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Effects of dietary inclusion of condensed tannins from *Schinopsis lorentzii* and age on the physicochemical properties, and the content of minerals and amino acids content of meat in *Eimeria*-challenged broilers

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Abstract: The aim of the study was to evaluate the dietary effect of condensed tannins (CT) from red quebracho (*Schinopsis lorentzii*) and broiler age on the physicochemical properties, mineral composition, and amino acid content in the meat of broilers challenged with *Eimeria* spp. Broilers were randomly assigned to four dietary groups: CT1 and CT2 received 10 and 20 g CT/kg, respectively; the control (C) group received a basal diet; and the R group received a basal diet with a coccidiostat. Meat quality indicators were assessed at 35 and 42 days of age. Supplementation with the higher CT level (2%) reduced carcass weight, particularly at 42 days (P < 0.05), and affected physical meat quality indicators, including cooking loss, pH, and shear force, although the relationships among individual indicators were not fully consistent. Broiler age significantly influenced most of the physical traits, with older birds showing higher cooking loss and shear force in breast meat and altered meat colour (P < 0.05). Both CT and age modified mineral composition, with significant differences in macro- and microelements depending on muscle type and fattening duration (P < 0.05; P < 0.01). CT supplementation consistently increased total essential (EAA) and non-essential amino acids (NEAA) in leg meat (P < 0.05), whereas in breast meat, a significant effect was observed only for NEAA in the CT1 group at 42 days of age. Extending fattening from 35 to 42 days did not affect total EAA or NEAA in either muscle (P > 0.05), although minor age-related differences were detected for several individual amino acids (P < 0.05; P < 0.01). Overall, dietary CT supplementation and broiler age significantly influenced meat quality, including mineral content, amino acid composition, and functional physical properties.

Keywords: breast meat; chicken; coccidiosis; leg meat; red quebracho; tannin

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The production of poultry meat plays a significant role in livestock production, both in terms of production volume and ensuring a sufficient supply of animal protein for the growing human population. In EU countries, poultry meat ranks among the most important animal-based foods and in some countries is already the most commonly consumed type of meat (Nassar 2026). Its long-term consumption growth is linked to its high nutritional value, favourable dietetic properties, low environmental impact of production, and affordability. The development of the poultry sector is also driven by the biological and economic advantages of poultry farming, particularly rapid growth rates, efficient feed conversion, and favourable fattening economics. In addition to these aspects, market demands are also becoming increasingly important, as consumer preferences are based not only on price but also on the origin of the product, the types of feed used, and the rearing conditions. At the same time, increasing importance is being attached to the sustainability of production, both in terms of agricultural systems and in relation to the health aspects of the production of animal-based foods (Sakr et al. 2025; Nassar 2026).

The high intensity of current production systems may contribute to increased infection pressure and more frequent health issues in farmed poultry. Additionally, increasing emphasis is being placed, both within the professional community and among consumers, on restricting the use of conventional antimicrobial agents in connection with the risk of antimicrobial resistance, the potential transfer of residues into food of animal origin, and, in general, growing demands for the safety and quality of animal production (Nassar 2026). In this regard, attention is also focused on phytogenic feed additives, whose effects are associated, among other things, with influencing the microbial environment of the digestive tract and modulating immune function. Tannins, an important group of these substances, are used in farm animal nutrition and, given their origin, are considered a promising component of sustainable feeding strategies (Hoffmann et al. 2026).

Condensed tannins (CT) are being studied for their various beneficial biological effects, which include, in particular, antioxidant, anti-inflammatory, and immunomodulatory effects (Redondo et al. 2022). Their effects are associated with mitigating the impacts of intestinal infection, supporting intestinal mucosal integrity, and, in some cases, modulating the immune response of the host (Cejas et al. 2011; Hoffmann et al. 2026). However, higher concentrations of CT in feed can adversely affect feed intake, nutrient utilisation, and production performance; therefore, under some conditions, they are considered to have an antinutritional effect (Hidayat et al. 2021). Significant sources of CT include wood from the red quebracho of the *Schinopsis* spp., from which extracts with a high content of proanthocyanidin compounds are obtained (EFSA et al. 2022). Their use has been evaluated in various poultry species, whereas published findings are inconsistent (Marzoni et al. 2005; Castillo et al. 2020; Marzoni et al. 2020; Eski and Gulsen 2025). The variability in the observed effects is likely due not only to the chemical nature of the tannins used but also to the composition of the feed mixture, the tannin dose, the animal species, and its physiological status (Choi and Kim 2020). For broilers, current knowledge regarding the dietary effects of CT on meat quality at different ages and under stress induced by *Eimeria* spp. infection is still limited. Therefore, the aim of the present study was to evaluate the effect of adding CT from red quebracho to feed on the carcass traits, physicochemical properties, and mineral and amino acid content in the meat of broilers challenged with *Eimeria* spp. Another part of the study aimed to evaluate the effect of broiler age on quality indicators of breast and leg meat.

MATERIAL AND METHODS

The experiment was approved by the Animal Welfare Committee of the University of Veterinary Sciences (UVS) Brno (Project No. 11-2024).

Broiler management and dietary treatments. A total of 192 one-day-old male broilers (Ross 308) were used in the experiment. The chickens were randomly divided into four dietary groups (48 birds in each group), with four replicates per dietary group (12 birds/replicate). All broilers were reared in floor litter pens under the same controlled conditions, according to Ross 308 guidelines (Aviagen 2025). The broilers had *ad libitum* access to feed and water. A three-phase feeding programme was used, with starter, grower, and finisher diets fed on days 1–13, 14–27, and 28–42, respectively. The starter diet was given to the broilers in the form

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of crumbled pellets, while the grower and finisher diets were given in the form of pellets. The experiment lasted 42 days.

The experimental groups were fed diets supplemented with condensed tannins (CT) extracted from red quebracho (*Schinopsis lorentzii*). The commercial product Natutan Blanc F® (OENOBIOTECH, France), derived from *Schinopsis lorentzii* and containing 60% CT, was used for dietary supplementation. Natutan Blanc F® was used in dry powder form, and the determined amount for each experimental group was carefully mixed with the other dietary components. Subsequently, the individual mixture diets were formed into pellets. Broilers in the experimental CT1 and CT2 groups were fed diets supplemented with 10 and 20 g CT/kg of feed, respectively. For the nutrition of broilers in the CT1 and CT2 groups, CT was incorporated into all types of diets (starter, grower, and finisher). Broilers in the control (C) group were fed basal starter, grower, and finisher diets (Table 1). The R group was fed starter and grower basal diets containing the coccidiostat robenidine (33 mg/kg of feed) and without CT supplementation; the finisher basal diet for the R group did not contain either the coccidiostat or CT. The analysed nutrient compositions of the diets are shown in Table 2.

At 18 days of age, the broilers in all dietary groups were challenged with a tenfold overdosing of the live vaccine LIVACOX T (Biopharm Co., Prague, Czech Republic) to induce a mild coccidiosis infection according to the procedure described by Zapletal et al. (2025). Each dose of inoculum administered to each broiler contained 15 000 live oocysts of the species *Eimeria acervulina*, *Eimeria tenella*, and *Eimeria maxima*.

