

Dietary supplementation with herbs and microalgae in HYL rabbits: Effects on metabolism, carcass traits, and meat quality

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Received July 3, 2026

Accepted September 7, 2026

Abstract

The aim of this study was to evaluate the dietary effects of phytogetic supplements on selected blood profile indices in young rabbits, and their consequences on carcass traits and meat quality. Forty weaned farm rabbits were randomly divided into four groups: Control (C), Artichoke leaves (receiving a diet supplemented with 2.5% artichoke; A), Herbs (receiving a diet supplemented with a five-herb mixture, each included at 0.5%; H), and Green Algae (receiving a diet supplemented with 1.25% *Chlorella vulgaris* and 1.25% *Arthrospira platensis*; GA). At 80 days of age, rabbits were slaughtered at a slaughterhouse, and samples of blood and muscle were taken. The most pronounced dietary effects were observed in rabbits fed the artichoke- and green algae-supplemented diets, where reduced glutathione S-transferase ($P < 0.01$) and aspartate aminotransferase ($P < 0.01$) activities coincided with increased concentrations of both total protein and albumin ($P < 0.01$), suggesting lower oxidative stress and improved metabolic adaptation. The chosen dietary supplements did not affect carcass traits, with the exception of hind leg weight and hind leg percentage ($P < 0.05$). The highest amino acid (AA) values were consistently recorded in the artichoke group (A), showing a marked increase in critical limiting AA such as lysine and leucine ($P < 0.01$). These findings suggest that the phytogetic additives used in this study induced significant changes in the metabolism of fattening rabbits, particularly related to muscle protein synthesis and protein metabolism in rabbits.

Phytogetic additives, artichoke, spirulina, rabbit meat quality, blood indicators

Phytogetic products are widely studied as dietary supplements for both farm and pet animals. Intensively farmed animals are usually fed a uniform diet, which provides sufficient protein and energy; however, it may still be deficient in antioxidants, and other bioactive compounds. These animals may suffer from various health problems associated with oxidative stress (Lykkesfeld and Svendsen 2007), which is one of the reasons why the addition of phytogetic additives has been found beneficial for both animal health and the quality of animal products (Kowalczyk-Vasilev et al. 2025). Antioxidants can also mitigate the adverse effects of contaminants present in feed (Moumen et al. 2024).

Plants traditionally used as culinary or medicinal herbs are often tested as animal feed additives. Thyme (*Thymus vulgaris*) has strong antioxidative properties and has been proven effective in enhancing digestion and immunity in pigs (Czech et al. 2023). Fennel (*Foeniculum vulgare*) also provides antioxidants and supports digestive efficiency, thereby improving weight gain in broiler chickens (Liu et al. 2021). Apart from antioxidants, some phytogetic additives are also valued as sources of dietary fibre. Fructan inulin, considered beneficial for intestinal microflora (Samanta et al. 2013), is common in plants from the *Asteraceae* family, including artichoke (*Cynara scolymus*), which is cultivated for its flower buds; thus, the leaves are considered a low-cost by-product (Monllor et al. 2020). In rabbits, artichoke supports both digestion and mycotoxin resistance (Gad et al. 2025).

Another group of popular supplements includes the microalgae *Chlorella vulgaris* and

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Arthrospira platensis. Microalgae are valued for their high protein content, quick growth, and independence from arable soil. Both species are currently used in livestock feeding; they can partially replace soybean in the diet (Don et al. 2025), while also enhancing nitrogen metabolism and microbial populations (Malyugina 2025). Due to their intensive growth, farmed rabbits have increased requirements for maintaining good health status and welfare during both fattening and transport (Lakomá et al. 2025).

The use of feed supplements that enhance rabbit metabolism against oxidative stress, with the aim of improving meat quality, is one of the important concerns in rabbit farming and meat production (Abdelnour et al. 2019). Therefore, the aim of this study was to evaluate the dietary effects of various natural phytogetic supplements on selected blood profile indicators in young farmed rabbits, and their consequences on carcass traits, as well as the composition and quality of rabbit meat.

