metabolizable energy (ME) (MJ/kg)	11.6	11.4	11.1	-	12.9	12.8	12.6	13.1	11.3	11.0	10.9	-	12.4	12.6	11.0	12.5
Dry matter (DM) (g/kg)	896	893	888	227	892	870	884	881	899	895	891	287	887	877	873	874
Crude protein (CP) (g/kg)	223	188	157	41.1	132	133	117	94.8	200	186	152	53.7	114	168	123	82.2
Crude fat (CFat) (g/kg)	27.3	25.6	22.6	6.39	27.5	12.8	14.6	46.9	29.8	31.8	28.7	9.91	40.7	13.8	14.6	40.1
Crude fiber (CF) (g/kg)	33.0	40.4	62.0	40.0	92.4	20.1	34.7	18.8	34.2	42.9	57.5	70.0	93.5	23.6	41.0	18.8
Ash (g/kg)	62.1	53.2	48.2	18.8	22.6	12.1	22.1	13.4	59.3	55.0	49.7	29.2	23.6	16.4	21.9	12.9
Starch (g/kg)	400	430	455	86.3	579	594	602	582	400	395	432	81.5	537	544	494	577
Total sugar content (expressed as sucrose) (g/kg)	39.5	32.4	25.5	11.0	20.7	27.2	22.4	22.2	37.0	35.4	23.7	14.6	23.0	33.7	27.0	19.9
Lysine (Lys) (g/kg)	11.8	8.26	5.99	1.15	4.56	10.9	8.15	9.47	11.1	8.39	5.68	1.41	5.02	8.80	6.72	8.65
Methionine (Met) (g/kg)	4.58	4.26	3.90	1.10	2.77	1.61	1.61	2.23	4.42	4.24	3.78	1.50	2.50	2.40	1.41	1.47
Methionine+Cystine (Met+Cys) (g/kg)	8.17	7.53	7.06	2.31	5.62	4.70	4.32	4.65	8.00	7.72	7.04	3.25	5.37	6.08	4.46	4.07
Tryptophan (Trp) (g/kg)	2.40	2.10	1.79	1.12	1.47	1.59	1.36	0.460	2.30	2.00	1.81	1.01	2.01	1.78	1.55	0.410
Threonine (Thr) (g/kg)	7.88	6.39	5.39	1.20	4.29	6.37	5.47	4.73	7.64	6.66	5.42	1.77	4.51	6.33	6.08	4.40
Minerals																
total phosphorus (P) (g/kg)	7.20	6.72	6.79	0.850	3.49	3.73	3.18	2.77	7.09	6.18	5.61	1.01	3.33	2.68	3.46	2.80
calcium (Ca) (g/kg)	13.5	9.89	7.27	1.74	0.806	0.345	0.448	0.049	13.9	9.57	5.72	1.48	0.708	0.259	0.397	0.028
magnesium (Mg) (g/kg)	2.14	2.19	2.59	1.42	1.19	0.911	1.13	0.861	2.10	2.16	2.47	2.08	1.20	0.872	1.12	0.812
sodium (Na) (g/kg)	0.895	1.13	1.30	0.680	0.0189	0.00327	0.0136	0.00129	1.12	1.24	0.927	0.518	0.0147	0.00438	0.0128	0.00308
potassium (K) (g/kg)	9.26	8.30	7.07	23.0	7.06	3.31	4.59	3.08	9.14	8.58	6.18	29.3	3.59	3.09	4.50	3.18
copper (Cu) (mg/kg)	22.4	24.1	23.1	6.31	2.71	2.07	4.67	1.17	34.2	25.7	28.3	6.51	2.42	2.38	4.58	1.15
manganese (Mn) (mg/kg)	140	106	99.7	40.1	41.9	21.3	9.42	2.20	138	105	73.2	44.0	44.1	20.9	9.60	2.17
iron (Fe) (mg/kg)	208	195	159	312	48.4	52.4	27.8	30.5	281	192	249	212	55.3	49.9	26.5	26.3
zinc (Zn) (mg/kg)	107	101	106	27.3	31.4	17.3	34.8	15.9	121	110	139	27.1	28.1	18.2	34.9	15.9

Analysis of meat and liver

Determination of amino acid content

The amino acid composition (excluding tryptophan) in meat and liver was analyzed by the standard AOAC procedure (AOAC Official Method 994.12). The analysis was conducted using an INGOS AAA400 amino acid analyzer (Ingos Corp., Prague, Czech Republic). To determine cysteine/cystine and methionine, samples were oxidized with an oxidizing mixture (hydrogen peroxide with formic acid), followed by acidic hydrolysis (hydrochloric acid). For the remaining amino acids, acid hydrolysis of unoxidized samples was performed. To determine the tryptophan content, the samples underwent alkaline hydrolysis using a saturated barium hydroxide solution, based on the AOAC Official Method 988.15.

Amino acid score (AAS)

An essential amino acid that is present in the smallest amount in the dietary protein compared to the reference protein is called a limiting amino acid. To determine which amino acid does not meet the body's needs, AAS was calculated based on the FAO formula (FAO/WHO/UNU, 2007) as the ratio of the amount of amino acid supplied by the test protein to the amount of amino acid in the human adult requirement pattern: isoleucine (Ile), 3.0; leucine (Leu), 6.1; lysine (Lys), 4.8; methionine+cystine (Met+Cys), 2.3; phenylalanine+tyrosine (Phe+Tyr), 4.1; threonine (Thr), 2.5; tryptophan (Trp), 0.66; valine (Val), 4.0 and histidine (His), 1.6 expressed in g/100g of protein (FAO, 2013) according to the following equation:

$$AAS = \frac{\text{g of AA in 100 g test protein}}{\text{g of AA in 100 g requirement pattern}} \times 100\%$$

Essential amino acid index (EAAI)

To describe protein quality, EAAI is used as the geometric mean of the ratio of the amounts of essential amino acids in a protein sample to their respective amounts in the protein pattern (Oser, 1959) according to the equation below:

$$EAAI = 100 \times \sqrt[n]{\frac{Lys_p}{Lys_s} \times \frac{Trp_p}{Trp_s} \times \dots \times \frac{Val_p}{Val_s}}$$

where the subscript *p* refers to the protein sample, *s* to the standard protein (protein pattern), and *n* to the number of amino acids (counting pairs of Met+Cys and Phe+Tyr as one).

Determination of protein content (CP)

The meat and liver samples were analyzed for total nitrogen (N) by the Kjeldahl procedure (ISO 5983-2:2009). The total nitrogen in feeds was determined by the procedure described in the Commission Regulation (EC) No 152/2009 using a KD-310 B2 KjeldROC Analyz-

er (OPSIS LiquidLINE, Furulund, Sweden). To calculate the total protein from nitrogen content, the coefficient of 6.25 was used.

Determination of ash content

For determination of ash content, the samples were incinerated at a temperature of 550 °C in a muffle furnace until the organic substances were completely burned and a constant mass was obtained (AOAC Official Method 920.153).

Meat color determination

The colorimetric parameters *L** (lightness), *a** (redness), *b** (yellowness) were determined using Chroma Meters CR-310 by Konica Minolta Sensing (Konica Minolta Healthcare Americas Inc., Wayne, NJ, USA). The device operated under the following parameters: calibration plate CR-A44; Case CR-A64*1; *Y_{x,y}* values 96.6, 0.3137, 0.3194, measuring area $\phi 50$ mm, degree of observer 2°, CIE illuminant: C. The measurements were performed 24 hours after slaughter on the smooth, tendon-free inner side of the muscles. Three readings per sample were taken and the average was recorded.

Determination of macro- and microelements

Macro- and microelements (except phosphorus) were determined by the atomic absorption spectrophotometric method (AOAC Official Method 965.09). Before analysis, samples of goose leg, breast and liver were freeze-dried. The content of P, Na, K and magnesium (Mg) in the meat and all elements in the liver were determined in a 0.5 g sample after wet digestion using a mixture of 7:1 v/v nitric acid and hydrogen peroxide in a microwave oven Ethos Plus (Milestone, Schio, Vicenza, Italy) according to Application Note HPR-FO-26 for lyophilized meat. The content of Ca, Cu, Mn, Fe and Zn in the meat was determined in 5 g samples mineralized in a muffle furnace (450 °C). These elements were analyzed using AAS Avanta Σ (GBC, Scientific Equipment, Keysborough, VIC, Australia). The phosphorus content in the meat and liver was determined spectrophotometrically using the molybdenum blue method, as outlined in ISO 10540-1:2003. The measurement was performed at a wavelength of 700 nm using a Shimadzu UV-1202 spectrophotometer (Shimadzu, Nakagyo-ku, Kyoto, Japan).