Body dissection and meat analysis. At 35 and 42 days of age, 10 broilers were randomly selected from all replicates within each dietary group to evaluate specific meat quality indicators. Before slaughter, the broilers were weighed. The broilers were then stunned and slaughtered by cutting the jugular vein. After scalding and defeathering, the broilers were eviscerated and their carcasses were dissected in accordance with standard procedures. To evaluate carcass traits, the weight of the carcass with kidneys, the proportion of breast muscle, and the proportion of legs in carcass weight were determined. To evaluate the physical properties of chicken meat, samples of breast meat with skin and leg meat with skin were taken. Subsequently, additional samples of skinless breast and leg meat were taken, packaged, and stored at –20 °C until analysis of chemical and amino acid (AA) composition.

Regarding physical properties of meat, the analyses used to determine pH, water holding capacity (WHC), cooking loss (CL), Warner–Bratzler shear force (WB), and colour were based on the methods used by Zapletal et al. (2026).

As for the proximate chemical composition of meat, a Soxhlet method was used to determine the ether extract by a Soxtec apparatus (Thermo Scientific, Warrington, UK). The crude protein (CP) content was determined using the Kjeldahl method with a Buchi analyser (Centec automatika, spol. s r.o., Prague, Czech Republic), and the determined nitrogen content was multiplied by a factor of 6.25. The ash content was determined by weighing the sample after incineration at 550 °C.

Table 1. Ingredient compositions (%) of basal diets fed to broilers

Item	Diet		
	starter	grower	finisher
Wheat	8.47	9.18	9.56
Maize	49.8	50.0	50.0
Soybean meal	36.4	30.3	30.2
Canola oil	1.00	4.80	3.50
Monocalcium phosphate	1.00	0.70	0.70
Limestone	1.40	1.17	1.17
NaCl	0.25	0.24	0.24
$NaHCO_3$	0.20	0.20	0.20
Lysine	0.20	0.14	0.14
Methionine	0.28	0.23	0.23
Threonine	0.08	0.06	0.06
Maize sprouts	0.00	2.00	3.00
Vitamin and mineral premix[a]	0.70	0.50	0.50
Mastercube®	0.27	0.50	0.50

[a]Vitamin and mineral premix provided per kilogram of premix: retinol, 3 000 000 IU; cholecalciferol, 1 000 000 IU; alpha-tocopherol, 11 000 mg; menadione, 9 000 mg; L-ascorbic acid, 6 000 mg; thiamine, 595 mg; riboflavin, 1 800 mg; pyridoxine, 1 000 mg; cobalamin, 6 000 mg; biotin, 20 mg; niacinamid, 5 385 mg; folic acid, 386 mg; choline chloride, 60 000 mg; calcium, 150 g; iron, 13 630 mg; manganese, 23 880 mg; zinc, 20 980 mg; copper, 4 180 mg; iodine, 240 mg; selenium, 60 mg; calcium pantothenate, 2 665 mg; phytase, 100 000 FTU; butylated hydroxytoluene, 1 100 mg and butylated hydroxyanisole, 220 mg

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Table 2. Analysed nutrient composition (g/kg) in diets fed to broilers as fed basis

Item	Diet			
	C	R	CT1	CT2
Starter (day 1 to 13)				
Dry matter	882	891	890	889
Crude protein	209	209	204	199
Crude fibre	24.2	25.3	25.5	25.3
Crude fat	24.1	25.0	19.1	19.4
Crude starch	387	392	378	367
Ash	61.5	62.3	67.9	61.5
Calcium	9.01	11.2	13.0	11.2
Inorganic phosphorus	5.40	5.80	6.20	5.70
Metabolisable energy (MJ/kg)	12.9	13.0	12.7	12.7
Grower (day 14 to 27)				
Dry matter	907	908	908	906
Crude protein	197	198	197	183
Crude fibre	21.3	22.1	22.0	21.4
Crude fat	80.3	79.9	79.1	75.7
Crude starch	382	386	390	372
Ash	50.8	51.4	51.1	54.7
Calcium	8.60	8.80	7.74	8.76
Inorganic phosphorus	5.10	5.30	5.30	5.00
Metabolisable energy (MJ/kg)	14.4	14.5	14.4	14.2
Finisher (day 28 to 42)				
Dry matter	903	906	898	900
Crude protein	196	196	191	191
Crude fibre	24.6	24.8	23.2	24.3
Crude fat	68.7	69.4	68.1	70.3
Crude starch	372	377	387	373
Ash	54.5	54.7	54.2	54.9
Calcium	12.1	13.5	9.3	9.1
Inorganic phosphorus	5.20	5.50	5.50	5.20
Metabolisable energy (MJ/kg)	14.1	14.1	14.0	14.0

C = control group; CT = condensed tannins; CT1 = supplemented with 10 g CT/kg of feed; CT2 = supplemented with 20 g CT/kg of feed; R = starter and grower basal diets containing the coccidiostat robenidine (33 mg/kg of feed) and without CT supplementation

The mineral content of the meat was determined by sample ashing, extraction, and subsequent titration according to standardised procedures of the Czech National Standards (CSN ISO 6869:2011, CSN 46 7092-11). The contents of calcium (Ca), potassium (K), sodium (Na), magnesium (Mg), copper (Cu), iron (Fe), manganese (Mn), and zinc (Zn) were determined using an Agilent Technologies 200 Series AA atomic absorption spectrometer (HPST, Ltd., Prague, Czech Republic). A spectrophotometer Helios α (Thermo Scientific, UK) was used to determine the phosphorus (P) content.

The amino acid content of the meat was determined using the Automatic Amino Acid Analyser AAA 400 (Ingos a.s., Prague, Czech Republic) according to the procedures described by Strakova et al. (2025). The following essential amino acids (EAA) were determined: lysine (Lys), methionine (Met), isoleucine (Ile), leucine (Leu), threonine (Thr), valine (Val), histidine (His), arginine

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(Arg), and phenylalanine (Phe); and the following non-essential amino acids (NEAA) were determined: asparagine (Asn), serine (Ser), glutamine (Gln), proline (Pro), glycine (Gly), alanine (Ala), cysteine (Cys), and tyrosine (Tyr).

Statistical analysis. Statistical analyses were performed using STATISTICA CZ software, v10 (StatSoft Inc., Tulsa, USA).

The arithmetic mean and standard error of the mean (SEM) were determined for all assessed indicators. The Shapiro–Wilk test was used to test the normality of the distribution of data in the respective broiler groups.

Regarding the evaluation of dietary effects on carcass traits and meat quality indicators in broilers, in the case of data showing normality, the GLM procedure was used, with diet included as a fixed effect and pen as a random effect. Tukey's HSD post-hoc test was used for subsequent testing of differences among means. The pen was regarded as the experimental unit. For data that were not normally distributed, the Kruskal–Wallis test was used for evaluation; subsequently, multiple comparisons of mean ranks were performed when a significant effect was detected.

Regarding the effect of broiler age on carcass traits and meat quality, in the case of data showing normality, the GLM procedure was used, with age included as a fixed effect and individual as a random effect. For data that were not normally distributed, the Mann–Whitney *U* test was used for evaluation.