Materials and Methods

Animals and experimental design

A total of forty weaned HYLA rabbits, 35 days of age, were used in a dietary trial conducted at the Genetic HYL A Rabbit Centre in Jaroměřice nad Rokytnou-Ratibořice (Czech Republic). The rabbits were randomly divided into one control group and three experimental groups. Each group consisted of ten rabbits (five males and five females). The dietary groups were formed to ensure equal average body weight at the beginning of the experiment. Each rabbit was individually identified using an ear tag number. The rabbits were housed in standard farm wire cages, with two rabbits per cage (one male and one female). The lighting regime was 12 h light/12 h dark. The ambient temperature ranged from 17 °C to 21 °C, and relative humidity was maintained between 55% and 60%. The health status of all rabbits was checked daily.

Throughout the entire feeding trial (from 35 to 80 days of age), the rabbits received pelleted complete diets (producer Biokron, s.r.o., Blučina, Czech Republic) under an *ad libitum* feeding regime. The basic (control) diet consisted of the following components: alfalfa pellets, wheat bran, white lupine seeds, straw, sugar beet pulp, barley, molasses, monocalcium phosphate, limestone, a mineral and vitamin premix, and salt. During the fattening period, rabbits were fed four types of pelleted diets: a control basal diet without additions (C; n = 10), a diet with the addition of 2.5% dried artichoke (*Cynara scolymus*) leaves (A; n = 10), a diet enriched with a mixture of five dried herbs (*Thymus vulgaris*, *Capsella bursa-pastoris*, *Rosa canina*, *Mentha piperita*, *Foeniculum vulgare*), each included at 0.5% (H; n = 10), and a diet with the addition of 1.25% *Arthrospira platensis* powder and 1.25% *Chlorella vulgaris* powder (GA; n = 10). Chemical analysis of the experimental diets was performed as described by Gál et al. (2022), and the analysed nutrient composition is presented in Table 1. Drinking water was provided *ad libitum* via nipple drinkers.

Table 1. Analysed nutrients (g/kg in 1 kg 100% dry matter) of pelleted diets for rabbits.

Analysed nutrients	Dietary group			
	C	A	H	GA
Crude protein	198.6	191.1	194.4	202.0
Crude fat	20.5	23.1	21.8	24.4
Crude fibre	182.3	180.6	184.7	177.6
Acid detergent fibre	241.7	246.1	243.4	229.7
Neutral detergent fibre	435.4	440.6	425.2	431.5
Acid detergent lignin	65.8	66.4	63.5	59.0
Crude starch	124.7	117.4	115.6	115.1
Ash	108.9	111.8	111.3	117.3
Calcium	14.2	14.5	14.7	17.9
Inorganic phosphorus	7.2	8.3	5.5	8.9

C, control group; A, 2.5% addition of dried artichoke leaves; H, addition of 5 herbs at 0.5% each; GA, addition of 1.25% spirulina and 1.25% chlorella

Sampling and slaughter traits

At 80 days of age, all rabbits were individually weighed and subsequently slaughtered in accordance with legislative requirements at a slaughterhouse. All rabbits were mechanically stunned using a captive bolt gun, immediately suspended by the hind legs, and exsanguinated by severing the jugular veins and carotid arteries, at which point blood samples were collected. Plasma was obtained from blood samples by centrifugation. Carcass processing was performed according to the methodology described by Blasco and Ouhayoun (1996). A total of 20 samples (five samples per dietary group) of *musculus longissimus dorsi* were collected from rabbit carcasses immediately after slaughter. All samples were stored in a portable refrigerator set to 4 °C. Subsequently, the samples were frozen and stored at -20 °C until analysis.

Laboratory methods

The proximate chemical composition and amino acid (AA) profile of the meat samples were determined according to the methodology described by Gál et al. (2022). Briefly, dry matter and ash contents were measured gravimetrically, crude protein was analysed using the Kjeldahl method (Buchi analyzer, Donau Lab s.r.o., Prague, Czech Republic), and crude fat was determined using the Soxhlet method (Soxtec apparatus, Thermo Scientific, Warrington, UK). The total amino acid profile, including essential (EAA), non-essential (NEAA), and semi-essential (SEAA) amino acids, was quantified using an Automatic Amino Acid Analyzer AAA 400 (Ingos s.r.o., Prague, Czech Republic) by ion-exchange chromatography with photometric detection.