Statistics

The results were statistically analyzed using 2-way ANOVA to explore variations between fattening systems (type of grain $\times$ year, Tables 2–7) and tissues (type of tissue $\times$ type of grain, Figures 1–4). The statistical significance of the differences was assessed at both the 95% and 99% significance levels. Tukey's HSD test was applied to determine significant differences between groups. The Grubbs test was also employed to identify and reject outliers. All calculations were performed using Statgraphics® ver.16.1.17 (StatPoint Technologies, Inc., Warrenton, VA, USA).

Results

Protein

The protein content in the legs, breasts, and livers, depending on the fattening method and examined tissues, is presented in Tables 2–4 and Figure 1.

Irrespective of the fattening method employed, goose livers in both experiments exhibited a notably higher protein content in comparison to goose leg muscles ($P<0.01$). Nevertheless, in the first experiment, there was no significant difference in protein content between the livers and breasts, as shown in Figure 1.

A higher protein content was detected in the thigh muscles of geese that were fed with corn for fattening, compared to the other groups (mostly oat and barley-fed, $P<0.05$). Conversely, the greatest amount of protein in breast muscles was found in geese that were fattened with oats, while the lowest was in geese fattened with barley ($P<0.05$). In the livers, as presented in Table 4, fattening with oats and wheat led to a statistically significant increase in protein content compared to fattening with barley and corn grains ($P<0.01$). It is also worth noting that the significant differences in protein content were most pronounced in the livers, approximately 1.0–1.4 (%), compared to the legs and also breast muscles, approximately 0.3–0.5 (%).

Amino acids

The study investigated the profiles of 18 amino acids, with 11 of them falling within the group of essential amino acids (EAA). The results are presented in Tables 2–4 and Figures 2 and 3.

Geese provide valuable sulfur-containing amino acids (Met and Cys) as well as aromatic amino acids (Phe and Tyr). Additionally, among amino acids, Trp and His are recognized as some of the most deficient in the human diet, along with Cys and Met (Dai et al., 2022). As demonstrated in Tables 2–4, fattening with whole barley grain resulted in the highest content of Phe+Tyr in the legs ($P<0.01$) and His in the livers ($P<0.05$) compared to the other fattening groups. However, the differences were not statistically significant when compared to oats. On the other hand, fattening with whole oat grain resulted in the highest content of His (with statistically significant difference compared to wheat, $P<0.01$), as well as Phe+Tyr and Met+Cys in the breasts (although the differences were not significant compared to barley, $P<0.05$, Table 3). Meanwhile, feeding with whole corn grain led to the lowest content of Trp in the legs compared to the other fattening groups ($P<0.01$, Table 2), while wheat led to the lowest content of His in the breasts compared only to oats ($P<0.01$, Table 3).

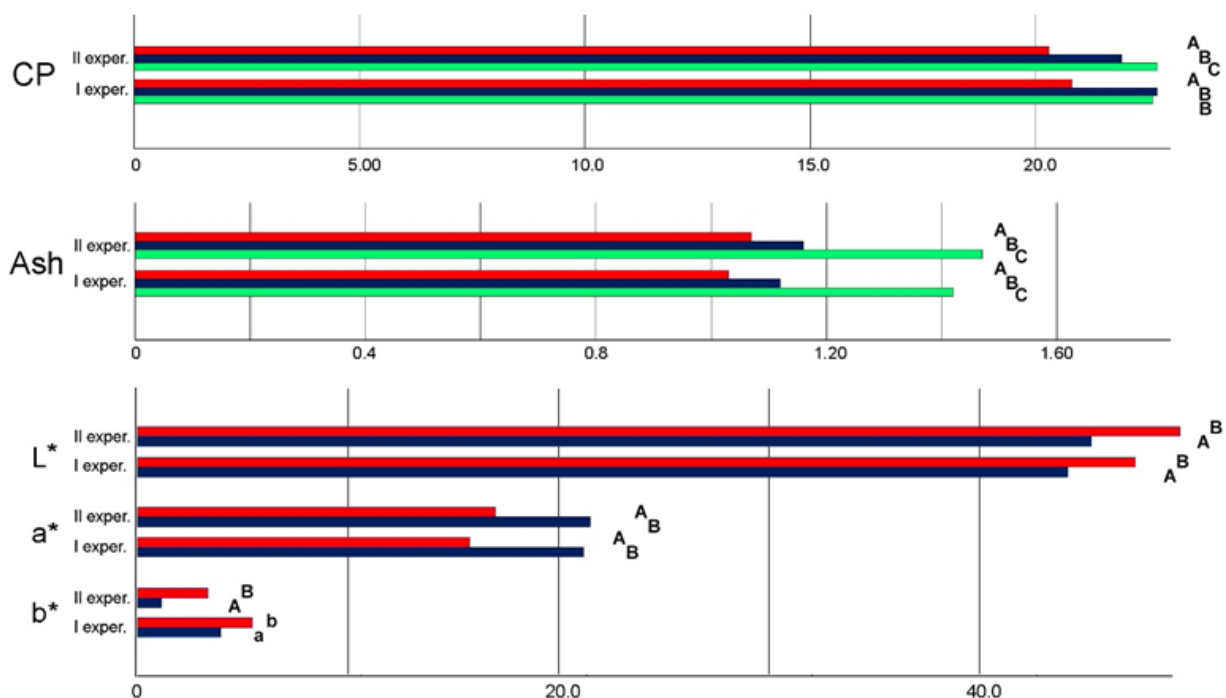


Figure 1. Content of crude protein (CP, %), ash (%) and color parameters (L* – lightness, a* – redness, b* – yellowness) in males (W33) of 17-week-old White Koluda® geese depending on the examined tissues; red – thigh muscles, navy blue – breast muscles, green – liver. Different letters a, b, c means difference at $P<0.05$ and letters A, B, C means difference at $P<0.01$

Table 2. Amino acid composition (g/100g of protein) and crude protein (%) content of thigh muscle from male (W33) 17-week-old White Koluda® geese (n=64)

	Nutrient (n)				Experiment (e)		P-value of interaction	SEM
	oat grain	wheat grain	barley grain	corn grain	I	II	n × e	
Crude protein (CP)	20.4 aA	20.5 aAB	20.4 aA	20.9 bB	20.8 B	20.3 A	0.0361	0.07
Nonessential AA								
Glutamic acid (Glu)	15.2 ab	14.9 a	15.6 b	14.7 a	15.8 B	14.4 A	0.0009	0.17
Aspartic acid (Asp)	9.59 ab	9.45 ab	9.95 b	9.42 a	9.99 B	9.21 A	0.0131	0.115
Arginine (Arg)	9.86 b	8.58 ab	9.38 ab	7.80 a	8.62	9.19	0.0293	0.322
Proline (Pro)	4.12	3.95	4.07	4.08	4.18 b	3.93 a	0.0012	0.058
Alanine (Ala)	5.94	5.88	6.12	5.99	6.11 b	5.85 a	0.0624	0.057
Serine (Ser)	4.23 B	4.06 A	4.24 B	4.01 A	4.24 B	4.03 A	0.0002	0.033
Glycine (Gly)	4.98 b	4.58 a	4.92 b	4.94 b	5.12 B	4.59 A	0.0004	0.081
Essential AA								
Leucine (Leu)	8.20	8.22	8.56	8.25	8.58 B	8.03 A	0.1052	0.079
Lysine (Lys)	9.96 ab	9.46 a	10.5 b	9.39 a	10.1	9.52	0.0489	0.191
Valine (Val)	4.28 AB	4.10 A	4.44 B	4.07 A	4.28	4.16	0.0017	0.050
Phenylalanine (Phe)	4.39 ab	4.22 a	4.58 b	4.21 a	4.39	4.30	0.0141	0.059
Isoleucine (Ile)	4.28	4.37	4.49	4.36	4.44	4.31	0.6573	0.045
Tyrosine (Tyr)	3.01 AbB	3.02 AbB	3.05 bB	2.87 aA	2.90 A	3.08 B	0.0172	0.026
Tryptophan (Trp)	1.25 AbB	1.33 bBc	1.34 Bc	1.17 aA	1.24 A	1.30 B	0.0073	0.016
Threonine (Thr)	4.71	4.86	4.97	4.85	5.03 B	4.67 A	0.1135	0.055
Histidine (His)	3.01	3.07	3.20	3.06	3.15	3.02	0.2212	0.046
Methionine (Met)	2.91	2.76	2.86	2.73	2.87	2.76	0.7673	0.036
Cystine (Cys)	1.24	1.18	1.17	1.15	1.27 B	1.10 A	0.2232	0.020
Σ EAA	47.2	46.6	49.1	46.1	48.3 b	46.3 a	0.0605	0.51
Phe+Tyr	7.40 AB	7.23 A	7.62 B	7.09 A	7.29	7.38	0.0131	0.075
Met+Cys	4.14	3.94	4.04	3.88	4.14 B	3.86 A	0.6032	0.053
AAS Leu	135	135	140	135	141 B	132 A	0.1106	1.3
AAS Lys	207	197	219	196	211	198	0.0497	4.0
AAS Val*	107 ab	103 a	111 b	102 a	107	104	0.0020	1.3
AAS Phe+Tyr	180 ab	177 ab	186 b	173 a	178	180	0.0135	1.8
AAS Ile	143	146	150	145	148	144	0.6330	1.5
AAS Trp	189 AbB	201 bBc	202 Bc	177 aA	187 A	197 B	0.0061	2.4
AAS Met+Cys	180	171	176	169	180 B	168 A	0.5959	2.3
AAS Thr	188	195	199	194	201 B	187 A	0.1062	2.2
AAS His	188	192	200	191	197	189	0.2218	2.9
EAAI	165 ab	165 ab	172 b	161 a	168 b	163 a	0.0596	1.5