Statistical significance was defined as $P < 0.05$.

RESULTS AND DISCUSSION

Carcass traits and meat chemical composition. Dietary supplementation with 1% and 2% CT from red quebracho in the present study resulted in a decrease in carcass weight of *Eimeria*-challenged broilers at 35 days of age compared with the C group ($P < 0.05$; Table 3). When the fattening period was extended to 42 days of age, a higher dietary CT level in the CT2 group resulted in the lowest carcass weight ($P < 0.01$); furthermore, carcass weight in the CT1 group was also lower than that in the C group ($P < 0.01$). The findings of the present study are consistent with those of Kumanda et al. (2019), who reported decreased carcass weight in broilers fed a diet containing 10% red grape pomace as a source of CT compared with a commercial control diet. In contrast, Godoy et al. (2024) did not observe a decrease in carcass weight in broilers fed a diet containing 0.09% CT. In the present study, diet did not significantly affect breast meat yield at any of the evaluated ages of the broilers ($P > 0.05$). Concerning leg yield, a significant effect of diet was observed in 42-day-old broilers, with the R group showing a significantly higher value compared with both the CT2 group ($P < 0.01$) and the CT1 group ($P < 0.05$). This finding is not consistent with the results of studies by Mahmoudi et al. (2022) and Godoy et al. (2024), which evaluated the dietary effects of other CT sources and found no effect on broiler leg yield. Tannins have traditionally been considered phytotoxins with antinutritional properties (Choi and Kim 2020). However, it has recently been proven that, at appropriate doses, they may have the potential to improve broiler performance (Hidayat et al. 2021).

At 35 days of age, broilers in the CT2 group of the present study showed significantly higher dry matter (DM) and CP contents in breast meat compared to the R group ($P < 0.05$; Table 3). In the case of leg meat at this age, the C group showed significantly lower DM content ($P < 0.01$) and also lower fat content ($P < 0.05$; $P < 0.01$) compared to all other dietary groups. In addition, lower ash content was confirmed in the R group compared to the CT1 group ($P < 0.05$). At 42 days of age, greater differences were observed in the assessed indicators of proximate chemical composition in breast meat than in leg meat (Table 3). Specifically, the DM and CP contents in breast meat were again highest in the CT2 group ($P < 0.05$). The R group showed a significantly higher fat content in this meat compared to the CT1 group ($P < 0.01$). Regarding leg meat at 42 days of age, only a lower DM content was observed in the R group compared to the C and CT1 groups ($P < 0.05$).

An increase in DM content in the breast meat of *Eimeria*-challenged broilers fed a diet containing 2% CT from red quebracho was always associated with an increase in CP content in the present study, indicating an alteration in nitrogen and amino acid (AA) metabolism. However, Starcevic et al. (2015) recently described the opposite trend, in which dietary supplementation with 0.5% tannic acid led to a decrease in CP content in chicken meat without affecting DM content. It appears that different sources, forms, and doses of dietary tan-

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Table 3. Carcass traits and proximate chemical composition (g/kg) of fresh meat in 35- and 42-day old male broilers depending on diet

Trait	Diet				SEM	*P*-value
	C	R	CT1	CT2		
35 days of age						
CS (g)	1 868^{a}	1 840^{ab}	1 704^{b}	1 704^{b}	23.2	0.003
Breast meat of CS (%)	30.5	29.3	31.1	31.1	0.309	0.105
Legs of CS (%)	35.7	36.2	35.2	35.2	0.263	0.364
Breast meat						
Dry matter	233^{ab}	232^{b}	239^{ab}	241^{a}	1.28	0.016
Crude protein	204^{ab}	201^{b}	206^{ab}	212^{a}	1.55	0.044
Ether extract	20.2	21.5	22.0	18.1	0.736	0.276
Ash	12.0	11.9	12.0	12.2	0.062	0.581
Leg meat						
Dry matter	257^{B}	271^{A}	269^{A}	277^{A}	1.73	<0.001
Crude protein	177	182	186	184	1.44	0.213
Ether extract	66.7^{B,c}	81.6^{A,ab}	74.6^{AB,b}	82.0^{A,a}	1.44	<0.001
Ash	10.7^{ab}	10.3^{b}	11.5^{a}	10.7^{ab}	0.142	0.047
42 days of age						
CS (g)	2 687^{A}	2 528^{AB}	2 401^{BC}	2 213^{C}	37.4	<0.001
Breast meat of CS (%)	31.9	31.1	31.9	31.9	0.383	0.805
Legs of CS (%)	35.5^{AB,ab}	37.0^{A,a}	34.4^{AB,b}	33.7^{B}	0.336	0.002
Breast meat						
Dry matter	241^{b}	242^{ab}	246^{ab}	256^{a}	1.87	0.029
Crude protein	204^{b}	207^{ab}	205^{b}	217^{a}	1.74	0.024
Ether extract	25.2^{AB}	28.1^{A}	20.5^{B}	23.5^{AB}	0.848	0.013
Ash	11.7	11.5	11.9	11.9	0.096	0.594
Leg meat						
Dry matter	275^{a}	262^{b}	275^{a}	273^{ab}	1.57	0.013
Crude protein	185	182	189	189	0.998	0.115
Ether extract	81.7	72.3	78.8	78.4	1.38	0.124
Ash	10.1	10.1	10.5	10.4	0.097	0.374

$^{a–c}$Means within a row with different superscript letters differ ($P < 0.05$); $^{A–C}$Means within a row with different superscript letters differ ($P < 0.01$)

C = control group; CS = carcass; CT = condensed tannins; CT1 = supplemented with 10 g CT/kg of feed; CT2 = supplemented with 20 g CT/kg of feed; R = starter and grower basal diets containing the coccidiostat robenidine (33 mg/kg of feed) and without CT supplementation

nins have varying effects on chicken physiology and metabolism. In addition, dietary tannins are known to reduce lipid absorption by binding to digestive enzymes and forming complexes (Molino et al. 2023). Nevertheless, Bourckhardt et al. (2025) demonstrated an increase in breast meat fat content in 42-day-old chickens that were administered higher doses of CT from *Acacia mearnsii* via drinking water. This finding is partly consistent with the results of the present study regarding increased fat content in leg meat of 35-day-old broilers, but for breast meat and older broilers, this effect of CT on fat content was inconsistent.

In the present study, age had a greater effect on the proximate chemical composition of breast meat than of leg meat in *Eimeria*-challenged

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broilers (Table 4). Extending the broiler fattening to 42 days of age resulted in a significant increase in DM content in breast meat, which was directly associated with an increase in fat content ($P < 0.01$). In contrast, older broilers showed a significant decrease in ash content in this meat ($P < 0.01$). Similarly, prolonged fattening resulted in a decrease in ash content in leg meat ($P < 0.01$). By contrast, Suliman et al. (2023) did not confirm the effect of age on DM content and other indicators of the proximate chemical composition of breast meat in Ross 308 broilers.

Physical properties of meat. In breast meat at 35 days of age in the present study, the WHC value in the CT2 group was significantly lower than that in the R group ($P < 0.01$; Table 5). Similarly, the CL value was lower in the CT2 group compared with the C and R groups ($P < 0.01$) and compared to the CT1 group ($P < 0.05$). Conversely, in the R group, there was a significant decrease in pH in this meat compared to the CT1 group ($P < 0.05$) and lower lightness compared with group C ($P < 0.01$) and groups CT1 and CT2 ($P < 0.05$).

