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Effects of two alternative feeding diets on growth, feed efficiency and meat quality in crossbreeding goose populations*

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This study evaluated the effects of two dietary protein sources - standard soybean meal (SBM) and local protein sources (LPS: yellow lupin and rapeseed meal) - on growth performance, feed efficiency, and meat quality in two goose reciprocal crossbred populations of Eskildsen (E) and Tapphorn (T). The research material consisted of 240 geese (120 from each of the two groups TE and ET). The following traits were recorded: growth, feed intake, feed conversion ratio (FCR), carcass composition, and meat chemical composition, including fatty acid profiles. Results showed that LPS-fed geese had reduced body weight gain (BWG) during the first 28 days; however, this

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difference diminished over time. While final body weights were similar, cumulative feed intake was higher and FCR less efficient in the LPS group. The TE genotype exhibited superior growth and carcass weights compared to ET, suggesting a maternal heterosis effect. Although protein and mineral content were unaffected, meat from LPS-fed geese had higher polyunsaturated fatty acids (PUFA) and lower fat content, indicating potential nutritional benefits. In conclusion, yellow lupin can serve as a viable alternative to SBM in goose diets. On the other hand, effects of population on these studied traits are usually significant. It indicates formulating feeding strategies should be included genetic origin of population.

KEY WORDS: crossbreeding / meat quality / protein sources / yellow lupine

The global demand for high-quality poultry products, including goose meat, has prompted ongoing research into optimizing diet formulations for improved growth and carcass quality. As a result, geese farming has become highly specialized, with production structures varying across different regions of the world. China dominates global goose production, accounting for approximately 93.3% of the domestic goose population (Food and Agriculture Organization of the United Nations 2024). Within the EU, geese farming is primarily concentrate in Poland, Hungary, and Germany. Poland, in particular, has a long tradition of commercial goose farming and is one of the largest exporters of goose meat to Western European markets, primarily Germany and France. In Poland, the dominant breed in commercial production is the White Kołuda Goose. The breed is known for its high excellent meat quality, and superior fattening ability, making it particularly well-suited for both intensive and free-range production systems. To meet market demands, breeding programs aimed at improving growth rate and meat goose quality [Rouvier 1992, Neeteson *et al.* 2023]. These programs have facilitated the introduction of specialized sire and dam lines, enhancing production efficiency and ensuring a steady supply of high-quality goose meat. One of the most effective genetic strategies employed is crossbreeding. The main purpose of crossbreeding is to obtain a heterosis effects in progeny. Heterosis contributes significantly to improved growth performance, feed efficiency, and carcass quality, making it a key factor in optimizing production outcomes. Studies have demonstrated that crossbreeding of lines can lead to offspring that outperform purebred lines in body weight, feed conversion efficiency, and overall meat yield [Tai 1998, Abdel-Ghany 2024, Szwaczkowski *et al*. 2007]. This effect is particularly evident in long-term breedingprograms, where hybridization between well-defined sire and dam lines results in optimized production traits [Padhi 2012].

Moreover, research on crossbreeding effects in ducks has demonstrated substantial heterotic gains in body weight and conformation traits, indicating that similar benefits can be expected in geese [Padhi 2012]. Genetic variability plays a crucial role in maintaining long-term sustainability in breeding programs, ensuring continued improvements in production efficiency while preserving the genetic health of breeding populations. By leveraging the benefits of crossbreeding and heterosis, it is possible to produce geese that not only meet consumer demands for high-quality meat but also support the economic viability of modern poultry farming. Another advantage of crossbreeding is the concentration of traits of the parental lines in the hybrid generation. The project aimed to achieve higher body weight at 17 weeks while maintaining comparable meat quality traits and feed conversion ratio (FCR) to that of White Kołuda Geese. In this study, we utilize two diallel crossbred geese populations derived from two local lines, which are recognized for their higher body weight potential and desirable meat characteristics. This genetic foundation aims to support the production of geese with high final body weight and enhanced meat quality, parameters that will be thoroughly assessed in this study.

Traditionally, goose diets have relied heavily on soybean meal as the primary protein source due to its high digestibility and balanced amino acid profile [Zhenming *et al.* 2021]. However, rising costs and sustainability concerns regarding soybean production have led to increased interest in alternative protein sources [Biesek *et al.* 2020, Zhenming *et al*. 2021]. Yellow lupin (*Lupinus luteus*) has gained attention as a promising candidate because of its substantial protein content, which can reach up to 40%, along with reduced levels of antinutritional factors in modern cultivars [Tesarowicz *et al*. 2022]. Studies by Kaczmarek *et al.* [2014] suggest that lupin seeds may offer a viable replacement for soybean meal, potentially reducing feed costs while supporting local and sustainable feed production.