AAS – amino acid score, EAA – essential amino acid, EAAI – essential amino acid index.

Values in rows with different capital letters means difference at P<0.01 and small letters difference at P<0.05.

* – limiting amino acid.

Table 3. Amino acid composition (g/100g of protein) and crude protein (%) content of breast muscle from male (W33) 17-week-old White Koluda® geese (n=64)

	Nutrient (n)				Experiment (e)		P-value of interaction	SEM
	oat grain	wheat grain	barley grain	corn grain	I	II	n × e	
Crude protein (CP)	22.4 b	22.3 ab	22.1 a	22.3 ab	22.7 B	21.9 A	0.0085	0.07
Nonessential AA								
Glu	15.4 B	14.0 A	14.5 AB	13.8 A	14.7 b	14.2 a	0.0126	0.16
Asp	10.0 B	9.22 A	9.51 AB	9.17 A	9.57	9.38	0.0128	0.100
Arg	9.56 B	7.18 A	9.22 B	7.12 A	9.08 B	7.46 A	0.0001	0.289
Pro	3.79 b	3.55 a	3.54 a	3.52 a	3.77 B	3.43 A	0.0390	0.044
Ala	6.42 B	5.90 A	6.06 AB	5.90 A	6.11	6.03	0.0699	0.060
Ser	4.31 B	3.94 A	3.99 A	3.89 A	4.10 b	3.97 a	0.0292	0.042
Gly	4.95 B	4.41 A	4.49 A	4.46 A	4.65	4.50	0.1855	0.057
Essential AA								
Leu	8.88 b	8.25 a	8.44 ab	8.22 a	8.50	8.40	0.0187	0.085
Lys	10.4 B	8.67 A	10.1 B	8.63 A	10.1 B	8.77 A	0.0000	0.199
Val	4.73 Bc	4.23 aAb	4.50 AbBc	4.20 Aa	4.46	4.37	0.0035	0.052
Phe	4.52 b	4.11 a	4.40 ab	4.14 a	4.35	4.24	0.0350	0.057
Ile	4.73 b	4.39 a	4.50 b	4.38 a	4.53	4.47	0.0162	0.046
Tyr	3.23 b	3.02 a	3.12 ab	3.03 a	3.19 B	3.01 A	0.0194	0.032
Trp	1.31	1.37	1.39	1.43	1.41	1.34	0.1170	0.026
Thr	5.00	4.71	4.78	4.71	4.93 b	4.67 a	0.0049	0.063
His	3.84 B	3.53 A	3.76 AB	3.62 AB	3.78 B	3.60 A	0.0035	0.040
Met	2.88 b	2.60 a	2.72 ab	2.64 a	2.76	2.65	0.1020	0.036
Cys	1.22	1.14	1.10	1.10	1.25 B	1.03 A	0.0579	0.025
Σ EAA	50.7 B	46.0 A	48.8 AB	46.1 A	49.3 B	46.5 A	0.0041	0.54
Phe+Tyr	7.75 b	7.13 a	7.53 ab	7.17 a	7.54 b	7.25 a	0.0172	0.085
Met+Cys	4.10 b	3.73 a	3.81 ab	3.74 a	4.01	3.68	0.0843	0.057
AAS								
AAS Leu	146 b	135 a	138 ab	135 a	139	138	0.0179	1.4
AAS Lys	216 B	181 A	210 B	180 A	211 B	183 A	0.0000	4.2
AAS Val*	118 bBc	106 aAb	112 AbBc	105 aA	111	109	0.0041	1.3
AAS Phe+Tyr	189 b	174 a	184 ab	175 a	184	177	0.0163	2.1
AAS Ile	158 b	146 a	150 ab	146 a	151	149	0.0160	1.5
AAS Trp	199	208	210	216	213	203	0.1176	4.0
AAS Met+Cys	178 b	162 a	166 ab	162 a	174 B	160 A	0.0893	2.5
AAS Thr	200	189	191	188	197 b	187 a	0.0052	2.5
AAS His	240 bB	220 aA	235 AbB	227 aAbB	236 B	225 A	0.0032	2.5
EAAI	179 B	165 A	173 AB	166 A	175	166	0.0065	1.6

Abbreviation explanations as in Table 2.

Values in rows with different capital letters means difference at P<0.01 and small letters difference at P<0.05.

* – limiting amino acid.

Table 4. Amino acid composition (g/100g of protein) and crude protein (%) content of liver from male (W33) 17-week-old White Kółuda® geese (n=64)