In the CT2 group, a significantly lower CL value was similarly observed in leg meat compared to the R group ($P < 0.05$), and conversely, a significantly higher value for WB ($P < 0.05$) and pH ($P < 0.01$) compared to the R group. At 42 days of age, an increase in redness was observed in the breast meat of the CT2 group ($P < 0.05$), alongside a higher WB value in leg meat ($P < 0.01$) compared with the R group.

The WHC of meat refers to its ability to retain water during processing, handling, and cooking. A high WHC reduces water loss and improves tenderness, juiciness, and yield, whereas a low WHC results in drier and paler meat. WHC is primarily determined by pH, protein denaturation, and myofibril structure. Dietary supplementation with CT from red quebracho in the present study resulted in inconsistent relationships among the main physical meat indicators, particularly in 35-day-old broilers and at higher levels of CT in the diet. In the CT2 group, a decrease in WHC was observed in breast meat at 35 days of age, accompanied by a significant reduction (improvement) in CL. However, pH did not differ significantly from the other dietary groups. The cause of these inconsistent relationships between the meat indicators assessed in the present study may be related to the interactions between CT and muscle proteins. It is known that polyphenolic compounds interact with myofibrillar proteins and can alter their structural properties and water-binding capacity during heat treatment. Moreover, the relationships between the WHC value determined in raw meat and weight loss after heat treatment may not always be directly related, as thermal denaturation and

Table 4. Age effect on proximate chemical composition and minerals content of male broiler meat

Trait	Breast meat		Leg meat		SEM	*P*-value	
	35 days	42 days	35 days	42 days		breast	leg
Chemical composition (g/kg on basis of fresh meat)							
Dry matter	236	246	268	271	1.42	<0.001	0.195
Crude protein	206	208	182	186	1.17	0.270	0.064
Ether extract	20.4	24.3	76.2	77.8	2.24	<0.001	0.435
Ash	12.0	11.7	10.8	10.3	0.075	0.009	0.003
Mineral (mg/100 g of fresh meat)							
P	208	219	179	173	2.19	0.014	0.112
Ca	11.6	11.5	10.6	14.4	0.271	0.561	<0.001
K	358	366	318	307	2.68	0.073	0.070
Na	68.0	58.9	86.0	66.0	1.04	<0.001	<0.001
Mg	28.0	29.1	23.1	22.5	0.366	0.015	0.040
Cu	0.049	0.068	0.076	0.053	0.001	<0.001	<0.001
Fe	0.73	0.67	0.61	0.91	0.021	0.593	<0.001
Mn	0.048	0.014	0.061	0.073	0.003	<0.001	<0.001
Zn	0.575	0.587	1.39	1.36	0.032	0.121	0.213

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Table 5. Physical properties of male broiler meat depending on diet

Trait	Diet				SEM	*P*-value
	C	R	CT1	CT2		
35 days of age						
Breast meat						
WHC (%)	1.31^{AB}	1.74^{A}	1.28^{AB}	0.92^{B}	0.078	0.002
CL (%)	23.8^{A,a}	25.5^{A,a}	23.7^{AB,a}	20.5^{B,b}	0.420	0.000
WB (N)	13.7	13.4	12.7	13.1	0.323	0.787
pH	5.74^{ab}	5.71^{b}	5.84^{a}	5.78^{ab}	0.018	0.045
*L**	54.2^{A,a}	50.1^{B,b}	53.6^{AB,a}	53.5^{AB,a}	0.441	0.003
*a**	2.37	3.74	1.88	2.40	0.253	0.079
*b**	15.0	15.5	14.8	14.7	0.200	0.549
Leg meat						
WHC (%)	0.91	1.18	2.16	0.77	0.339	0.478
CL (%)	23.4^{ab}	26.0^{a}	23.6^{ab}	22.7^{b}	0.441	0.023
WB (N)	27.4	25.5^{b}	29.0	30.7^{a}	0.757	0.048
pH	6.39^{AB,a}	6.15^{B,b}	6.35^{AB,ab}	6.52^{A,a}	0.038	0.002
*L**	48.8	49.1	48.6	51.4	0.419	0.100
*a**	8.40	10.0	7.47	12.3	1.157	0.504
*b**	18.0	19.0	17.8	17.0	0.349	0.304
42 days of age						
Breast meat						
WHC (%)	1.42	1.10	1.33	1.05	0.074	0.270
CL (%)	26.8	25.7	25.7	22.6	0.581	0.069
WB (N)	16.1	14.0	15.0	16.4	0.383	0.139
pH	5.79	5.82	6.08	5.83	0.075	0.513
*L**	54.4	53.1	54.9	54.6	0.407	0.410
*a**	0.40^{ab}	–0.17^{b}	0.25^{ab}	0.95^{a}	0.132	0.036
*b**	14.1	13.7	13.7	14.0	0.212	0.876
Leg meat						
WHC (%)	1.02	1.11	1.09	0.80	0.057	0.185
CL (%)	26.0	26.4	27.8	27.6	0.314	0.062
WB (N)	26.2^{AB}	24.0^{B}	27.8^{AB}	32.1^{A}	0.877	0.011
pH	5.95	6.04	5.92	6.01	0.023	0.308
*L**	51.2	50.9	50.3	51.8	0.374	0.518
*a**	8.19	8.63	9.94	9.15	0.251	0.073
*b**	18.2	18.5	19.2	18.4	0.171	0.205

^{a,b}Means within a row with different superscript letters differ ($P < 0.05$); ^{A,B}Means within a row with different superscript letters differ ($P < 0.01$)

*a** = redness; *b** = yellowness; C = control group; CL = cooking loss; CT = condensed tannins; CT1 = supplemented with 10 g CT/kg of feed; CT2 = supplemented with 20 g CT/kg of feed; *L** = lightness; R = starter and grower basal diets containing the coccidiostat robenidine (33 mg/kg of feed) and without CT supplementation; WB = Warner–Bratzler shear force; WHC = water holding capacity

structural rearrangement of muscle proteins can affect the intrinsic water distribution in different ways during cooking (Hughes et al. 2014; Bowker and Zhuang 2015; Jia et al. 2017). Cooking loss refers to the weight loss that occurs in meat during cooking as a result of moisture evaporation and fat

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rendering. It is primarily caused by the contraction of muscle fibres, which intensifies as the temperature rises and cooking time increases. As regards leg meat from 35-day-old broilers in the present study, an improvement in the CL value was again observed in the CT2 group, but this was associated with a significant increase (deterioration) in the pH value (6.52) and this time without a significant effect on the WHC level, which is again a rather contradictory phenomenon that can be considered undesirable from the point of view of these meat quality indicators.