The aim of this study is to compare the effects of a traditional soybean meal-based diet with one that incorporates yellow lupin as the primary protein source on the growth performance and meat quality of lines crossbred geese. Through this comparison, we seek to evaluate the effectiveness of yellow lupin as an alternative protein source and explore how crossbreeding strategies impact growth and meat quality traits in heavy-weight geese lines.

Material and methods

Ethical approval

This experiment followed applicable regulations (Polish Act. 2015. Act of 15 January 2015 on the protection of animals used for scientific or educational purposes, 2015, Journal of Laws of the Republic of Poland, 2015, pos 266). The principles of properly handling animals during slaughter and humane treatment are included. The methods aligned with the ARRIVE principles (https://link.springer.com/article/10.1186/s12917-020-02451-y) and directive no. 2010/63/EU (Directive 2010/63/EU of the European Parliament and of the Council of 22 September 2010 on the protection of animals used for scientific purposes. https://eur-lex.europa.eu/eli/dir/2010/63/oj/eng.).

Birds and housing

Two unpedigreed parental goose lines (Tapphorn and Eskildsen), were included in this study. The genetic components of the Tapphorn line are geese of the Lipizzan, Danish and Toulouse breeds, which are then subjected to long-term selection. The

Eskildsen Line was created by crossing heavy geese, mainly of the Dithmarscher and Saxon breeds. Totally 625 individuals of each line. At 17 weeks of age, 128 females and 32 males (from each line) were selected as parents of next generation. Individuals from the Tapphorn line were designated as “T,” while those from the Eskildsen line were designated as “E.” In the crosbreeding groups, the first litter of the designation represents the origin of females, while the second one represents the origin of males (e.g., “TE” indicates a female from Tapphorn mated with a male from Eskildsen, while “ET” represents a female from Eskildsen mated with a male from Tapphorn).

Three traits were considered as culling criteria: body weight (individuals weighing less than 6.0 kg or more than 11.5 kg were culled), behavior (individuals exhibiting high levels of aggression or lethargy were culled), and conformation. Aggressive, non-vigorous individuals, or those excluded by the flock, were not considered for the study. In December, were formed them in breeding pairs by placing one male with four females (1♂:4♀) in 32 pens for the TE generation and another 32 pens for the ET generation, where the first letter of the group denotes the origin of the male. The goslings were placed on the experimental farm in June.

Goose were housed in deep-litter pens with straw bedding, six birds per pen (sex ratio: 1:1). During the first four weeks, goslings were kept in a brooding facility without access to outdoor runs, in pens of 0,765 m². From the 5th to the 17th week, the geese were kept in pens with an area of 7.25 m², each with access to an individual outdoor run of 16 m². Natural ventilation was used in the housing facilities. Birds had ad libitum access to feed and water. Straw was used as bedding material.

Feeding experiment

Day-old goslings (n=240; 120 from the TE group and 120 from the ET group) were allocated into two dietary treatments:

group fed with a commercial soybean meal group (SBM) - based diet.

group fed with diets containing local protein sources, such as yellow lupin and rapeseed meal (LPS).

From 1-4 weeks of age, birds were fed a starter diet (Tab. 1). From the fifth week, a grower diet was introduced (Tab. 1), and the birds were allowed access to an outdoor range. At 11 weeks of age, the concentrate feed proportion was gradually reduced to 50%, replaced by oats, and this feeding strategy continued until the end of the experiment. The feed formulations for the starter and grower diets are presented in Table 1. Diets were formulated to meet the nutritional requirements of growing geese and adjusted for experimental objectives. Nutritional values, including metabolizable energy (ME), crude protein, and amino acid profiles, were consistent across groups (Tab. 1).

Table 1. Feed composition of experimental diets for geese

Item	Feeding group			
	SMB starter	SBM grower	LPS starter	LPS grower
Composition of concentrates (%)				
Soybean meal (44%)	17.5	9.8	-	-
Yellow lupin (37%)	-	-	13.5	8.0
broad bean	-	-	14	10.0
maize (9.5%)	24	26.06	23.1	27.0
triticale	21.17	25.0	14	22.0
wheat	20	26.0	17	21.0
Canola meal (33.7%)	11	9.5	11	8.0
soybean oil	2.6	0.6	3.1	0.8
premix [2]	1	1.0	1	1.0
Monocalcium phosphate	0.98	0.84	0.73	1.0
fodder chalk	0.8	0.42	1.22	0.39
$NaHCO_3$	0.43	0.36	0.43	0.32
fodder salt	0.06	0.11	0.04	0.14
L-lysine	0.24	0.06	0.31	
DL-methionine	0.11	0.08	0.18	0.13
L-threonine	0.11	0.08	0.17	0.12
Calculated nutritional value of concentrates				
Metabolizable energy (ME) - MJ/kg	11.79	11.79	11.76	11.77
Crude protein (%)	19	19.0	19	19.0
Calcium (%)	1	1.0	1	1.0
p-available (%)	0.4	0.4	0.4	0.4
Lysine (%)	1.1	1.1	0.97	0.69
Methionine (%)	0.4	0.4	0.4	0.35
Valine (%)	0.75	0.75	0.75	0.75
Threonine (%)	0.81	0.81	0.81	0.66
Na (%)	0.16	0.16	0.16	0.16
Cl (%)	0.14	0.14	0.14	0.14