Blood plasma biochemical indices, including glucose (GLC), total protein (TP), albumin (ALB), triacylglycerols (TAG), cholesterol (CHOL), creatinine (CREA), creatine kinase (CK), alkaline phosphatase (ALP), alanine aminotransferase (ALT), aspartate aminotransferase (AST), and gamma-glutamyl transferase (GGT), were analysed using an automated biochemical analyser (Thermo Fisher Scientific, Brno, Czech Republic) with commercial diagnostic kits (BioVendor, Brno, Czech Republic). Globulin (GLO) content was calculated. Blood plasma samples were also used for the determination of glutathione peroxidase (GPx) and glutathione S-transferase (GST) activities: GPx activity was determined spectrophotometrically by monitoring NADPH oxidation at 340 nm; GST activity was measured using 1-chloro-2,4-dinitrobenzene (CDNB) as a substrate. Total protein concentration was determined using the bicinchoninic acid (BCA) assay, and enzyme activities were expressed per milligram of protein.

Statistical analysis

The data were statistically analysed using STATISTICA CZ version 10 software (StatSoft Inc., Tulsa, USA). Arithmetic means and standard errors of the mean (SEM) were calculated for particular slaughter traits, biochemical and oxidative stress indices, chemical composition, and amino acid content of rabbit meat. Normality of data distribution across the evaluated groups was verified using Shapiro-Wilk test and K-S & Lilliefors test. Normal distribution was confirmed for all variables. When one-way ANOVA revealed significant differences among groups, Tukey's *post hoc* test was applied. Statistical significance was set at $P < 0.05$ and $P < 0.01$.

Results

Effect of dietary supplements on metabolism and blood indices

Dietary supplementation significantly affected several biochemical and oxidative stress indices (Table 2). Compared to the control group (C), CK activity was significantly lower in group H (-11.72 $\mu\text{kat/l}$, $P < 0.05$). Notably, a highly significant decrease in AST activity was observed across all supplemented groups: A (-0.75 $\mu\text{kat/l}$, $P < 0.01$), H (-0.75 $\mu\text{kat/l}$, $P < 0.01$) and GA (-0.64 $\mu\text{kat/l}$, $P < 0.01$). In contrast, group GA showed highly significant increases in TP (+9.25 g/l, $P < 0.01$), ALB (+5.78 g/l, $P < 0.01$) and GLO (+3.47 g/l, $P < 0.01$) compared to the control group. Regarding oxidative stress markers, GST activity was lowest in group H, showing a highly significant decrease compared with group GA (-25.18 nmol/min, $P < 0.01$) and a significant decrease compared with group A (-5.68 nmol/min, $P < 0.05$).

Effect of dietary supplements on carcass traits

The dietary regime had no significant effect on rabbit slaughter weight or carcass characteristics, with the exception of hind leg weight, and hind leg-to-carcass percentage (Table 3). The rabbits in group H showed a higher hind leg weight than those receiving diet A (+98 g, $P < 0.05$). Similarly, rabbits fed the herbal mixture diet exhibited higher hind

Table 2. Blood biochemical profile of rabbits in dietary groups (mean $\pm$ SEM).