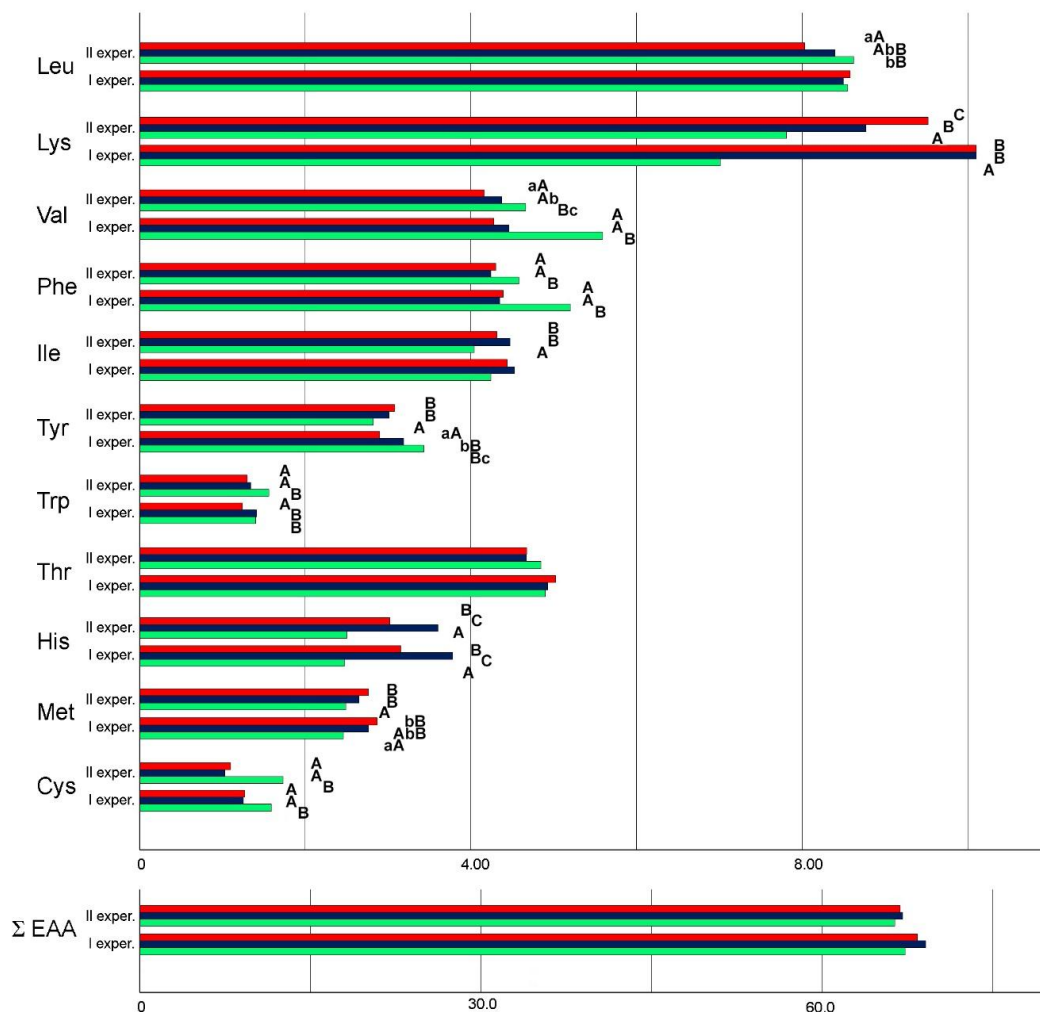
	Nutrient (n)				Experiment (e)		P-value of interaction	SEM
	oat grain	wheat grain	barley grain	corn grain	I	II	n × e	
Crude protein (CP)	23.3 C	23.1 C	22.3 B	21.9 A	22.6	22.7	0.0000	0.09
Nonessential AA								
Glu	11.6 a	11.7 a	13.4 b	12.1 ab	12.2	12.2	0.0015	0.26
Asp	8.63	8.60	9.30	8.50	8.30 A	9.21 B	0.0385	0.155
Arg	7.15 a	7.20 ab	8.10 b	7.11 a	6.82 A	7.95 B	0.0170	0.161
Pro	4.47	4.38	4.80	4.60	4.39 a	4.74 b	0.0696	0.085
Ala	6.12	6.08	6.71	6.16	6.55 B	5.99 A	0.0184	0.113
Ser	4.64	4.67	5.25	4.73	5.01 b	4.64 a	0.0335	0.103
Gly	4.62 a	4.67 a	5.29 b	4.67 a	4.84	4.78	0.0102	0.089
Essential AA								
Leu	8.20 aA	8.33 aAB	9.38 bB	8.44 aAB	8.55	8.62	0.0010	0.151
Lys	7.30 aAB	7.27 aAB	8.01 bB	7.08 aA	7.01 A	7.81 B	0.0010	0.131
Val	5.00	4.97	5.58	4.94	5.59 B	4.66 A	0.0155	0.118
Phe	4.81	4.77	5.28	4.70	5.20 B	4.58 A	0.0035	0.103
Ile	4.06	4.04	4.47	4.00	4.24	4.04	0.0342	0.074
Tyr	3.14	3.06	3.32	2.98	3.43 B	2.82 A	0.0430	0.071
Trp	1.41 aAB	1.32 aA	1.63 bC	1.56 bBC	1.40 A	1.56 B	0.0000	0.032
Thr	4.79	4.79	5.15	4.76	4.90	4.85	0.0920	0.082
His	2.43ab	2.42 a	2.74 b	2.35 a	2.47	2.50	0.0003	0.054
Met	2.46ab	2.77 b	2.43 ab	2.24 a	2.46	2.49	0.4648	0.069
Cys	1.66	1.87	1.53	1.58	1.59	1.73	0.3084	0.051
ΣEAA	45.3 ab	45.6 ab	49.5 b	44.6 a	46.8	45.7	0.0102	0.74
Phe+Tyr	7.95	7.82	8.61	7.68	8.63 B	7.40 A	0.0103	0.172
Met+Cys	4.13	4.64	3.96	3.82	4.06	4.22	0.4066	0.117
AAS								
AAS Leu	134 aA	137 aAB	150 bB	138 aAB	138	141	0.0002	1.9
AAS Lys	152 ab	151 ab	156 b	148 a	141 A	163 B	0.0035	2.0
AAS Val*	125	124	127	123	133 B	116 A	0.3285	1.6
AAS Phe+Tyr	194	191	195	187	203 B	181 A	0.0197	2.3
AAS Ile	135	135	141	133	137	135	0.0832	1.3
AAS Trp	213 aAB	200 aA	247 bC	236 bBC	212 A	236 B	0.0000	4.8
AAS Met+Cys	179	202	172	166	176	184	0.4108	5.1
AAS Thr	192	192	206	191	196	194	0.0892	3.3
AAS His	152	151	156	147	147A	156B	0.0036	1.9
EAAI	161 ab	162 ab	176 b	159 a	165	164	0.0097	2.5

Abbreviation explanations as in Table 2.

Values in rows with different capital letters means difference at P<0.01 and small letters difference at P<0.05.

* – limiting amino acid.

Essential



Nonessential

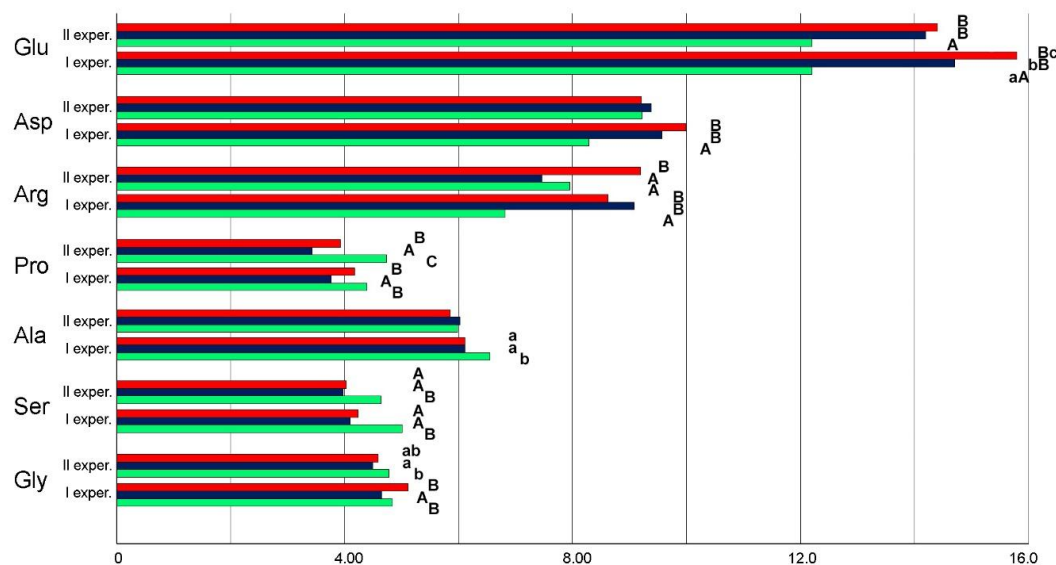


Figure 2. Content of nonessential amino acids (g/100g of protein), essential amino acids (EAA, g/100g of protein) and their sum in males (W33) of 17-week-old White Koluda® geese depending on the examined tissues; red – thigh muscles, navy blue – breast muscles, green – liver. Different letters a, b, c means difference at P<0.05 and letters A, B, C means difference at P<0.01