A pH value above 6.2 in chicken meat generally indicates reduced quality and shorter shelf life. In the present study, pH values higher than 6.2 were found only in leg meat at 35 days of age, specifically in the C, CT1, and CT2 groups. Extending broiler fattening to 42 days of age did not lead to significant changes in pH, and no increase above the aforementioned critical value was observed. The pH value is directly related to meat quality traits such as tenderness, WHC, colour, juiciness, and shelf life (Mir et al. 2017). Ozbek et al. (2020) report that higher pH values are, among other things, associated with a higher water-binding capacity in broiler breast meat, which does not correspond with the results of the present study. The WB shear force is the most commonly used objective method for measuring meat tenderness. The marked increase in WB values (i.e. meat firmness) observed in the CT2 group in leg meat in the present study may instead be associated with structural changes in muscle tissue, which may be related to a change in the water-to-protein ratio.

With the exception of WHC, extending the fattening period to 42 days of age in *Eimeria*-challenged broilers in the present study had a significant effect on all monitored physical meat indicators (Table 6). Concerning individual indicators, the age effect was more obvious in breast meat, in which increased age at slaughter was associated with higher CL and WB values ($P < 0.01$) and also higher L^* value ($P < 0.05$), and conversely with lower a^* and b^* values ($P < 0.01$). In the case of leg meat, an increase in broiler age led to a similar increase in CL and L^* values ($P < 0.01$) and, conversely, to a decrease in the pH value ($P < 0.01$).

As for meat colour, a yellower colour usually makes the meat more attractive to consumers. In the present study, extending the fattening period resulted in increased lightness and decreased redness and yellowness of breast meat, suggesting potentially lower attractiveness to consumers. By contrast, Baeza et al. (2012) demonstrated a significant decrease in lightness in the breast meat of heavy-line Ross broilers at 42 days of age compared to 35 days, while redness and yellowness values remained unchanged.

Furthermore, when compared to the results of the present study, Baeza et al. (2012) also found an increase in WB values with prolonged broiler fattening, but conversely a decrease in CL and WHC levels and an increase in pH value. Furthermore, the significant decrease in the pH value of leg meat in older broilers observed in the present study may be considered beneficial from the perspective of meat quality.

Minerals in meat. At 35 days of age, a higher Na content in breast meat was observed in the CT2 group compared to the C group in the present study ($P < 0.05$; Table 7). Conversely, a significant decrease in Fe content was observed in broiler meat from the CT2 and CT1 groups compared to the R group ($P < 0.01$) and also to the C group

Table 6. Age effect on physical properties of male broiler meat

Trait	Breast meat		Leg meat		SEM	P value	
	35 days	42 days	35 days	42 days		breast	leg
WHC (%)	1.31	1.22	1.25	1.01	0.090	0.368	0.353
CL (%)	23.4	25.2	24.0	27.0	0.248	0.005	<0.001
WB (N)	13.2	15.4	28.1	27.5	0.623	<0.001	0.324
pH	5.77	5.88	6.35	5.98	0.028	0.059	<0.001
L^*	52.8	54.3	49.5	51.1	0.249	0.021	0.004
a^*	2.60	0.36	9.53	8.97	0.436	<0.001	0.292
b^*	15.0	13.9	17.9	18.6	0.197	<0.001	0.107

a^* = redness; b^* = yellowness; CL = cooking loss; L^* = lightness; WB = Warner–Bratzler shear force; WHC = water holding capacity

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Table 7. Minerals content (mg/100 g) of fresh meat in 35- and 42-day old male broilers depending on diet

Trait	Diet				SEM	*P*-value
	C	R	CT1	CT2		
35 days of age						
Breast meat						
P	204	211	204	211	2.97	0.635
Ca	11.4	12.9	11.6	10.3	0.356	0.136
K	360	367	358	348	3.00	0.191
Na	63.0^{b}	67.9^{ab}	69.2^{ab}	71.8^{a}	1.09	0.046
Mg	27.1	26.8	27.4	30.8	0.701	0.162
Cu	0.044	0.047	0.056	0.048	0.002	0.224
Fe	0.87^{AB,a}	0.97^{A}	0.53^{B,b}	0.54^{B,b}	0.046	0.001
Mn	0.050^{AB,ab}	0.067^{A,a}	0.042^{AB,b}	0.034^{B}	0.004	0.001
Zn	0.62^{a}	0.57^{ab}	0.55^{b}	0.56^{ab}	0.009	0.024
Leg meat						
P	187	177	178	175	3.54	0.582
Ca	9.90	11.5	9.90	10.9	0.457	0.483
K	315	334	315	308	4.13	0.115
Na	87.3	88.6	84.2	83.8	1.27	0.351
Mg	22.5	23.4	23.4	23.0	0.194	0.096
Cu	0.071^{B}	0.073^{AB,b}	0.078^{AB,ab}	0.082^{A,a}	0.001	0.002
Fe	0.58^{B}	0.71^{A}	0.57^{B}	0.58^{B}	0.013	<0.001
Mn	0.005^{B}	0.008^{A}	0.005^{B}	0.005^{B}	0.000	<0.001
Zn	1.35	1.44	1.36	1.40	0.022	0.301
42 days of age						
Breast meat						
P	210^{AB,b}	219^{AB,ab}	207^{B}	240^{A,a}	3.80	0.004
Ca	9.60	11.1	12.0	13.1	0.563	0.155
K	367	374	357	365	3.04	0.327
Na	57.4^{ab}	58.0^{ab}	63.6^{a}	56.7^{b}	1.91	0.026
Mg	28.3	27.5	30.9	29.5	0.853	0.105
Cu	0.069^{AB,a}	0.057^{B,b}	0.074^{A,a}	0.071^{A,a}	0.002	<0.001
Fe	0.66^{ab}	0.53^{b}	0.83^{a}	0.64^{ab}	0.036	0.025
Mn	0.016	0.015	0.016	0.008	0.002	0.075
Zn	0.55	0.62	0.62	0.56	0.014	0.039
Leg meat						
P	175	180	167	169	2.21	0.152
Ca	11.3^{B}	15.4^{AB}	14.6^{AB}	16.5^{A}	0.571	0.012
K	306^{ab}	298^{b}	296^{b}	328^{a}	4.21	0.029
Na	66.8^{AB,ab}	70.9^{A,a}	65.1^{AB,b}	61.3^{B,b}	0.940	0.001
Mg	22.1^{ab}	21.8^{b}	22.2^{ab}	24.0^{a}	0.251	0.017
Cu	0.054	0.050	0.052	0.056	0.001	0.463
Fe	1.00^{ab}	0.67^{b}	1.10^{a}	0.87^{ab}	0.049	0.013
Mn	0.10^{A}	0.05^{B}	0.07^{AB}	0.07^{AB}	0.005	0.002
Zn	1.41	1.38	1.27	1.37	0.019	0.097

^{a,b}Means within a row with different superscript letters differ ($P < 0.05$); ^{A,B}Means within a row with different superscript letters differ ($P < 0.01$)

C = control group; CT = condensed tannins; CT1 = supplemented with 10 g CT/kg of feed; CT2 = supplemented with 20 g CT/kg of feed; R = starter and grower basal diets containing the coccidiostat robenidine (33 mg/kg of feed) and without CT supplementation

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($P < 0.05$). Similarly, broiler meat from the CT1 and CT2 groups showed a significantly lower Mn content compared to the R group ($P < 0.05$; $P < 0.01$). Regarding Zn content in breast meat, the CT1 group showed lower levels compared to the C group ($P < 0.05$). In leg meat, a significantly higher Cu content was found in the CT2 group compared to the C group ($P < 0.01$) and the R group ($P < 0.05$). Conversely, Fe and Mn contents in the meat were significantly higher in the R group compared to all other dietary groups ($P < 0.01$).