Indicator	Dietary group			
	C	A	H	GA
Creatinine ($\mu\text{mol/l}$)	109.75 $\pm$ 6.74	101.98 $\pm$ 3.01	102.26 $\pm$ 3.04	105.00 $\pm$ 5.50
CK ($\mu\text{kat/l}$)	31.15 $\pm$ 5.18 ^a	30.36 $\pm$ 2.81	19.43 $\pm$ 1.10 ^b	28.25 $\pm$ 4.39
ALP ($\mu\text{kat/l}$)	1.81 $\pm$ 0.06 ^a	2.11 $\pm$ 0.13	1.98 $\pm$ 0.08	2.22 $\pm$ 0.19 ^b
ALT ($\mu\text{kat/l}$)	0.90 $\pm$ 0.16	0.82 $\pm$ 0.07	0.98 $\pm$ 0.12	0.89 $\pm$ 0.07
AST ($\mu\text{kat/l}$)	1.54 $\pm$ 0.07 ^A	0.79 $\pm$ 0.16 ^B	0.79 $\pm$ 0.12 ^B	0.90 $\pm$ 0.19 ^B
GGT ($\mu\text{kat/l}$)	0.04 $\pm$ 0.01	0.07 $\pm$ 0.02	0.08 $\pm$ 0.01	0.06 $\pm$ 0.02
TP (g/l)	53.93 $\pm$ 1.67 ^B	55.00 $\pm$ 1.35 ^B	54.96 $\pm$ 1.21 ^B	63.18 $\pm$ 3.04 ^A
ALB (g/l)	35.75 $\pm$ 0.53 ^B	37.13 $\pm$ 0.73 ^B	35.55 $\pm$ 0.92 ^B	41.53 $\pm$ 1.77 ^A
TAG (mmol/l)	0.71 $\pm$ 0.08	0.75 $\pm$ 0.07	0.95 $\pm$ 0.12	1.07 $\pm$ 0.26
CHOL (mmol/l)	1.71 $\pm$ 0.16	1.71 $\pm$ 0.05	2.03 $\pm$ 0.15	1.77 $\pm$ 0.06
GLC (mmol/l)	7.18 $\pm$ 0.34	7.78 $\pm$ 0.92	7.01 $\pm$ 0.27	8.03 $\pm$ 0.57
GLO (g/l)	18.18 $\pm$ 1.16 ^B	17.86 $\pm$ 0.81 ^B	19.41 $\pm$ 1.18	21.65 $\pm$ 1.34 ^A
A/G	1.99 $\pm$ 0.09	2.09 $\pm$ 0.08	1.86 $\pm$ 0.12	1.93 $\pm$ 0.06
GPx (nmol NADPH/min)	550.07 $\pm$ 71.46	651.47 $\pm$ 68.89	528.61 $\pm$ 78.87	543.73 $\pm$ 19.44
GST (nmol/min)	41.02 $\pm$ 7.97	28.86 $\pm$ 4.91 ^b	23.18 $\pm$ 2.99 ^{aA}	48.36 $\pm$ 7.94 ^B

C, control group; A, 2.5% addition of dried artichoke leaves; H, addition of 5 herbs at 0.5% each; GA, addition of 1.25% spirulina and 1.25% chlorella; CK, creatine kinase; ALP, alkaline phosphatase; ALT, alanine aminotransferase; AST, aspartate aminotransferase; GGT, gamma-glutamyl transferase; TP, total protein; ALB, albumin; TAG, triacylglycerols; CHOL, cholesterol; GLC, glucose; GLO, globulin; A/G, albumin/globulin ratio; GPx, glutathione peroxidase; GST, glutathione S-transferase; ^{a,b} values with different superscripts differ significantly ($P < 0.05$); ^{A,B} values with different superscripts differ highly significantly ($P < 0.01$)

Table 3. Mean slaughter weights (g) and carcass characteristics of rabbits from dietary groups (mean $\pm$ SEM).