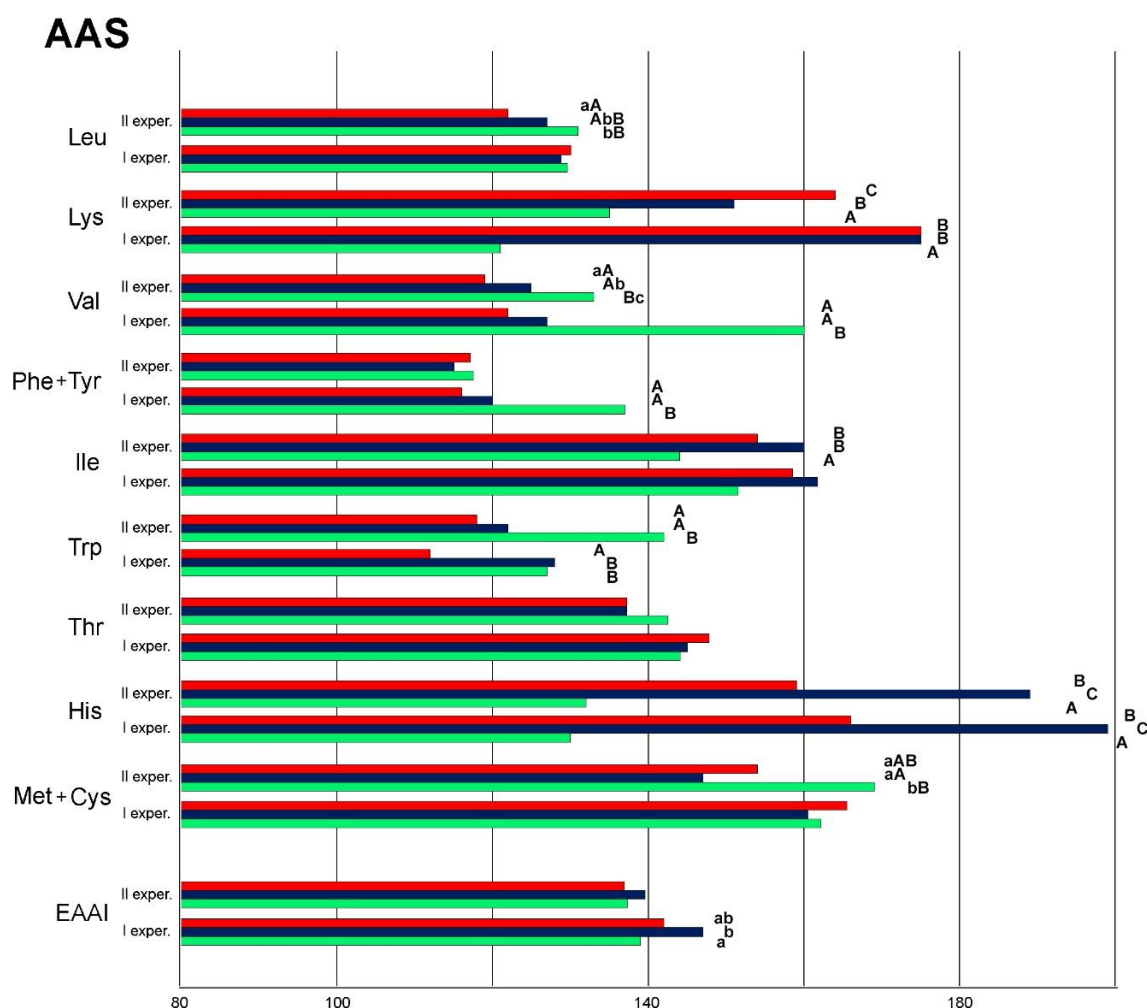


Figure 3. Content of essential amino acids score (AAS) and essential amino acid index (EAAI) in males (W33) of 17-week-old White Kozłuda® geese depending on the examined tissues; red – thigh muscles, navy blue – breast muscles, green – liver. Different letters a, b, c means difference at $P<0.05$ and letters A, B, C means difference at $P<0.01$.

In both experiments, the liver, compared to other tissues, exhibited the highest or among the highest levels of proline (Pro), serine (Ser) (nonessential AA), Val, Phe, Trp, and Cys (EAA), with the lowest or among the lowest levels observed for glutamic acid (Glu), arginine (Arg) (nonessential AA), and Lys, His, and Met (EAA) – in both instances, $P<0.01$ (Figure 2).

Likewise, in both experiments (Figure 2), the highest or among the highest concentrations in breast muscles were found for Glu (nonessential AA), Tyr, His (EAA) ($P<0.01$), while the lowest or among the lowest concentrations were noted for Pro, Ser ($P<0.01$), glycine (Gly) ($P<0.01$, $P<0.05$) (nonessential AA), Val, Phe, Cys (EAA) ($P<0.01$). Finally, in both experiments, thigh muscles displayed the highest or among the highest concentrations of Glu, Arg (nonessential AA), as well as Lys, Met (EAA), with the lowest or among the lowest concentrations observed for Ser (nonessential

AA) and Val, Phe, Trp, and Cys (EAA) – in both cases, $P<0.01$ (Figure 2).

The same relationships as mentioned earlier were observed for AAS values. However, the associations for the sums AAS Phe+Tyr and AAS Met+Cys were not as pronounced. The former value was notably elevated for livers in the initial experimental year ($P<0.01$, compared to both breast and leg muscles), in line with the Phe content. Meanwhile, the latter was the highest for livers in the second experimental year ($P<0.05$, compared to both breast and leg muscles), consistent with the Cys content (Figure 3).

All AAS values consistently exceed 100, indicating adequate protein nutritional value regardless of the feeding method for the geese. It is worth noting that the lowest AAS values were observed for Val in the legs (102–111), breasts (105–118), and liver (123–127). Therefore, valine remains the limiting amino acid for each tissue examined. However, AAS for Val exceeds 100, indicating

that the tested protein is still nutritionally complete (Tables 2–4).

The analysis of protein quality in various fattening methods for White Koluda® geese, based on calculated AAS values, demonstrated that barley and oat-based fattening yielded the most favorable results, often resulting in higher AAS values compared to the other two groups. Oat-based fattening displayed the most favorable amino acid composition (expressed as AAS) in breast muscle protein, especially in terms of the presence of Leu, Lys, Val, Phe+Tyr, Ile, Met+Cys, and His. Barley-based fattening revealed a beneficial amino acid profile (also expressed as AAS) in leg muscle protein concerning the presence of Val, Phe+Tyr, and Trp, as well as in breast muscle protein for Lys, Val, and His presence, and in liver protein for Leu, Lys, and Trp content. Meanwhile, corn-based (liver protein) and wheat-based (leg protein) fattening demonstrated advantageous protein composition in terms of Trp content (Tables 2–4).

There were no statistically significant differences in the sum of EAA (Σ EAA) between the analyzed tissues (Figure 2). However, regardless of the experimental year, Σ EAA was the lowest in the livers for corn-based fattening ($P < 0.05$, statistically significant differences confirmed against barley-based fattening) and in breast muscles for both corn-based and wheat-based fattening (statistically significant differences confirmed against oats-based fattening, $P < 0.01$, Tables 2–4). In turn, the EAAI exhibited the lowest value for livers, which, however, was confirmed only in the first experiment when compared to breast muscles ($P < 0.05$, Figure 3).

There was no statistically significant difference in Σ EAA among the feeding groups in the leg muscles. The breast muscles of the oat-fed geese contained significantly higher total amounts of essential amino acids compared to the corn and wheat-fed geese ($P < 0.01$). In the livers, the highest total concentrations of essential

amino acids were observed in barley-fed geese, while the lowest concentrations were found in corn-fed geese ($P < 0.05$, Tables 2–4).

More favorable results in terms of protein quality were also supported by the EAAI for barley and oat-based fattening (161–179) in comparison to the other two groups (159–166) (Tables 2–4). Nevertheless, the most substantial and statistically significant differences were found between the barley-fed and corn-fed geese (in thigh muscles and liver, $P < 0.05$), as well as between the oat-fed and corn-fed and wheat-fed geese (in breast muscles, $P < 0.01$). Corn-fed and wheat-fed fattening consistently proved to offer the least favorable nutritional value of proteins for human adults, with the corn-fed results showing marginally poorer outcomes.

However, each method of feeding geese resulted in Σ EAA values that exceeded the WHO standard for human adults, which is 29.06 g/100g of protein (FAO, 2013). The average amounts of Σ EAA were 47.90, 47.26, and 46.26 in the breasts, legs, and livers, respectively.

Ash and minerals

Tables 5–7 and Figure 1 present the ash content results. Wheat-based fattening consistently resulted in the highest or one of the highest ash contents in goose products. The ash content in the meat of wheat-fed geese was significantly higher than that in meat from other feeding groups, showing statistical significance in comparison to oats-fed and corn-fed geese for leg meat, and in comparison to oats-fed and barley-fed geese for breast meat, all at $P < 0.01$. On the other hand, the ash content in the liver was highest in the barley-fed group and lowest in the corn-fed group ($P < 0.01$), although there was no significant difference in the ash content between the barley-fed and wheat-fed geese at $P < 0.01$.