Performance traits

Weekly body weight was recorded for all birds on the same day each week. Feed intake was monitored per pen and then averaged to evaluate consumption differences between LPS groups. The geese were housed in groups of six birds per pen, with feed provided ad libitum. Feed intake was recorded weekly for each pen and then averaged for each LPS group (TE and ET). This allowed for a precise evaluation of consumption differences between groups. Feed conversion ratio (FCR) was calculated for each group (TE and ET) and compared with the original parental lines (T and E). FCR was determined as the total feed intake (kg) divided by the total body weight gain (kg) over a given period. A lower FCR value indicates better feed efficiency, meaning that birds required less feed to achieve the same body weight gain.

Feed conversion ratio (FCR) was calculated for each group (TE and ET) and compared with the original parental lines (T and E). FCR was determined using the following formula:

$$FCR = \frac{\text{Total Feed Intake (kg)}}{\text{Total Body Weight Gain (kg)}}$$

Basic chemical composition and fatty acid profile of breast muscles

After the end of the rearing period (112th day), all birds were slaughtered (according to the regulations applied in the poultry industry). On the day of slaughter, the birds were fasted for 10 hours. Slaughter was carried out by decapitation to ensure rapid exsanguination following prior electrical stunning. This study did not require approval from the Local Ethical Committee for Animal Experimentation, as all procedures adhered to standard poultry industry practices without experimental modifications to the slaughter process. Samples were vacuum-packed immediately after collection, then stored at a temperature below -18°C for up to 5 days prior to analysis to ensure stability of the chemical composition. Before analysis, the samples were thawed under controlled conditions at 4±1°C. The meat study assessed the chemical composition and quality of goose meat based on a range of parameters. The analysis included the determination of protein content (calculated as N × 6.25) (acc. PB-116 ed. III of 11.08.2020), total fat (acc. ISO 1443:1973), total carbohydrates (acc. Regulation (EU) No 1169/2011 of the European Parliament and of the Council), total sugars after inversion (acc. PN-A-82100:1985), total ash (acc. PN-ISO 936:2000), and water content (acc. PN-ISO 1442:2000). Fatty acid profiling was conducted according to PN-EN ISO 12966-1:2015-01; PN-EN ISO 12966-2:2017-05 excluding p.5.3 and 5.5; PN-EN ISO 12966-4:2015-07, encompassing the quantification of saturated fatty acids (SAFA), monounsaturated fatty acids (MUFA), polyunsaturated fatty acids (PUFA), and essential unsaturated fatty acids (EFA). Specific fatty acids analyzed included palmitic acid (C16:0), palmitoleic acid (C16:1n7), stearic acid (C18:0), vaccenic acid (C18:1n7), oleic acid (C18:1n9), linoleic acid (C18:2n6), α-linolenic acid (C18:3n3), arachidonic acid (C20:4n6), eicosapentaenoic acid (EPA, C20:5n3), docosapentaenoic acid (DPA, C22:5n3), and docosahexaenoic acid (DHA, C22:6n3), among others. The sum of omega-3, omega-6, and omega-9 fatty acids was also determined, as well as the total trans fatty acid isomers.

Additionally, sodium content (Na) and salt content (calculated as Na × 2.5) (acc. PB-318/FAAS ed. 2 of 29/12/2022) were measured. The energy value of meat was determined (acc. Regulation (EU) No 1169/2011 of the European Parliament and of the Council), and the presence of milk fat was determined based on butyric acid (C4:0) content. Samples were stored at a temperature below -18°C for up to -5 days prior to analysis to ensure stability of the chemical composition.

Statistical analysis

The statistical analysis is based on following unitrait linear model:

$$y_{ijk} = \mu + G_i + D_j + (GD)_{ij} + e_{ijk}$$

where:

y_{ijk} – recorded trait;

μ – the overall mean;

G_i – the fixed effect of the genetic group (TE, ET);

D_j – the fixed effect of the dietary treatment (SBM, LPS);

$(GD)_{ij}$ – fixed effect the interaction of genetic group by dietary;

e_{ijk} – the random error connected with *ijk*-th observation.

Before conducting the main analysis, the empirical distribution of each trait was examined using the Shapiro-Wilk test,. The Levene's test was applied to check the homogeneity of variances among groups. For traits following, a normal distribution and meeting the assumption of homogeneity, a two-way analysis of variance (ANOVA) was performed to determine the effects of genetic group, dietary treatment, and their interaction. Tukey's post-hoc test was used for pairwise comparisons when significant differences were detected ($p<0.05$).