Trait	Dietary group			
	C	A	H	GA
Initial live weight (g)	1,193.00 $\pm$ 24.17	1,203.00 $\pm$ 21.89	1,211.00 $\pm$ 36.55	1,223.00 $\pm$ 14.20
Live weight at slaughter (g)	2,594.00 $\pm$ 152.79	2,459.00 $\pm$ 39.16	2,624.00 $\pm$ 137.24	2,622.00 $\pm$ 64.49
Hot carcass weight (g)	1,399.60 $\pm$ 88.36	1,294.40 $\pm$ 21.81	1,419.60 $\pm$ 91.63	1,408.40 $\pm$ 65.21
Skin weight (g)	464.00 $\pm$ 27.86	466.00 $\pm$ 39.03	464.00 $\pm$ 39.48	490.00 $\pm$ 26.08
Forepart weight (g)	386.20 $\pm$ 30.37	360.40 $\pm$ 12.10	426.20 $\pm$ 28.39	406.00 $\pm$ 22.16
Midpart part weight (g)	294.80 $\pm$ 25.11	297.60 $\pm$ 18.15	299.60 $\pm$ 19.69	298.60 $\pm$ 16.98
Hind leg weight (g)	410.00 $\pm$ 26.65	384.00 ^b $\pm$ 5.10	482.00 ^a $\pm$ 48.41	411.00 $\pm$ 16.53
Head weight (g)	119.00 $\pm$ 4.00	114.80 $\pm$ 3.54	113.20 $\pm$ 6.53	115.20 $\pm$ 2.87
Skin of carcass (%)	33.20 $\pm$ 0.99	35.90 $\pm$ 2.72	32.60 $\pm$ 1.40	34.80 $\pm$ 1.07
Forepart of carcass (%)	27.50 $\pm$ 0.71	27.80 $\pm$ 0.56	30.40 $\pm$ 2.43	28.80 $\pm$ 0.32
Midpart of carcass (%)	20.90 $\pm$ 0.27	23.10 $\pm$ 1.74	21.30 $\pm$ 1.63	21.20 $\pm$ 0.28
Hind leg of carcass (%)	29.30 ^b $\pm$ 0.30	29.70 ^b $\pm$ 0.12	33.90 ^a $\pm$ 2.40	29.20 ^b $\pm$ 0.39
Head of carcass (%)	8.60 $\pm$ 0.30	8.90 $\pm$ 0.39	8.10 $\pm$ 0.49	8.20 $\pm$ 0.25
Dressing percentage (%)	53.90 $\pm$ 0.00	52.70 $\pm$ 0.01	54.00 $\pm$ 0.01	53.60 $\pm$ 0.01

C, control group; A, 2.5% addition of dried artichoke leaves; H, addition of 5 herbs at 0.5% each; GA, addition of 1.25% spirulina and 1.25% chlorella; ^{a,b} values with different superscripts differ significantly ($P < 0.05$)

Table 4. Proximate chemical composition and amino acid content of rabbit meat in dietary groups (mean $\pm$ SEM).