Table 5. Minerals composition (macro: g/kg, micro: mg/kg), ash (%) and color parameters (L^* – lightness, a^* – redness, b^* – yellowness) of thigh muscle from male (W33) 17-week-old White Koluda® geese ($n=64$)

	Nutrient (n)				Experiment (e)		P-value of interaction	SEM
	oat grain	wheat grain	barley grain	corn grain	I	II	$n \times e$	
Ash	1.03 aA	1.11 bB	1.04 aAB	1.02 aA	1.03	1.07	0.0003	0.012
Color: L^*	48.5 aAbB	49.8 bB	49.0 AbB	46.4 aA	47.4 a	49.5 b	0.1384	0.48
a^*	16.3	16.4	16.7	16.3	15.8 a	17.1 b	0.9724	0.25
b^*	5.25 b	3.77 a	3.77 a	4.80 ab	5.46 B	3.34A	0.1239	0.289
Potassium (K)	3.54 A	4.02 B	3.49 A	3.46 A	3.62	3.64	0.0023	0.051
Copper (Cu)	1.69 ab	1.78 ab	1.84 b	1.50 a	1.55 A	1.85 B	0.0524	0.047
Manganese (Mn)	0.122 AbB	0.156 cC	0.099 aA	0.141 BcC	0.134	0.124	0.0000	0.0044
Iron (Fe)	16.3 Bc	15.0 aAbB	16.0 bBc	14.3 aA	14.7 A	16.1 B	0.0000	0.25
Zinc (Zn)	29.8 a	33.6 b	30.4 ab	29.9 a	31.5	30.4	0.0586	0.51

Table 6. Minerals composition (macro: g/kg, micro: mg/kg), ash (%) and color parameters (L* – lightness, a* – redness, b* – yellowness) of breast muscle from male (W33) 17-week-old White Kofuda® geese (n=64)

	Nutrient (n)				Experiment (e)		P-value of interaction	SEM
	oat grain	wheat grain	barley grain	corn grain	I	II	n × e	
Ash	1.13 A	1.16 B	1.13 A	1.14 AB	1.12 A	1.16 B	0.0000	0.005
Color: L*	44.7	44.4	44.9	44.9	44.2	45.3	0.6601	0.28
a*	21.0	21.9	21.4	21.1	21.2	21.5	0.9771	0.22
b*	2.06	2.54	2.34	3.28	3.95 B	1.16 A	0.7365	0.344
P	2.43 C	2.34 A	2.38 B	2.36 AB	2.34	2.41	0.0000	0.008
Ca	0.0436	0.0422	0.0407	0.0399	0.0430 b	0.0402 a	0.1142	0.00071
Mg	0.262	0.257	0.261	0.263	0.261	0.260	0.0055	0.0011
Na	0.544 aAbB	0.561 bB	0.534 aAB	0.529 aA	0.542	0.542	0.0002	0.0039
K	3.75	3.80	3.77	3.76	3.70 A	3.83 B	0.0397	0.019
Cu	4.52 B	4.63 B	4.40 B	3.48 A	4.12	4.40	0.5232	0.101
Mn	0.161 aAB	0.207 bC	0.145 aA	0.186 bBC	0.212 B	0.137 A	0.0000	0.0067
Fe	35.3 bB	30.8 aA	35.1 bB	30.7 aA	30.8 A	35.1 B	0.0000	0.58
Zn	13.8 B	13.6 B	12.0 A	11.7 A	13.3 B	12.2 A	0.3365	0.20

Abbreviation explanations as in Table 5.

Values in rows with different capital letters means difference at P<0.01 and small letters difference at P<0.05.

Table 7. Minerals composition (macro: g/kg, micro: mg/kg) and ash (%) of liver from male (W33) 17-week-old White Kofuda® geese (n=64)

	Nutrient (n)				Experiment (e)		P-value of interaction	SEM
	oat grain	wheat grain	barley grain	corn grain	I	II	n × e	
1	2	3	4	5	6	7	8	9
Ash	1.41 aAb	1.45 AbB	1.54 Bc	1.38 aA	1.42 a	1.47 b	0.0049	0.016
P	3.32 bB	3.28 AbB	3.13 aA	3.19 aAbB	3.24	3.22	0.0000	0.022
Ca	0.0783 bB	0.114 cC	0.0710 AbB	0.0580 aA	0.0630 A	0.0976 B	0.0000	0.00463
Mg	0.231 B	0.260 C	0.219 AB	0.213 A	0.227 a	0.235 b	0.0000	0.0032
Na	0.899 a	0.962 b	0.945 ab	0.922 ab	0.909 A	0.955 B	0.0115	0.0082
K	2.87 bB	2.84 bB	2.78 AbB	2.66 aA	2.82	2.76	0.0062	0.023
Cu	292	305	278	342	270 a	338 b	0.1738	14
Mn	4.41 C	4.70 C	3.70 B	2.92 A	4.46 B	3.40 A	0.0000	0.121
Fe	295 A	275 A	244 A	537 B	329	347	0.1249	18
Zn	48.2 B	45.5 B	44.9 B	39.2 A	45.8 b	43.1 a	0.5137	0.69

Abbreviation explanations as in Table 5.

Values in rows with different capital letters means difference at P<0.01 and small letters difference at P<0.05.

Tables 5–7 and Figure 4 presents data for the minerals composition in the legs, breasts, and livers, depending on the fattening method and examined tissues. In this study, K and P emerged as the most abundant macronutrients in all examined tissues of White Kofuda® goose and Ca

was the least abundant. Regarding microelements, Fe and Zn constituted the highest amounts, with the livers also exhibiting a substantial content of Cu. Conversely, Mn had the lowest content among all the examined elements (Figure 4).

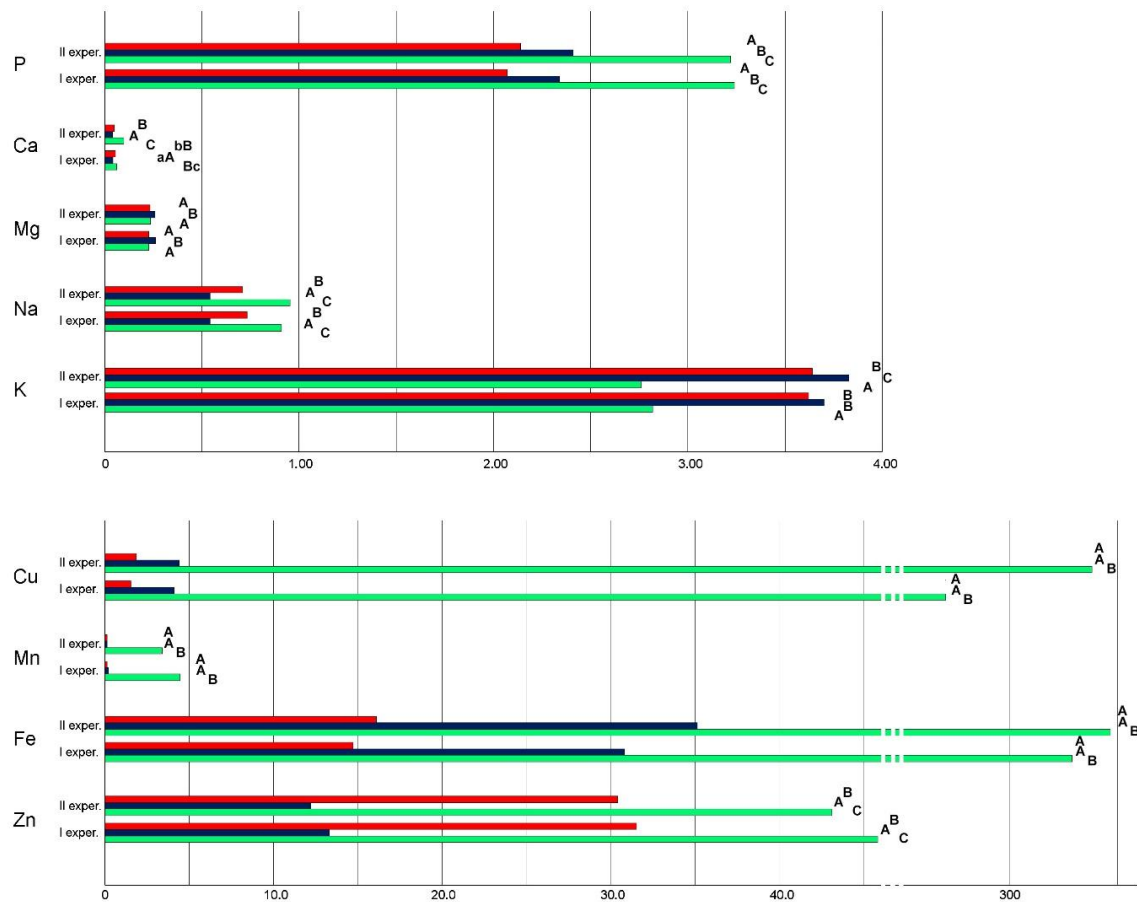


Figure 4. Content of micro- and macroelements (mg/kg and g/kg, respectively) in males (W33) of 17-week-old White Koluda® geese depending on the examined tissues; red – thigh muscles, navy blue – breast muscles, green – liver. Different letters a, b, c means difference at $P < 0.05$ and letters A, B, C means difference at $P < 0.01$