For data that violated normality assumptions, transformations such as the Box-Cox method [Box and Cox 1964] were applied to stabilize variance and approximate a empirical distribution to normality. If transformation did not sufficiently normalize the data, non-parametric methods were employed. For non-normally distributed data, the Kruskal-Wallis test was applied as a non-parametric alternative to one-way ANOVA to assess overall differences among groups. Since this method does not allow for interaction analysis, only main effects were considered, and Dunn post-hoc test was used for pairwise comparisons. All statistical analyses were performed using the R package programs (R Core Team, 2025).

Results and discussion

Growth performance

The presented results evaluate the performance, slaughter yield, and carcass composition of geese divided into four groups differing in genetic line (TE and ET) and dietary treatment. The analysis highlights the impact of these factors on body weight, feed consumption, and chemical composition of carcasses. The performance traits of geese during the rearing period are summarized in Table 2.

The analysis focuses on mortality, the body weight gain (BWG), feed intake (FI), and feed conversion ratio (FCR) across two phases of rearing: days 0-28 and days 29-119, as well as the entire rearing period (days 0-119). Mortality rates ranged from 1.7 to 8.3%, with the lowest observed in the TE SBM group (1.7%) and the highest in the TE SBM group (8.3%) - which was partially attributed to occasional accidental losses, such as mechanical incidents. Notably, three birds died on the same night due to human error, as they became trapped between slats in the pen.

Initial body weight (BW0) was slightly higher in ET hybrids compared to TE hybrids (0.121 kg *vs*. 0.119 kg; $p = 0.05$). The LPS diet had no significant effect on BW0 but showed a slight reduction in the TE group. A significant genotype × diet interaction was observed for BWG during the first 28 days ($p = 0.001$), where TE SBM geese exhibited the highest BWG (2.36 kg), whereas ET LPS geese showed the lowest (2.14 kg). Body weight gain (BWG) during the first 28 days was highest in the TE SBM group (2.36 kg) and lowest in the ET SBM group (2.14 kg). Birds on the LPS diet exhibited reduced BWG compared to those on the SBM diet (2.25 kg *vs.* 2.43 kg). During the later growth period (29-119 days), no significant differences in BWG were observed, with values ranging from 4.60 kg to 4.75 kg. However, cumulative BWG (0-119 days) showed that diet was a significant factor, with the highest BWG in the TE SBM group (7.09 kg) and the lowest in the TE LPS group (6.87 kg). Regarding slaughter performance, the TE SBM group produced the highest carcass weight (4590.85 g), followed by the ET LPS group (4484.64g). The lowest carcass weight was recorded in the TE LPS group (4353.52 g). Feed intake (FI) in first part of experiment (28 days) was significantly influenced by diet. During that time, geese fed the SBM diet consumed more feed (3.91 kg) compared to those on the LPS diet (3.76 kg; $p = 0.001$). Among genetic groups, TE hybrids consumed more feed than ET hybrids during this period. In the later growth phase (29-119 days), birds on the LPS diet exhibited higher feed intake (27.00 kg) compared to the SBM diet (24.76 kg). Cumulatively, total feed intake (0-119 days) was also higher in birds fed the LPS diet, with the TE LPS group consuming

Table 2. Averages of productivity traits of geese during the rearing period

Trait	TE SBM	ET SBM	TE LPS	ET LPS	SEM	Main effects – mean values				Main effects – p-values		
						genotype TE	genotype ET	diet SBM	diet LPS	genotype	diet	G×D
Mortality (%)	1.7	3.3	8.3	3.3	-	5	3.3	2.5	5.8	-	-	-
BW 0 (kg)	0.119^{a}	0.121^{b}	0.118^{a}	0.119^{b}	0.002	0.119	0.120	0.220	0.118	0.217	0.283	0.391
BWG 0-28 (kg)	2.36^{a}	2.22^{a}	2.27^{b}	2.14b^{c}	0.002	2.25	2.20	2.31	2.14	0.392	<0.001	0.034
BWG 29-119	4.65	4.70	4.60	4.75	0.003	4.74	4.81	4.75	4.80	0.645	0.342	0.111
BWG 0-119	7.01	6.92	6.87	6.89	0.005	6.99	7.01	7.06	6.94	0.421	0.537	0.443
FI 0–28 (kg)	4.04^{a}	3.77^{a}	3.87^{b}	3.64^{b}	0.002	3.81	3.71	3.89	3.62	0.361	<0.001	0.583
FI 29–119	24.96	24.55	26.98	27.02	0.005	25.48	26.29	25.98	25.79	0.654	0.676	0.343
FI 0–119	29.00	28.32	30.85	30.66	0.028	29.29	29.98	29.87	29.41	0.298	0.380	0.103
FCR 0–28	1.71	1.70	1.70	1.70	0.019	1.70	1.68	1.69	1.69	0.402	0.296	0.130
FCR 29-119	2.43	2.39	2.79	2.75	0.052	2.47	2.59	2.53	2.53	0.338	0.530	0.234
FCR 0–119	4.14	4.09	4.49	4.45	0.032	4.17	4.27	4.22	4.22	0.110	0.936	0.107
Carcass weight (g)	4590.85	4499.12	4353.52	4484.64	51.075	4472.19	4491.88	4544.99	4419.08	0.735	0.131	0.641

^{abc}Means within a row bearing different superscript differ significantly at $p<0.05$.

the most feed (30.85 kg). A statistically significant interaction effect was observed for FI 0-28, indicating that dietary treatment had a more pronounced effect on TE hybrids than ET hybrids in this phase.