In broilers slaughtered at 42 days of age (Table 7), a significant increase in the P content was observed in the breast muscle of the CT2 group compared to the CT1 ($P < 0.01$) and C ($P < 0.05$) groups. Copper content was higher in the CT1 and CT2 groups compared to the R group ($P < 0.01$), and the Fe content was higher in the CT1 group compared to the R group ($P < 0.05$). In leg meat, the CT2 group showed higher Ca content compared to the C group ($P < 0.01$), higher K content compared to the CT1 and R groups ($P < 0.05$), and also higher Mg content compared to the R group ($P < 0.05$). A higher Fe content was found in the CT1 group compared to the R group ($P < 0.05$). The Na content in this meat was lower in the CT1 and CT2 groups compared to the R group ($P < 0.05$; $P < 0.01$). Furthermore, a higher Mn content was detected in the C group compared to the R group ($P < 0.01$).

An increase in mineral content with advancing age of the broilers (Table 4) was observed in breast meat for the contents of Mg and Cu ($P < 0.01$) and for P ($P < 0.05$); whereas decreases were observed for Na and Mn ($P < 0.01$). In leg meat, an increase in Ca, Fe, and Mn content ($P < 0.01$) was observed with increasing age, while a decrease in Na and Cu content ($P < 0.01$) and Mg content ($P < 0.05$) was observed.

Stef and Gergen (2012) proved that dietary inclusion of polyphenol-rich herbs can alter the accumulation of Fe, Mn, Zn, and Cu in the liver and leg muscles of chickens. In addition, Eski and Gulsen (2025) found in chukar partridges that a dietary addition of 2% quebracho CT reduced Ca digestibility, while P and Mg digestibility were not affected. In the present study, it was found that dietary supplementation with red quebracho CT can significantly alter the mineral profile of meat, with the effects depending on both the CT dose and the muscle type and age of the broilers. Moreover, the effect of coccidiostat use in the feed was observed, particularly on the Fe and Mn contents in broiler meat. At 35 days of age, the highest Fe content in meat was found in the broilers fed a starter and grower diet with a coccidiostat, whereas at 42 days of age, a decrease in Fe content was observed in these broilers.

In addition to the major influence of genetics and nutrition, age also plays a role in the mineral content of poultry meat. Cao et al. (2021) demonstrated the effect of age on changes in mineral content in Cherry Valley hybrid ducks, finding that a one-week prolongation of fattening led to a decrease in Ca, Mg, Fe, and Zn levels. In the present study, however, extending the fattening period of broilers led to an increase in Mg content in breast meat and also to an increase in Ca and Fe contents in leg meat, albeit with a simultaneous decrease in Mg content.

Amino acids in meat. With the exception of Gly, the contents of individual AA in the breast meat of 35-day-old broilers (Table 8) were significantly influenced by diet in the present study ($P < 0.05$; $P < 0.01$). Similarly, with the exception of Cys, a significant dietary effect on the contents of individual AA in the leg meat of these broilers was observed ($P < 0.01$; Table 8). While the total contents of EAA and NEAA in breast meat of 35-day-old broilers differed markedly ($P < 0.01$) between the C group (highest) and the R group (lowest), in leg meat, a significant difference ($P < 0.01$) was recorded between the CT1 and CT2 groups (higher levels) compared with the C and R groups (lower).

When the fattening period was extended to 42 days, the breast meat AA contents (Table 9) were influenced by diet for 8 out of 9 evaluated EAA ($P < 0.05$; $P < 0.01$) and for 5 out of 8 evaluated NEAA ($P < 0.05$; $P < 0.01$). In the leg meat of these broilers (Table 9), diet had a substantial effect on the contents of all evaluated AA ($P < 0.05$; $P < 0.01$). In breast meat of 42-day-old broilers, the largest differences ($P < 0.01$) in the total EAA content were observed between the C group (highest value) and the R group (lowest value), whereas for the total NEAA content, a higher value was found in the CT1 group compared with the R group ($P < 0.05$). In leg meat, the total contents of both EAA and NEAA were highest in the CT1 group and significantly lowest in the R and C groups ($P < 0.01$).

It is known that a higher tannin content in poultry diets reduces growth performance and AA digest-

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Table 8. Amino acids content of male broiler meat at 35 days of age depending on diet (g/100 g of fresh meat)

Trait	Diet				SEM	*P*-value
	C	R	CT1	CT2		
Breast meat						
Lysine	1.78^{A}	1.55^{B}	1.69^{AB}	1.67^{AB}	0.026	0.010
Methionine	0.53^{B,b}	0.47^{C}	0.59^{A,a}	0.55^{AB,b}	0.010	<0.001
Isoleucine	1.02^{A}	0.90^{B}	0.99^{B}	0.96^{AB}	0.014	0.009
Leucine	1.72^{A}	1.48^{B}	1.64^{AB}	1.59^{AB}	0.027	0.007
Threonine	1.01^{A}	0.90^{B}	1.02^{A}	1.00^{A}	0.012	0.001
Valine	1.10^{a}	0.97^{b}	1.08^{a}	1.05^{a,b}	0.016	0.013
Histidine	1.12^{A}	0.97^{B}	0.98^{B}	0.93^{B}	0.017	<0.001
Arginine	1.40^{A}	1.21^{B}	1.46^{A}	1.42^{A}	0.024	0.001
Phenylalanine	0.85^{a}	0.77^{b}	0.85^{a}	0.85^{a}	0.011	0.011
Suma EAA	10.5^{A,a}	9.21^{B,b}	10.3^{AB,a}	10.0^{AB,ab}	0.139	0.003
Asparagine	2.08^{a}	1.80^{b}	1.95^{ab}	1.95^{ab}	0.034	0.029
Serine	0.87^{A,a}	0.78^{B,b}	0.88^{A,a}	0.87^{AB,a}	0.012	0.003
Glutamine	3.52^{A}	3.11^{B}	3.49^{A}	3.37^{AB}	0.047	0.004
Proline	0.73^{AB,a}	0.67^{B,b}	0.75^{A}	0.74^{A}	0.009	0.002
Glycine	0.98	0.85	0.95	0.92	0.014	0.058
Alanine	1.26^{a}	1.09^{b}	1.21^{ab}	1.17^{ab}	0.020	0.015
Cysteine	0.19^{ab}	0.17^{b}	0.20^{ab}	0.21^{a}	0.005	0.030
Tyrosine	0.77^{a}	0.70^{b}	0.78^{a}	0.77^{a}	0.010	0.008
Suma NEAA	10.4^{A}	9.17^{B,b}	10.2^{AB,a}	10.0^{AB,ab}	0.143	0.008
Total AA	20.9^{A}	18.4^{B,b}	20.5^{AB,a}	20.0^{AB,ab}	0.281	0.004
Leg meat						
Lysine	1.05^{B}	1.13^{B}	1.34^{A}	1.39^{A}	0.028	<0.001
Methionine	0.21^{C}	0.23^{BC,b}	0.29^{AB,a}	0.33^{A,a}	0.011	<0.001
Isoleucine	0.57^{B}	0.61^{B}	0.72^{A}	0.75^{A}	0.014	<0.001
Leucine	0.98^{B}	1.04^{B}	1.26^{A}	1.25^{A}	0.024	<0.001
Threonine	0.56^{B}	0.61^{B}	0.73^{A}	0.72^{A}	0.014	<0.001
Valine	0.60^{B}	0.62^{B}	0.76^{A}	0.75^{A}	0.015	<0.001
Histidine	0.49^{B}	0.51^{B}	0.61^{A}	0.59^{A}	0.011	<0.001
Arginine	0.84^{B,b}	0.92^{B,a}	1.03^{A}	1.08^{A}	0.018	<0.001
Phenylalanine	0.51^{B}	0.54^{B}	0.64^{A}	0.65^{A}	0.012	<0.001
Suma EAA	5.80^{B}	6.21^{B}	7.38^{A}	7.50^{A}	0.141	<0.001
Asparagine	1.28^{B}	1.38^{B}	1.59^{A}	1.55^{A}	0.026	<0.001
Serine	0.54^{B}	0.58^{B}	0.71^{A}	0.69^{A}	0.014	<0.001
Glutamine	2.03^{B}	2.21^{B}	2.56^{A}	2.51^{A}	0.042	<0.001
Proline	0.55^{B,b}	0.55^{B,b}	0.62^{AB,a}	0.68^{A,a}	0.012	<0.001
Glycine	0.63^{B}	0.68^{B}	0.87^{A}	0.86^{A}	0.021	<0.001
Alanine	0.73^{B}	0.79^{B}	0.98^{A}	0.97^{A}	0.020	<0.001
Cysteine	0.12	0.12	0.13	0.13	0.004	0.648
Tyrosine	0.44^{B}	0.49^{AB}	0.52^{A}	0.54^{A}	0.009	0.001
Suma NEAA	6.33^{B}	6.79^{B}	7.98^{A}	7.92^{A}	0.137	<0.001
Total AA	12.1^{B}	13.0^{B}	15.4^{A}	15.4^{A}	0.276	<0.001