The liver was a source of particularly large amounts of P, Mn, Fe, Zn, and Cu. Cu in the liver reached a high level of approximately 300 mg/kg. The Na content in the livers was also higher ($P < 0.01$) than in the meat. We found lower levels of Mg in the livers compared to the breast muscles, and lower levels of K when compared to both the breast and leg muscles (both at $P < 0.01$), as illustrated in Figure 4.

Despite year-to-year differences, significant variations in the content of various elements were observed among the dietary groups in both the meat and liver. Generally, products from the wheat group showed the highest or one of the highest levels of P, Mg, Na, K, Mn, Zn in the leg; Na, Cu, Mn, Zn in the breast; and P, Ca, Mg, Na, K, Mn, Zn in the liver. Conversely, the products from the corn group generally exhibited the lowest or among the lowest levels of P, Mg, Na, K, Cu, Fe, Zn in the leg; Na, Cu, Fe, Zn in the breast; and Ca, Mg, K, Mn, Zn in the liver. However, both the corn-based and wheat-based groups displayed elevated content of Mn in the leg and breast, as well as Fe in the liver.

The remaining dietary groups, oat and barley, compared to the other groups, exhibited elevated levels of

certain elements: for the leg muscles – Fe (oat-based and barley-based groups compared to corn and wheat-based, $P < 0.05$); for the breast muscles – P (oat-based group compared to corn and wheat-based, $P < 0.01$, and barley-based compared to wheat-based, $P < 0.01$), Cu (oat group compared to corn-based, $P < 0.01$), Fe (oat and barley groups compared to corn and wheat-based, $P < 0.01$), Zn (oat group compared to barley and corn-based, $P < 0.01$); and in the liver – K (oat group compared to corn-based, $P < 0.01$), Mn (oat group compared to barley and corn-based, $P < 0.01$), Zn (oat and barley groups compared to corn-based, $P < 0.01$).

Meat color parameters

Tables 5–6 and Figure 1 display the outcomes of color measurements conducted on meat samples from the legs and breasts, categorized by the fattening method and the respective tissues examined. It was observed in Figure 1 that the breast meat exhibited a higher value of the a^* parameter (indicating redness) and a lower value of the L^* parameter (indicating lightness) compared to the leg meat ($P < 0.01$). Additionally, the b^* value was lower for breasts (suggesting less yellowing) than for legs ($P < 0.05$ in experiment I

and $P < 0.01$ in experiment II). In the leg meat of geese fed with whole corn grain, the L^* parameter exhibited the lowest value, whereas those fed with wheat grain showed the highest value ($P < 0.01$); conversely, geese fed with oat grain displayed the highest values of the b^* parameter, while those fed with wheat and barley grain had the lowest values (in both instances $P < 0.05$, Table 5).

Discussion

Protein

Haraf (2014), in her review work, compiled results indicating that in the breast muscles of 17-week-old White Kołuda® geese of the W33 lineage, the crude protein content ranged from 21.90% to 22.98%. In her study, there was a lack of data for the leg muscles of W33 geese. Meanwhile, in the case of 17-week-old crossbred W31 geese, depending on the cited source, the contents of total protein in breast muscles were reported to be between 22.89% and 23.33%, while in leg muscles they ranged from 19.96% to 20.78%. Furthermore, Gumulka and Połtowicz (2020), in research conducted on 10-week-old White Kołuda® geese, demonstrated that the protein contents in breast and leg muscles were 21.21% and 21.07%, respectively. In our study, the protein content did not importantly differ from those presented by other authors (Tables 2–4).

Amino acids

According to Straková et al. (2002), the content of amino acids in geese broiler breast muscles was generally found to be higher than that in the thigh muscles ($P < 0.01$), except for Pro. This does not entirely align with our observations. In our research across various dietary groups, it was found that only His was significantly higher in the breasts than in the legs in both experiments, and for Trp and Tyr, such a relationship was observed only in one of the experiments as shown in Figure 2 (in both cases $P < 0.01$). However, in both years, the opposite trend was observed for Pro. For example, Okruszek et al. (2013) also demonstrated that the Trp content was higher in the breast muscles of Rypińska (Ry) geese but higher in the thigh muscles of Garbonosa (Ga) geese. In our study, we observed a higher content of this amino acid in the breasts during the first experiment, with no differences between the breasts and thighs in the second one.

In our research (Tables 2–3), we found higher levels of amino acids in the breast (except for Val in the wheat- and corn-fed geese) and leg (except for Val, Tyr, and His) compared to the study conducted by Gumulka and Połtowicz (2020). However, their study was conducted on 10-week-old White Kołuda® geese, and the results were an average of both males and females, probably of genotype W31. On the other hand, the AA contents we obtained are closer to those presented in the study by Okruszek et al. (2013), which was conducted

on 17-week-old Ry and Ga geese, which were raised for a similar duration as in our research. An exception was Lys and Leu in the legs and breasts, where Okruszek et al. (2013) showed higher levels than in our research. In 17-week-old large gray (Lg) and large white (Lw) geese, Melnik et al. (2023) also reported results that are more similar to our study. They observed higher content of aspartic acid (Asp), Leu, Val, Phe, Tyr, Met, and Cys in the legs, and Pro, Leu, Lys (in relation to wheat- and corn-fed), Val, Phe, and Met in the breasts. In their study, the geese were fed with a mixture of wheat, corn, and oat whole grains during the last 3 weeks of fattening.

To the best of our knowledge, there are no reports in the literature regarding the AA content in the livers of geese raised under an *ad libitum* feeding system. In our research, we discovered that the muscles of the thighs and breasts, as well as the livers of White Kołuda® geese, indeed contain all essential amino acids (Tables 2–4). According to the studies conducted by Haraf et al. (2018, 2021) and Okruszek et al. (2013), 17-week-old geese of the Ry, Ga, Kartuska (Ka), Suwalska (Su), Lubelska (Lu), and Kielecka (Ki) breeds exhibit slightly higher levels of EAAs in their leg muscles compared to the White Kołuda® geese. In contrast, in breast muscles, it was found that Ry and Ga geese have more essential amino acids (Okruszek et al., 2013), while Ka, Su, Lu, and Ki geese have less EAA compared to the White Kołuda® geese we examined, except for those fed with corn. However, younger geese (10 weeks old), both White Kołuda® and Zatory Landrace (Za) breeds, have lower EAA content in both breast and thigh muscles (Gumulka and Połtowicz, 2020). The considerations took into account the lack of Trp in Gumulka and Połtowicz's research.

Ash and minerals

The ash is the residue that remains after incinerating a food sample at high temperatures, representing the total mineral content. Typically, the ash content in meat falls within the range of approximately 1% to 2% (Siham, 2019). In the case of raw goose meat without skin, an ash content of 1.21% was detected (Wereńska et al., 2023). This is consistent with our findings (1.02% to 1.54%). However, the method of goose fattening influences the ash content. Consequently, within our research, fattening with wheat contributed to an increased ash content in the meat (breasts and thighs), which was also in line with the mineral content findings. Furthermore, the ash content in the liver was the highest among the comparable tissues, also clearly corresponding to the content of most elements.