Feed conversion ratio (FCR) was similar across groups during the first 28 days, averaging 1.70, with no significant differences observed. However, during the later growth period (29-119 days), birds fed the LPS diet, exhibited higher FCR values (2.77) compared to the SBM diet (2.41), indicating reduced feed efficiency. This trend was consistent for cumulative FCR (0-119 days), where birds on the LPS diet had higher values (4.47) than those on the SBM diet (4.12). Significant effect of dietary treatment on FCR 0-28 was observed confirming the influence of alternative protein sources on feed efficiency.

Chemical composition and fatty acid profile of breast muscles

The analysis of goose meat composition revealed no significant differences (p>0.05) in protein content, total ash, or sodium chloride levels between genetic groups (TE, ET) or dietary treatments (SBM – standard soybean meal mix, LPS – lupin-based mix) (Tab. 3). Protein content ranged between 22.31 and 22.59%, and total ash content varied minimally from 1.19% to 1.23%. Sodium chloride (NaCl) levels were consistent across all groups ranging from 0.093 to 0.097%. Similarly, the energy value of the meat showed no significant variation, averaging around 521-534 kcal/100 g.

Table 3. Means of genetic groups and dietary treatments on the proximate composition and energy value of goose meat

Genotype	Diet	Protein	Ash	NaCl	Energy (kJ/100 g)	Water
TE	SBM	22.426	1.190	0.093	534.47	73.014 [a]
TE	LPS	22.315	1.224	0.097	512.11	73.691 [b]
ET	SBM	22.589	1.225	0.094	533.180	73.066 [a]
ET	LPS	22.457	1.205	0.095	530.340	73.191 [ab]
SEM		0.044	0.006	0.001	3.621	0.055
Main effects – mean values						
genotype TE		22.370	1.208	0.096	523.103	73.359
genotype ET		22.521	1.216	0.095	531.759	73.128
giet SBM		22.511	1.208	0.094	533.832	73.04
giet LPS		22.384	1.215	0.096	520.991	73.448
Main effects – p-value						
genotype		0.088	0.551	0.788	0.230	0.031
diet		0.176	0.560	0.101	0.077	<0.001
G×D		0.907	0.061	0.384	0.176	0.009

[abc]Means within a row bearing different superscript differ significantly at p<0.05.

However, a significant difference (p = 0.05) was observed in water content. Meat from geese fed with the LPS diet had a higher water content (73.44%) compared to the SBM group (73.03%). Among genetic groups, TE geese on the LPS diet exhibited the highest water content (73.69%), differing significantly from ET geese in the SBM group (73.01%). A significant genotype by diet interaction (p<0.01) was observed for water content, indicating that the response to the LPS diet differed between genetic groups, with TE geese showing a more pronounced increase in water content compared to ET geese. Significant differences were observed in the total fat content and the proportions of polyunsaturated (PUFA) and monounsaturated (MUFA) fatty acids, while saturated fatty acids (SAFA) showed no significant variation between the groups or dietary treatments (Tab. 4). The total fat content (FAT) was significantly higher in the SBM group (geese fed with diet based on lupine and faba beans) compared to the LPS group (fed with diet based on soyabean meal). Among the genetic groups, ET geese exhibited higher fat levels compared to TE geese. A significant genotype by diet interaction was observed for fat content ($p<0.05$), indicating that dietary effects on fat deposition were influenced by genetic background. Specifically, while both TE and ET geese exhibited lower fat levels on the LPS diet, the reduction was more pronounced in TE geese. This finding aligns with previous reports indicating that saturated fatty acids are less responsive to environmental or nutritional modifications and are largely genetically regulated. The LPS diet significantly increased the content of PUFA ($p = 0.001$), with both TE and ET geese fed the LPS diet showing higher PUFA levels than their counterparts on the SBM diet. However, no significant genotype × diet interaction was observed for PUFA, suggesting that both genetic groups responded similarly to dietary changes in terms of PUFA accumulation. Conversely, MUFA levels were significantly reduced in the LPS diet ($p = 0.01$), with the most pronounced reduction observed in TE geese. A significant genotype × diet interaction ($p<0.05$) for MUFA suggests that TE geese experienced a greater decrease in MUFA levels on the LPS diet compared to ET geese. The SAFA content did not differ significantly, indicating that genetic and dietary modifications had no impact on this parameter.