Trait	Dietary group			
	C	A	H	GA
Chemical composition (g/kg dry matter)				
Dry matter	245.42 $\pm$ 6.66	239.08 $\pm$ 4.04	241.03 $\pm$ 4.34	246.98 $\pm$ 8.17
Crude protein	876.65 $\pm$ 9.73	888.76 $\pm$ 18.67	893.48 $\pm$ 12.74	821.68 $\pm$ 55.20
Crude fat	84.35 $\pm$ 9.27	79.15 $\pm$ 18.14	75.39 $\pm$ 11.19	92.47 $\pm$ 19.30
Ash	48.26 $\pm$ 0.76	48.94 $\pm$ 0.83	48.21 $\pm$ 0.74	48.12 $\pm$ 1.65
Amino acid content (g/kg dry matter)				
Lys	59.25 $\pm$ 1.35 ^{ACD}	64.51 $\pm$ 1.38 ^B	54.61 $\pm$ 0.48 ^{AC}	52.28 $\pm$ 0.77 ^{AD}
His	31.14 $\pm$ 1.12 ^{AaCD}	34.86 $\pm$ 0.97 ^B	31.43 $\pm$ 0.33 ^C	28.48 $\pm$ 0.64 ^{bCD}
Phe	32.62 $\pm$ 1.06 ^A	37.27 $\pm$ 1.43 ^B	31.56 $\pm$ 0.30 ^A	28.90 $\pm$ 0.61 ^A
Leu	61.10 $\pm$ 1.47 ^A	66.67 $\pm$ 1.61 ^B	54.65 $\pm$ 0.53 ^A	51.63 $\pm$ 0.71 ^A
Iso	36.57 $\pm$ 1.28 ^A	41.09 $\pm$ 1.37 ^B	34.36 $\pm$ 0.49 ^{Ab}	31.28 $\pm$ 0.61 ^{Aa}
Met	22.43 $\pm$ 0.88	24.64 $\pm$ 1.70 ^{Bb}	20.84 $\pm$ 0.53 ^a	19.17 $\pm$ 0.64 ^A
Val	39.67 $\pm$ 1.79 ^a	44.10 $\pm$ 1.43 ^{Bb}	37.59 $\pm$ 0.48 ^A	34.29 $\pm$ 0.63 ^A
Tre	38.30 $\pm$ 1.24 ^A	43.56 $\pm$ 1.81 ^B	38.47 $\pm$ 0.34 ^A	35.16 $\pm$ 0.84 ^A
Total EAA	321.08 $\pm$ 9.99 ^{AC}	356.70 $\pm$ 11.29 ^{BD}	303.49 $\pm$ 2.78 ^{CD}	281.19 $\pm$ 4.72 ^{AD}
Asp	73.31 $\pm$ 2.20 ^{bB}	82.94 $\pm$ 2.51 ^B	67.15 $\pm$ 0.78 ^a	61.92 $\pm$ 1.19 ^A
Ser	33.31 $\pm$ 0.92 ^A	37.83 $\pm$ 1.40 ^B	33.15 $\pm$ 0.27 ^A	30.62 $\pm$ 0.80 ^A
Glu	129.23 $\pm$ 4.35 ^{Ab}	146.24 $\pm$ 5.60 ^B	128.13 $\pm$ 1.37 ^A	116.57 $\pm$ 3.21 ^{Aa}
Ala	46.18 $\pm$ 0.94 ^{aB}	49.34 $\pm$ 1.33 ^{bC}	42.37 $\pm$ 0.40 ^A	40.11 $\pm$ 0.57 ^A
Total NEAA	282.03 $\pm$ 8.36 ^A	316.35 $\pm$ 10.77 ^B	270.80 $\pm$ 2.52 ^C	249.21 $\pm$ 5.68 ^{AC}
Pro	34.30 $\pm$ 0.74 ^a	39.23 $\pm$ 1.89 ^{Bb}	34.18 $\pm$ 0.72 ^a	31.74 $\pm$ 1.50 ^A
Gly	40.38 $\pm$ 0.49 ^{BC}	42.35 $\pm$ 1.05 ^C	35.22 $\pm$ 0.58 ^A	33.82 $\pm$ 0.66 ^A
Cys	7.87 $\pm$ 0.89	7.84 $\pm$ 0.76	8.03 $\pm$ 0.16	7.26 $\pm$ 0.25
Tyr	28.77 $\pm$ 0.98 ^{BCb}	33.08 $\pm$ 1.30 ^A	28.77 $\pm$ 0.15 ^C	26.14 $\pm$ 0.59 ^a
Arg	56.72 $\pm$ 1.84 ^{AD}	65.96 $\pm$ 2.18 ^{BCD}	15.05 $\pm$ 0.32 ^{AC}	57.32 $\pm$ 1.18 ^{AD}
Total SEAA	168.03 $\pm$ 3.98 ^{AD}	188.47 $\pm$ 6.61 ^{BCD}	121.25 $\pm$ 1.13 ^{AC}	156.28 $\pm$ 3.46 ^{AD}
Total AA	771.14 $\pm$ 21.97 ^A	861.52 $\pm$ 28.51 ^{BCD}	695.54 $\pm$ 5.57 ^{AC}	686.68 $\pm$ 13.46 ^{AD}

C, control group; A, 2.5% addition of dried artichoke leaves; H, addition of 5 herbs at 0.5% each; GA, addition of 1.25% spirulina and 1.25% chlorella; Lys, lysine; His, histidine; Phe, phenylalanine; Leu, leucine; Iso, isoleucine; Met, methionine; Val, valine; Tre, threonine; EAA, essential amino acids; Asp, aspartate; Ser, serine; Glu, glutamate; Ala, alanine; NEAA, non-essential amino acids; Pro, proline; Gly, glycine; Cys, cysteine; Tyr, tyrosine; Arg, arginine; SEAA, semi-essential amino acids; AA, amino acids; ^{a,b} values with different superscripts differ significantly ($P < 0.05$); ^{A,B} values with different superscripts differ highly significantly ($P < 0.01$)

leg-to-carass percentage compared with rabbits in groups GA, C, and A (+4.7%, $P < 0.05$; +4.6%, $P < 0.05$; and +4.2%, $P < 0.05$, respectively).