In the available literature, we observe quite a wide range of mineral content in goose meat. Thus, the contents presented in the leg muscles of geese of various breeds were 0.23–2.4 g/kg Ca, 7.49 g/kg P, 0.883 g/kg Mg, 1.35 g/kg Na, 0.681–4.2 g/kg K, 1.2–1.47 mg/kg Cu, 0.17–5.0 mg/kg Mn, 7.6 mg/kg Fe and 29.1–58.7 mg/kg Zn (Goluch and Haraf, 2018; Oz and Celik, 2015) and

in the breast muscles were 0.0461–1.68 g/kg Ca, 1.667–9.11 g/kg P, 0.15–1.196 g/kg Mg, 0.211–3.51 g/kg Na, 0.612–11.49 g/kg K, 1.5–18.4 mg/kg Cu, 0.2–1.7 mg/kg Mn, 10.1–142 mg/kg Fe and 9.0–49.1 mg/kg Zn (Goluch et al., 2021; Goluch and Haraf, 2018, 2023; Nowicka et al., 2018; Oz and Celik, 2015). Generally, the content of micro- and macroelements obtained in our research from raw goose breast meat did not considerably differ from those presented in the literature. However, in raw meat from leg muscles (Table 5), we typically found lower levels of P, Ca, Mg, Na, and Mn, as well as higher levels of Fe compared to those reported by Goluch and Haraf (2018), Goluch et al. (2021), Nowicka et al. (2018) and Oz and Celik (2015).

As previously stated, in the case of White Køluda® geese, the available research papers fail to provide the mineral composition in the livers of birds fattened using an *ad libitum* system. In the literature, we found information on the content of Fe, Cu, Mn, and Zn in the Zatory Landrace goose, as reported by Cieřlik et al. (2011). The concentrations of Fe (52.93–659.84 mg/kg), Mn (3.43–5.32 mg/kg), and Zn (50.87–67.20 mg/kg) observed in their study were comparable to those found in our research. Particularly noteworthy was the abundance of Cu in the liver, reaching levels as high as approximately 300 mg/kg (Table 7). The liver appears to exhibit a specific propensity for accumulating Cu. For comparison, in other studies involving geese (Johnson et al., 1989), the Cu content in this tissue was reported at 108.7 mg/kg, while in calf liver, it could reach up to 146 mg/kg (USDA, 2019). Conversely, in other parts of the goose carcass, the copper content was considerably lower. In our research (Tables 5–6), the content of this element was approximately 1.7 mg/kg in the legs and 4.2 mg/kg in the breasts, while in other goose studies, the values were 1.2 mg/kg (Oz and Celik, 2015) and even 9.2 mg/kg (Zhang et al., 2024), respectively.

It is worth noting that animal products can be a valuable source of minerals in the human diet. According to the recommendations outlined in the Codex Nutrient Reference Values (Lewis, 2019), Nutrient Reference Values (NRVs) for adults are as follows: 0.7, 1.0, 0.31, and 2 g/day for P, Ca, Mg, and Na, and 14, 11, 0.9, and 3 mg/day for Fe, Zn, Cu, and Mn, respectively. In turn, Dietary Reference Value (DRV) for K is determined as 3.5 g/day (EFSA, 2016). Daily requirements in a 100 g serving (%NRV/100g serving) across all examined products for these elements were approximately within the ranges of 10% to 380% (Fe) and 17% to 3 800% (Cu). These values for other elements ranged between 29% and 47% (P), 11% and 44% (Zn), 7% and 8% (Mg), 0.4% and 1.1% (Ca), and 2.6% and 4.8% (Na). In turn, for K, the daily requirements expressed as %DRV/100g serving ranged between 7.6% and 11.5% (data not presented in the Tables). It is worth noting that the livers were notably rich in Fe and Cu, significantly exceeding %NRV/100g serving.

The differences in the elemental content in products from White Køluda® geese fattened with different grains

were generally small yet statistically noteworthy. However, the results varied depending on the tissue and exhibited different relationships with the mineral content in the grains (Tables 1 and 5–7). Attributing these differences consistently to the feed used for fattening proves challenging. For example, in the leg, the group fattened with oats exhibited a higher level of Ca content compared to the group fattened with barley ($P < 0.05$). Similarly, in the liver, the oat-fattened group showed a higher level of Ca content compared to the corn-fattened group ($P < 0.01$), possibly reflecting a similar trend observed in cereal grains, with oats displaying the highest amount. Additionally, a positive correlation was observed between Cu content in the breast ($P < 0.01$) and leg ($P < 0.05$) and the nominal Cu content in barley and corn grains. Furthermore, Mg content in the liver and leg muscles in the corn-fattened group was among the lowest levels ($P < 0.01$), consistent with the macronutrient content in corn grains. Turning to Mn, the content was higher in the liver of the oat-fattened group compared to the corn-fattened group ($P < 0.01$), aligning with the trend observed in the content of Mn in these cereals. However, the opposite relationship was observed in other tissues. Similarly, regarding Zn, a positive correlation was found in the liver. The Zn content in this tissue was greater in the oat- and barley-fattened geese compared to the corn-fattened geese ($P < 0.01$), following the trend of Zn content in these cereals.

However, as mentioned above, an opposing correlation between the elemental content in tissues and grains was also observed. In wheat, the nominal Na content was the lowest, however, in all examined tissues, this element was the highest or among the highest in the group fattened with this grain ($P < 0.01$ or $P < 0.05$). A similar inverse relationship was noted in the case of Fe content in the liver and Fe content in the grains. The nominal content of this element was higher in oat grain than in corn grain, in contrast to the Fe content in the oat- and corn-fattened group ($P < 0.01$). Conversely, for the breast and leg muscles, a positive relationship was observed between the Fe content in the oat- and corn-fattened group and the Fe content in the respective grains. Thus, numerous discrepancies have been observed. It is worth noting that variations in the relationships between mineral content in cereals and those in products from geese fattened with these cereals may arise due to various factors, not necessarily resulting from the method of fattening.

Meat color parameters

In our research, we noted that the breast meat displayed a higher Fe content when compared to the leg meat across all the dietary groups. This finding was consistent with a higher value of the a^* parameter (redness), which is associated with the presence of type I fibers and myoglobin content, and the lower value of the L^* parameter (lightness), correlating with the existence of type IIB fibers in the muscles (Tables 5–6, Figure 1), as shown by other studies (Gumulka et al., 2009; Kirmizibayrak et

al., 2011; Oz and Celik, 2015). Moreover, the b^* value was lower for breasts (indicating less yellowness) than for legs, aligning with the findings of the study of Kirmizibayrak et al. (2011) conducted on 6–8-month-old Turkish native geese.

The introduction of various grains in the final stage of fattening did not significantly affect the color parameters of the goose breast muscles. However, in the leg muscles, it can be observed that they were darker for geese fattened with corn, and lighter for those fattened with whole grains of wheat and barley. Additionally, oat fattening resulted in a greater yellowing effect of leg muscles.

Conclusions

This study investigated how the use of oat, barley, corn, and wheat whole-grain cereals in the final stage of fattening affected the physicochemical properties of meat and liver in White Køluda® geese, and identified variations between the examined tissues.

For all the grains used in the experiments, products of high nutritional value were obtained. They were characterized by a high level of protein, an amino acid composition fully meeting human needs for essential amino acids, and were rich in macro- and micronutrients. The analyzed goose meat and liver are a source of high-quality protein, providing a sum of essential amino acids that surpasses the WHO standard for human adults. As each amino acid exhibited over 100% AAS value, the goose meat and liver serve as a source of complete protein in human nutrition.

The use of whole barley grain and, to a slightly lesser extent, oats in the final phase of fattening is particularly noteworthy. Both methods generally demonstrated better EAAI parameters. For many amino acids, they also provided a more favorable EAA profile compared to fattening with wheat and corn grain.

The White Køluda® goose livers boasted elevated levels of most elements (particularly Fe and Cu), with the exception of Mg and K. Moreover, products from the wheat group generally contained higher levels of macro- and microelements. Conversely, corn-based products typically displayed lower or among the lowest levels of many macro- and microelements. While the variations in elemental content among products from geese fattened with different grains were generally minimal, they were statistically significant. However, it remains unclear whether these differences can be consistently attributed to the feed used for fattening.

Competing interests

The authors have no conflicts of interest to declare. They declare that carried out their duties impartially and honestly.

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