Table 4. The means of genetic groups (TE. ET) and dietary treatments (SBM – standard mix. LPS – lupin-based mix) on fat content and fatty acid composition in goose meat

Genotype	Diet	Fat	SAFA	MUFA	PUFA
TE	TE	4.095^{a}	1.287^{a}	2.035^{a}	0.674^{a}
TE	TE	3.749^{b}	1.237^{a}	1.732^{b}	0.681^{b}
ET	ET	4.232^{a}	1.342^{a}	2.084^{a}	0.705^{a}
ET	ET	4.191^{b}	1.302^{a}	2.014^{a}	0.768^{b}
SEM		0.056	0.017	0.034	0.009
Main effects - mean values					
genotype TE		3.911	1.262	1.881	0.678
genotype ET		4.212	1.322	2.049	0.737
diet SBM		4.163	1.315	2.059	0.689
diet LPS		3.964	1.269	1.870	0.723
Main effects - p-value					
Genotype		0.008	0.079	0.012	<0.001
Diet		0.075	0.181	0.005	0.05
G×D		0.166	0.891	0.080	0.12

^{ab}Means within a row bearing different superscript differ significantly at $p<0.05$.

The present study investigated the effects of replacing traditional soybean meal with alternative protein sources namely, yellow lupin and rapeseed meal on growth performance and carcass composition in-line crossbred geese. The experimental design also allowed for a comparison between two genetic groups (TE and ET), thus providing insights into the putative heterosis effects and genetic variability, which are of significant interest in goose production. In discussing these findings, we compare our results with previous studies on both parental-line geese and White Kołuda Geese, whose responses to dietary modifications have been well documented [e.g., Kuźniacka *et al.* 2020, Biesek *et al.* 2020].

Our results indicate that the local protein sources diet had a multifaceted impact on growth performance. In the early rearing phase (days 0-28), geese receiving the alternative diet exhibited a slight but statistically significant reduction in body weight gain (BWG) compared to those on the SBM diet. This may be attributed to the lower digestibility or different amino acid profile of yellow lupin relative to soybean meal, as suggested by Ravindran [2013]. However, during the later growth period (days 29-119), BWG differences disminished, sugesting that geese may adapt to the alternative protein source over time. Similar adaptive responses have been observed in studies on pigs, where exposure to faba bean diets did not compromise final body weights [Biesek *et al*. 2020, Kuźniacka *et al*. 2020, Fu *et al*. 2021]. Despite comparable early performance, cumulative feed intake was higher and feed conversion ratio (FCR) was less favorable in geese fed the LPS diet, similar to White Kołuda Goose. These findings point to a trade-off between the potential economic and sustainability benefits of local protein sources and the need to optimize nutrient utilization. Similar trends have been reported in White Kołuda Geese [Kuźniacka *et. al*. 2020], where dietary modifications led to increased feed consumption, possibly due to compensatory mechanisms for lower nutrient availability. The comparative analysis between the TE and ET genetic groups revealed significant differences in body weight, suggesting that maternal effects play a crucial role in gosling development. Under ideal conditions, in the absence of specific parental influences, mean body weights should be similar between reciprocal crosses. However, in this study, geese from the TE group exhibited higher body weights than those from the ET group. This observation aligns with previous studies on maternal effects in poultry, where genetic contributions from the dam influence offspring growth and performance [Rouvier 1992, Fulla 2022]. The higher body weight observed in the TE group suggests a stronger maternal heterosis effect, where maternal inheritance may have enhanced early growth performance. Maternal effects in poultry production extend beyond direct genetic contributions to include factors such as egg quality, yolk nutrient reserves, and early post-hatch maternal imprinting. Studies on other avian species have demonstrated that genetic lines may differ in their ability to transfer nutrients during embryonic development, which can impact early growth rates and overall performance [Saleh 2020, Tai 1998]. These findings highlight the importance of considering maternal lineage in breeding programs aimed at optimizing growth performance and feed efficiency in geese. The results presented in Table 3 indicate that the protein content in goose breast muscle ranged from 22.315 to 22.589%, showing no significant differences between groups.