^{a,b}Means within a row with different superscript letters differ ($P < 0.05$); $^{A–C}$Means within a row with different superscript letters differ ($P < 0.01$)

AA = amino acids; C = control group; CT = condensed tannins; CT1 = supplemented with 10 g CT/kg of feed; CT2 = supplemented with 20 g CT/kg of feed; EAA = essential amino acids; NEAA = non-essential amino acids; R = starter and grower basal diets containing the coccidiostat robenidine (33 mg/kg of feed) and without CT supplementation

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Table 9. Amino acids content of male broiler meat at 42 days of age depending on diet (g/100 g of fresh meat)

Trait	Diet				SEM	*P*-value
	C	R	CT1	CT2		
Breast meat						
Lysine	$2.00^{A,a}$	$1.66^{B,b}$	$1.83^{AB,a}$	$1.71^{B,ab}$	0.030	<0.001
Methionine	0.45	0.4	0.46	0.44	0.011	0.207
Isoleucine	0.96^{AB}	0.88^{B}	1.00^{A}	0.93^{AB}	0.014	0.011
Leucine	1.65^{AB}	1.52^{B}	1.72^{A}	1.62^{AB}	0.023	0.008
Threonine	1.00^{a}	0.90^{b}	1.00^{a}	0.93^{ab}	0.014	0.007
Valine	$1.04^{AB,a}$	$0.94^{B,b}$	$1.08^{A,a}$	$0.95^{B,ab}$	0.016	0.001
Histidine	1.14^{A}	0.98^{B}	0.97^{B}	0.88^{B}	0.021	<0.001
Arginine	$1.42^{A,a}$	$1.16^{B,b}$	$1.40^{A,a}$	$1.32^{A,B,a}$	0.024	<0.001
Phenylalanine	$0.88^{A,a}$	$0.76^{B,b}$	$0.84^{AB,ab}$	$0.79^{A,B,b}$	0.013	0.002
Suma EAA	$10.5^{A,a}$	$9.19^{B,c}$	$10.3^{AB,ab}$	$9.57^{A,B,b}$	0.150	0.002
Asparagine	$2.15^{AB,a}$	$1.94^{B,b}$	$2.19^{A,a}$	$2.01^{AB,ab}$	0.031	0.004
Serine	0.90^{A}	0.79^{B}	0.90^{A}	0.83^{AB}	0.014	0.003
Glutamine	3.26	3.02	3.29	3.23	0.042	0.075
Proline	0.76^{ab}	0.71^{b}	0.80^{a}	0.72^{ab}	0.013	0.026
Glycine	0.94^{a}	0.86^{b}	0.95^{a}	0.89^{ab}	0.012	0.006
Alanine	1.21	1.13	1.26	1.32	0.030	0.127
Cysteine	0.19	0.17	0.2	0.18	0.006	0.377
Tyrosine	0.77^{ab}	0.70^{b}	0.79^{a}	0.74^{ab}	0.011	0.014
Suma NEAA	10.2^{ab}	9.32^{b}	10.4^{a}	9.9^{ab}	0.137	0.022
Total AA	20.7^{a}	18.5^{b}	20.7^{a}	19.5^{ab}	0.283	0.008
Leg meat						
Lysine	1.01^{C}	0.98^{C}	1.45^{A}	1.32^{B}	0.034	<0.001
Methionine	0.21^{b}	0.23^{ab}	0.29^{a}	0.28^{a}	0.010	0.003
Isoleucine	0.54^{C}	0.53^{C}	0.81^{A}	0.71^{B}	0.020	<0.001
Leucine	0.93^{C}	0.90^{C}	1.36^{A}	1.20^{B}	0.031	<0.001
Threonine	0.52^{C}	0.52^{C}	0.76^{A}	0.70^{B}	0.018	<0.001
Valine	0.55^{C}	0.53^{C}	0.83^{A}	0.71^{B}	0.020	<0.001
Histidine	0.48^{C}	0.47^{C}	0.65^{A}	0.57^{B}	0.013	<0.001
Arginine	0.83^{C}	0.86^{C}	1.18^{A}	1.03^{B}	0.024	<0.001
Phenylalanine	0.47^{C}	0.46^{C}	0.71^{A}	0.61^{B}	0.017	<0.001
Suma EAA	5.54^{C}	5.48^{C}	8.03^{A}	7.12^{B}	0.179	<0.001
Asparagine	1.21^{C}	1.17^{C}	1.84^{A}	1.60^{B}	0.046	<0.001
Serine	0.51^{C}	0.49^{C}	0.73^{A}	0.66^{B}	0.017	<0.001
Glutamine	1.94^{C}	1.86^{C}	2.70^{A}	2.52^{B}	0.061	<0.001
Proline	0.51^{C}	0.49^{C}	0.72^{A}	0.60^{B}	0.016	<0.001
Glycine	0.60^{C}	0.60^{C}	0.88^{A}	0.77^{B}	0.020	<0.001
Alanine	0.69^{C}	0.68^{C}	0.99^{A}	0.90^{B}	0.022	<0.001
Cysteine	$0.14^{a,b}$	0.13^{b}	0.17^{a}	0.14^{b}	0.005	0.015
Tyrosine	0.41^{C}	0.40^{C}	0.60^{A}	0.54^{B}	0.015	<0.001
Suma NEAA	6.00^{C}	5.82^{C}	8.62^{A}	7.74^{B}	0.196	<0.001
Total AA	11.5^{C}	11.3^{C}	16.7^{A}	14.9^{B}	0.374	<0.001