Effect of dietary supplements on proximal chemical composition and amino acid profile of rabbit meat

Dietary supplementation did not significantly influence the proximate chemical composition of the rabbit meat (Table 4). No significant differences ($P > 0.05$) were observed among experimental groups in dry matter, crude protein, crude fat, or ash contents. In contrast, the amino acid profile was significantly affected by the diet, with the exception of cysteine. Compared to the control group, rabbits in group A consistently

showed the highest amino acid concentrations, reaching significantly higher values for EAA (+35.62 g/kg, $P < 0.01$), NEAA (+34.32 g/kg, $P < 0.01$) and TAA (+90.38 g/kg, $P < 0.01$). Conversely, the lowest amino acid contents were recorded in groups H and GA, corresponding to the rabbits fed the herbal mixture and microalgae-supplemented diets, respectively. Notably, a highly significant decrease was observed in group H for arginine (−41.67 g/kg, $P < 0.01$) and total SEAA (−46.78 g/kg, $P < 0.01$) compared to the control group.

Discussion

Effect of dietary supplements on metabolism and blood indices

GPx activity did not differ significantly among dietary groups, although the highest mean value was observed in the artichoke-supplemented group and the lowest in the herbal mixture group. Stable GPx activity may indicate that the phytogetic additives did not induce oxidative stress of a magnitude requiring an adaptive increase in this enzyme activity. Previous studies in rabbits have shown that microalgae supplementation can influence antioxidant status and glutathione-related responses, depending on algal species, inclusion level, and the physiological condition of the animals (Kim et al. 2010; Abdelnour et al. 2019; El Basuini et al. 2023). In contrast, GST activity was significantly affected by dietary supplementation. The lowest activity was observed in the herbal mixture group, whereas the highest value was detected in the microalgae group. As GST is involved in glutathione-dependent detoxification of reactive metabolites and lipid peroxidation products, these differences may reflect diet-related modulation of detoxification pathways (Kim et al. 2010). The higher GST activity in the microalgae group may be associated with bioactive compounds in spirulina and chlorella, such as chlorophylls, carotenoids, phycocyanin, and tocopherols, which have been associated with improved antioxidant status in rabbits (Abdelnour et al. 2019; El Basuini et al. 2023).

The biochemical profile indicated no adverse effects of the tested dietary supplements. CK concentration did not differ among groups, suggesting no evidence of renal dysfunction. ALP activity was higher in the microalgae group than in the control group, but this was not accompanied by increased ALT or AST activities and therefore is unlikely to indicate liver damage. ALT activity was unaffected by diet, whereas AST activity was lower in all supplemented groups than in the control group, suggesting a possible beneficial effect on cellular integrity. Plasma concentrations of TP and ALB were highest in the GA group, which may reflect improved protein metabolism or nutrient utilisation associated with spirulina and chlorella supplementation. Similar effects on blood variables and antioxidant indices have been reported in growing rabbits (Abdelnour et al. 2019; El Basuini et al. 2023). Globulin concentration was also higher in the GA group than in some other groups, suggesting a possible influence on protein metabolism or immune-related plasma fractions. No significant differences were observed in TAG, CHOL, or GLC concentrations. Although the microalgae group showed numerically higher TAG and GLC values, these differences were not significant and did not indicate impaired metabolic homeostasis. Overall, the results suggest that the tested phytogetic supplements modulated selected antioxidant and biochemical indices without evidence of renal, hepatic, or metabolic impairment.

Effect of dietary supplements on carcass traits

The weight of rabbit carcass and cuts is one of the major characteristics important for modern consumers. Based on the results of the present study, supplementation of all chosen plant-based feed additives to the complete diet did not affect the majority of carcass traits in the fattening rabbits. These results support findings of Adli et al. (2024), who concluded that herbal plant supplementation had no major effects on rabbit organ weights and carcass

quality parameters. Besides, in the present study, significantly the highest hind leg weight and percentage were found in the rabbits receiving a five-herb mixture compared to all other evaluated dietary groups ($P < 0.05$). This finding suggests a selective effect on the growth and development of thigh muscles without significant changes in carcass yield of the rabbits ($P > 0.05$), and possible synergistic effects of the five-herb mixture supplement. The thigh cuts represent the most preferred part of the rabbit carcass (Szendrő et al. 2020). Synergistic effects of an herbal mixture consisting of thyme, anise, mint, rosemary, and black seed on the intestinal microbial population have been reported in 13-week-old rabbits; however, this dietary supplementation did not affect carcass traits, including hindquarters percentage (Abou-Kassem et al. 2025).