The lack of a significant impact of genetic factors and diet on protein content suggests that the feed composition did not substantially alter protein metabolism in goose muscles, which aligns with the observations of Adamski *et al.* [2014]. The total ash content (1.190-1.225%) fell within the range reported in the literature (1.05-1.39%), consistent with findings by Goluch *et al*. [2024] and Wereńska *et al.* [2023]. The absence of significant differences between groups indicates that the LPS diet did not significantly affect meat mineralization. The sodium chloride (NaCl) content ranged from 0.093 to 0.097%, aligning with values previously reported for goose meat, such as in the study by Haytowitz *et al*. [2019], where an average level of 0.095% was recorded. The energy value of the meat ranged from 512.11 to 534.47 kcal/100 g, which is slightly lower than the typical values for domestic geese meat, averaging 670 kcal/100 g [Haytowitz *et al*. 2019]. This difference may be attributed to a lower fat content in the meat of geese fed the LPS diet. The most significant differences were observed in water content, where significant variations between groups were recorded (73.014-73.691%). The higher water content observed in the TE LPS group further supports the influence of maternal heterosis, potentially contributing to enhanced water retention mechanisms in the muscle. Similar trends were reported by Biesek *et al.* [2020], where geese fed a diet with reduced fat content exhibited higher muscle water content. In conclusion, the obtained results in Table 3 confirm that genotype and diet composition can influence the chemical composition of goose meat. However, no significant differences were noted for protein, ash, or salt content. Energy value and water content appear to be more susceptible to dietary modifications, which should be considered in future research aimed at optimizing goose nutrition. This observation supports the hypothesis that dietary composition, especially the inclusion of lupin, may enhance water retention capacity in the muscle tissue of certain genetic lines.

The results of this study demonstrated significant differences in fat content and fatty acid profile in goose breast muscle, depending on both genetic group and dietary treatment. The fat content ranged from 3.749 to 4.232%, with a higher value observed in the ET SBM group, indicating a potential genetic influence on fat deposition. Similar findings were reported by Haraf *et al.* [2014], who suggested that differences in lipid metabolism among goose breeds may affect intramuscular fat accumulation. The obtained values were slightly lower than those observed in White Kołuda® Geese, a breed known for its high meat quality, where fat content typically ranges from 5.2 to 6,01% [Biesiada-Drzazga 2008]. It was also observed that the LPS diet, based on a lupin-enriched feed mixture, led to a reduction in total fat content, which aligns with the findings of Zhang *et al.* [2020], who indicated that plant-based protein can contribute to lipid reduction in muscle tissue.

The fatty acid profile also exhibited genotype-dependent variations. PUFA values were significantly higher in the ET LPS group, suggesting differences in lipid metabolism between genetic lines. This is consistent with the findings of Balev *et al.* [2015], who observed that breed differences influence the synthesis of polyunsaturated fatty acids. In contrast, the MUFA content was significantly lower in the TE LPS group, which may indicate a greater susceptibility of this line to dietary modifications. These results align with the findings of Gumułka *et al*. [2020], who reported that fat reduction in the diet decreases MUFA levels, although the extent of this effect may be genotype-dependent. A comparison with White Kołuda® Geese shows that their MUFA levels tend to be slightly higher, particularly in birds fed a diet rich in energy sources. The SAFA levels did not show significant differences, suggesting that their content may be less responsive to dietary and genetic changes, which is consistent with previous research on White Kołuda® Geese, where SAFA remained relatively stable despite dietary modifications [Biesiada-Drzazga *et al.* 2006].

In conclusion, the obtained results in Table 4 indicate that both genetic factors and diet composition significantly influence the lipid profile of goose breast muscle. In particular, the lupin-based diet was effective in increasing PUFA levels and reducing fat content; however, the extent of these changes was dependent on the birds' genotype. The higher PUFA levels in the ET LPS group suggest an interplay between maternal inheritance and lipid metabolism, reinforcing the importance of maternal heterosis in fat composition. Comparisons with White Kołuda® Geese suggest that these birds may have a slightly higher fat content and MUFA levels, which could be an important consideration for breeding strategies. These findings may have significant implications for goose breeding in terms of optimizing the fat composition of meat for both nutritional and technological purposes. It should be stressed considerable heterosis effects for geese meat quality have been reported by some authors as well [Huang *et al.* 2023]. The comparative analysis between the TE and ET genetic groups underscored the role of genetic factors in mediating responses to dietary modifications. Minor differences in initial body weights and carcass yields, as well as differential responses in meat quality parameters, suggest that heterosis may play a role in how geese metabolize and utilize alternative protein sources. These observations are in line with previous reports on White Koluda Geese [Biesiada Drzazga 2014], emphasizing that the genetic background is an important determinant of feed efficiency and carcass composition. Future studies should further dissect these genetic influences, potentially exploring gene-diet interactions to optimize breeding strategies in conjunction with alternative feeding regimes.

The increasing global demand for high-quality poultry products has prompted the exploration of sustainable and locally available feed resources. Our findings provide promising evidence that yellow lupin with faba bean can serve as a viable alternative to soybean meal without adversely affecting key meat quality traits. This shift not only has the potential to reduce feed costs but also supports local agriculture and reduces reliance on imported protein sources. The improvements observed in the fatty acid profile and certain sensory attributes further suggest that dietary adjustments can be used as a tool to enhance the nutritional and organoleptic quality of goose meat - a finding that is particularly relevant for both conventional and niche markets [Khan 2024, Sedláková 2016].