$^{a–c}$Means within a row with different superscript letters differ ($P < 0.05$); $^{A–C}$Means within a row with different superscript letters differ ($P < 0.01$)

AA = amino acids; C = control group; CT = condensed tannins; CT1 = supplemented with 10 g CT/kg of feed; CT2 = supplemented with 20 g CT/kg of feed; EAA = essential amino acids; NEAA = non-essential amino acids; R = starter and grower basal diets containing the coccidiostat robenidine (33 mg/kg of feed) and without CT supplementation

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ibility in the ileum due to the formation of tannin-protein complexes and the inhibition of digestive enzymes (Hidayat et al. 2021). Conversely, low dietary doses of tannins may have antioxidant and immunomodulatory effects and improve the intestinal environment without severely impairing growth performance (Choi and Kim 2020). In the present study, dietary inclusion of CT from red quebracho led to unfavourably lower carcass weights in *Eimeria*-challenged broilers, with a more pronounced effect at 42 days of age, when there was also a decline in the relative proportion of legs. However, in terms of AA content in meat, broilers fed CT supplementation showed markedly higher total EAA and NEAA contents, especially in leg meat. This increase in EAA and NEAA contents was confirmed at both 35 and 42 days of age and was reflected in the higher nutritional value of the leg meat.

Broilers fed red quebracho CT supplement in the present study, particularly in the CT2 group, also showed reduced water content in muscles, which may affect the relative proportion of proteins in muscle tissue, as reflected by changes in the water-to-protein ratio (Dias et al. 2020). Lower growth rates and altered tissue deposition may further contribute to changes in the relative accumulation of muscle proteins, which can subsequently increase the intrinsic AA content when expressed per unit of tissue mass. Since growth rate and body composition are known to influence the water-to-protein ratio in muscle tissue (Dias et al. 2020), this mechanism may partially explain the observed differences in AA contents in the present study. Interestingly, the effect of diet on AA contents was more pronounced in leg meat than in breast meat in the present study. This may be related to differences in muscle fibre composition and metabolic phenotype, as breast muscle in broilers is composed almost entirely of glycolytic fibres, whereas leg muscle contains a higher proportion of oxidative fibres with greater aerobic capacity (Weng et al. 2022).

Extending the fattening period by 7 days in the present study did not significantly affect ($P > 0.05$) total EAA or NEAA contents, either in breast or leg meat (Table 10). Regarding the respective AA, the

Table 10. Age effect on amino acids content of male broiler meat (g/100 g of fresh meat)

Trait	Breast meat		Leg meat		SEM	*P*-value	
	35 days	42 days	35 days	42 days		breast	leg
Lysine	1.67	1.80	1.23	1.19	0.026	<0.001	0.334
Methionine	0.534	0.438	0.267	0.251	0.011	<0.001	0.310
Isoleucine	0.965	0.943	0.662	0.645	0.014	0.210	0.338
Leucine	1.61	1.63	1.13	1.10	0.024	0.501	0.297
Threonine	0.981	0.955	0.654	0.625	0.015	0.112	0.105
Valine	1.05	1.00	0.682	0.652	0.016	0.018	0.180
Histidine	0.998	0.993	0.548	0.543	0.020	0.510	0.529
Arginine	1.37	1.32	0.968	0.974	0.019	0.059	0.958
Phenylalanine	0.830	0.817	0.582	0.562	0.012	0.371	0.329
Suma EAA	10.0	9.90	6.72	6.54	0.152	0.522	0.324
Asparagine	1.94	2.07	1.45	1.45	0.028	0.003	0.683
Serine	0.850	0.854	0.631	0.596	0.012	0.827	0.084
Glutamine	3.37	3.20	2.33	2.56	0.047	0.004	0.340
Proline	0.723	0.746	0.598	0.580	0.009	0.111	0.190
Glycine	0.924	0.909	0.762	0.712	0.011	0.288	0.086
Alanine	1.18	1.23	0.868	0.814	0.019	0.358	0.036
Cysteine	0.191	0.188	0.126	0.145	0.003	0.719	0.001
Tyrosine	0.757	0.751	0.496	0.489	0.012	0.650	0.479
Suma NEAA	9.94	9.95	7.26	7.04	0.135	0.979	0.394
Total AA	20.0	19.8	14.0	13.6	0.286	0.759	0.363

AA = amino acids; EAA = essential amino acids; NEAA = non-essential amino acids

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effect of age was more pronounced in breast meat, where 42-day-old broilers exhibited higher contents of Lys and Asn ($P < 0.01$), but lower contents of Met and Gln ($P < 0.01$) as well as Val ($P < 0.05$) compared to the 35-day-old broilers. In leg meat, older broilers showed only higher Cys ($P < 0.01$) and lower Ala ($P < 0.05$) contents as compared to the 35-day-old birds. These findings are partly consistent with those of Suliman et al. (2023), who reported that the contents of Val, Leu, Ile, His, and Glu increased in Ross 308 broilers up to 35 days of age and then declined up to 49 days, with only minor changes observed between 35 and 42 days of age. Taken together, these results suggest that although total EAA and NEAA contents remain relatively stable, broiler age may slightly affect the profile of individual AA, likely reflecting differences in muscle protein deposition dynamics, growth rate, and age-dependent variations in AA digestibility and metabolism.

CONCLUSION

Dietary supplementation with the higher CT level (2%) reduced carcass weight in *Eimeria*-challenged broilers, particularly when the fattening period was extended to 42 days, while simultaneously leading to a consistent increase in DM and CP contents in breast meat, indicating alterations in nitrogen metabolism. CT supplementation also markedly influenced physical meat quality indicators, including cooking loss, pH, and shear force, although these effects were not consistent across all indicators, suggesting a complex and multifactorial influence of CT on muscle tissue. Broiler age was likewise an important factor affecting most of the evaluated physical traits, with a more pronounced impact in breast meat, where increased slaughter age was associated with higher cooking loss and shear force values, as well as changes in meat colour.

Both dietary CT supplementation and broiler age significantly affected the mineral composition of meat, with alterations in macro- and microelement contents depending on muscle type and fattening duration. Together with changes in chemical composition, these effects may contribute to structural alterations in muscle tissue, potentially reflected in shifts in the water-to-protein ratio. Dietary CT supplementation resulted in a substantial and consistent increase in total EAA and NEAA contents in leg meat, whereas in breast meat, a significant effect was observed only for NEAA in the CT1 group at 42 days of age. Extending the fattening period from 35 to 42 days did not affect total EAA and NEAA contents in either breast or leg meat, although minor age-related differences were observed in several individual AA.

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Conflict of interest

The authors declare no conflict of interest.

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