Effect of dietary supplements on proximal chemical composition and amino acid profile of rabbit meat

The proximate chemical composition of the *m. longissimus dorsi* remained unaffected by the dietary supplementation ($P > 0.05$), demonstrating high stability across all experimental groups. The contents of dry matter, crude protein, and fat observed in the present study are consistent with the findings of previous studies for commercial hybrids selected for high muscularity and low-fat deposition (Tůmová et al. 2014; Cullere and Dalle Zotte 2018).

The highest individual and cumulative AA values were consistently recorded in the *m. longissimus dorsi* of rabbits receiving 2.5% dried artichoke leaves (Group A), showing a profound elevation in critical limiting EAAs such as lysine and leucine compared with the control. The significant increase in muscular AA content observed in Group A may be attributed to the hepatoprotective and anti-inflammatory properties of artichoke phytochemicals, such as cynarin and chlorogenic acid (Salem et al. 2017). By optimizing hepatic function and stimulating bile secretion, these compounds enhance intestinal nutrient micellization and nitrogen digestibility, leading to higher AA deposition in muscle tissue. The high content of total AA and EAA found in both the control and artichoke groups aligns closely with the findings reported by Gál et al. (2022), who confirmed that the *m. longissimus thoracis et lumborum* naturally acts as the primary reservoir for essential AAs in commercial meat rabbits. Conversely, the supplementation of microalgae in group GA induced a significant decrease in nearly all evaluated amino acids, culminating in the lowest recorded levels of total AA and EAA. Although both microalgae species are recognized for their rich individual AA profiles, their structural effects on protein deposition require careful evaluation (El Basuini et al. 2023). The reduced bio-accessibility and suboptimal ileal digestibility of these algal proteins in rabbits are likely limited by the rigid, complex cellulosic matrix of their cell walls, which resists endogenous digestive enzymes if no mechanical or chemical disruption is applied (Spínola et al. 2023). Furthermore, the metabolic impact of spirulina on amino acid deposition is strictly dose-dependent (Mahmoud et al. 2017); thus, the low inclusion rate (1.25% of each microalga in the present study) might have been insufficient to overcome these digestibility barriers. This sensitivity of the loin muscle AA matrix to minor dietary or genetic deviations aligns with Gál et al. (2022). These findings suggest that alternative dietary adjustments may have unintentionally interfered with the high-efficiency metabolism of commercial HYL hybrids, highlighting the need for further optimization of microalgae inclusion rates and processing methods in rabbit nutrition.

A significant metabolic shift was observed in group H, where the rabbits received a diet supplemented with a five-herb mixture, and where arginine (Arg) concentration markedly decreased to 15.05 g/kg compared to the control (56.72 g/kg; $P < 0.01$). This depletion suggests a localized metabolic shunt, as Arg is a critical semi-essential amino acid that plays a pivotal role in the urea cycle and nitric oxide generation (Wu et al.

2009). Phytogetic compounds within herbal mixtures, such as volatile essential oils, can act as potent enzymatic modulators (Windisch et al. 2008). It is likely that the specific herb combination accelerated the utilization of endogenous arginine to support immune responses and reduce oxidative stress, as previously documented in rabbits by Plachá et al. (2013), thereby reducing the pool available for skeletal muscle deposition.

Overall, the results of the present study suggest that the tested phytogetic additives resulted in significant changes in the metabolism of intensively fattened rabbits, with consequences to muscle protein synthesis. The chosen alternative feed supplements showed predominantly beneficial or neutral effects on rabbit health status. The most pronounced effects were observed in rabbits fed a diet with artichoke and a diet supplemented with microalgae, where reduced GST and AST activities coincided with increased TP and ALB concentrations, suggesting lower oxidative damage intensity and improved metabolic adaptation. These findings support the use of chosen phytogetic feed additives as a promising strategy for improving health status and oxidative stability in intensive rabbit production systems, while further systematic optimization of enriched diets is needed to clarify and deepen their specific effects on amino acid bioavailability and rabbit protein metabolism.

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