A key aspect of the study's practical implications is the comparison of the observed genetic groups with other goose populations, particularly the widely utilized White Kołuda Geese. While the crossbreds exhibited promising production traits, including favorable meat quality parameters and a beneficial fatty acid profile, their feed efficiency and growth rates should be evaluated in the context of established commercial breeds. White Kołuda Geese, known for their superior feed conversion efficiency and rapid growth [Biesek 2020], have been extensively studied in alternative feeding trials. Research has shown that dietary modifications, including the inclusion of alternative protein sources, can influence their feed intake and carcass composition [Biesek 2020, Kuźniacka 2020, Zduńczyk 2016]. In comparison, the crossbreds in this study demonstrated an increased feed intake and a less favorable feed conversion ratio, similar to previous reports on alternative feeding strategies in White Kołuda Geese. These results suggest that while dietary interventions can improve meat quality and sustainability, further refinements are needed to enhance efficiency. Future studies should explore whether targeted genetic selection within these crossbred populations can optimize their response to alternative protein sources, potentially bridging the gap between their performance and that of commercial breeds like White Kołuda Geese.

A comparison between the crossbreed geese and White Kołuda geese reveals differences in growth performance, meat quality, and fatty acid profile. While White Kołuda Geese are recognized as one of the most commercially important breeds in Europe, our study clearly demonstrates that the crossbreed geese exhibit superior body weight at every growth stage. By week 17, the body weight of our geese surpasses the typical slaughter weight of White Kołuda Geese [Kuźniacka *et al*. 2020, Biesiada Drzazga 2014]. The greater body mass observed in our crossbreed geese can be attributed to both their genetic potential and more efficient feed utilization over a longer rearing period.

In terms of meat quality, both genetic groups display high protein content in breast muscles, exceeding 21%, which aligns with previous findings on White Kołuda Geese [Haraf *et al*. 2014]. However, a distinct difference is observed in fat deposition. Our study revealed that the crossbreed geese, exhibit lower intramuscular fat content compared to White Kołuda Geese, particularly in breast muscles, making them a more attractive option for consumers seeking leaner poultry meat [Biesek *et al.* 2020]. In contrast, White Kołuda Geese, especially those subjected to oat fattening, accumulate higher levels of subcutaneous fat, which contributes to their characteristic flavor and texture [Biesiada-Drzazga 2014].

The fatty acid profile analysis further highlights differences between these two genetic groups. Previous studies have shown that White Kołuda Geese tend to have a higher concentration of monounsaturated fatty acids (MUFA), particularly oleic acid (C18:1), which enhances the sensory attributes of meat [Haraf *et al.* 2014, Biesiada-Drzazga 2008]. However, our founding's indicate that crossbreed geese, especially those fed a lupin-based diet, exhibit a higher proportion of polyunsaturated fatty acids (PUFA), particularly omega-3 fatty acids, which are associated with health benefits

[Kuźniacka *et al*. 2020]. Notably, the PUFA/SFA ratio in our geese was more favorable than in White Kołuda Geese, suggesting a higher nutritional value of the meat.

Slaughter performance analysis further reinforces the advantages of the crossbreed geese over White Kołuda Geese. While White Kołuda Geese are known for their high slaughter yield our study demonstrated that the crossbreed geese achieved even higher carcass weights, with lower fat deposition. The muscle-to-body mass ratio was more favorable in our group, suggesting that these geese could serve as a valuable alternative for the meat industry, offering both superior yield and enhanced meat quality [Adamski *et al.* 2014].

While the current study provides valuable insights, several limitations should be noted. The increased FCR observed in the LPS groups suggests that further refinement of the feed mixture - specifically optimizing the balance between lupin and faba bean is required to better harmonize sustainable, feed use with production efficiency. Future research should focus on fine-tuning the feed formulation and conducting detailed metabolic studies to elucidate the digestibility and amino acid utilization of lupin and faba bean proteins in geese.

Conclusion

This study demonstrates that replacing soybean meal with yellow lupin as the primary protein source in goose diets positively influences growth performance, meat quality, and sensory attributes.. The increased PUFA content and improved sensory parameters highlight the nutritional benefits of such interventions. The crossbred geese achieved a higher final body weight than White Kołuda Geese, both in the SBM and LPS groups. Despite challenges with feed efficiency, our results underscore the potential of alternative protein sources in sustainable goose production. Our findings indicate that the TE genetic group outperformed ET in overall body weight and carcass weight, suggesting a maternal effect from the Tapphorn line, favoring the TE cross for commercial production. The study aimed to develop a hybrid goose population achieving higher body weights at 17 weeks without compromising meat quality or feed conversion ratio. This goal was successfully met, as the crossbred geese maintained acceptable crude fat and protein levels. The inclusion of yellow lupin and rapeseed meal improved the meat's nutritional profile without significantly impacting growth. These findings offer valuable insights for optimizing goose breeding and feeding strategies, supporting sustainable production. Further research on feed formulation and genetic influences will aid commercial application.

Declaration of competing interest

The authors confirm that there are no conflicts of interest associated with this publication.

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