Effects of Dietary Inclusion of Casimiroa (Casimiroa edulis L) Seed Kernel Meal on Growth Performances, Carcass Yield and Profitability of Broilers Chicken

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Abstract

This study evaluated the effects of dietary inclusion of casimiroa seed kernel (CSK) meal on growth performance, carcass characteristics, and profitability of broiler chickens for 42 days. A total of 192 Cobb-500 chicks were randomly assigned into four treatments with four replicates of 12 chicks each. Rations consisted CSK meals at 0% (T1-control), 1.5% (T2), 3% (T3), and 4.5% (T4) were formulated. The crude protein and metabolizable energy content of CSK meal were 12.48% and 3571.26 kcal/kg, respectively. During the starter phase, broilers fed T3 exhibited a significantly lower feed conversion ratio ($P > 0.05$) than those on T4. They achieved a better ($P < 0.05$) FCR than those on T4, T2, and T1 diets during the finisher phase and entire period. Furthermore, chickens fed T3 showed significantly higher ($P < 0.05$) body weight changes, final body weight, and average daily gain than T4. Moreover, percentages of carcass, thigh, and breasts were significantly higher ($P < 0.05$) for T3 than T1 and T4. Weights of the liver and heart were highest ($P < 0.05$) for T4 compared to T1, T2, and T3. Lung and small intestine weights were higher for T2 and T3. However, abdominal fat weight significantly decreased with increasing level of CSK. Females had significantly higher ($P < 0.05$) fat weights than males. Total feed cost decreased with increasing levels of CSK meal. The highest net return was recorded in T3, followed by T2 and T1. Based on evaluated production parameters, it is advisable to incorporate underutilized CSK meal up to 3% in broiler rations to boost performance and profitability.

1. INTRODUCTION

There is an expected significant increase in broiler chicken production in the coming decades to meet the growing global demand for poultry meat (Mottet and Tempio 2017; Zampiga *et al.* 2021). However, feed shortages, primarily due to reliance on expensive conventional feed resources, are anticipated to challenge the sector's expansion and profitability (Makinde *et al.* 2021). These challenges have prompted a number of initiatives to explore alternative feedstuffs that do not compete with food staples for human consumption (Guaiume 2007). Utilization of alternative/ unconventional feed resources, for instance, can play a critical role in spicing up feed options as well as reducing over-reliance on conventional feeding substitutes (Mammo 2012). According to the works of Abd El Hack *et al.* (2019) Such alternatives feedstuffs, especially agricultural and agro-industrial by-products, contribute significantly to the health of broiler chickens, improve their general growth performance, and promote the economic sustainability of this sector. Use of these feedstuffs in broiler diets enhance digestibility of nutrients, control pathogenic microorganisms and improve absorption of energy-rich nutrients (Al-Harthi 2002; El-Deek *et al.* 2003). About this issue many researches revealed that, agri-food wastes (e.g., peels, fruit seeds) are rich in bioactive compounds, such as polyphenols, which are effective with antimicrobial, antioxidant, anti-inflammatory, antiparasitic, and immunostimulant properties that improve broiler chicken performance (George *et al.* 2020b; Corona *et al.* 2023; Valero and Salmeron 2003).

In this context, fruit of Casimiroa (Casimiroa edulis L.) belonging to family Rutaceae has been identified as a valuable by-product. These plants are abundantly available, cheaper, and highly yielder; a single mature plant of Casimiroa edulis yields close to one ton of fruit per year (Ahlawat 2016; Genanew *et al.* 2022). Though the fruit pulp can be eaten, seeds kernels become waste (Satheesh 2015; Agustín *et al.* 2017). But these seed kernels also contain phenolic compounds, flavonoids, alkaloids, coumarins, and limonoids (Awaad *et al.* 2007; Elkady *et al.* 2017), together with abundant amino acids and unsaturated fatty acids (94.2%) (Ahlawat *et al.* 2016; Elkady *et al.* 2017). These are also abundant with various sugars such as galacturonic acid, arabinose, and glucose (Ibrahim *et al.* 2019). This general picture of nutrition reveals the potential value of these seed kernels, which otherwise were not regarded as a valuable resource.

Pharmacological activity of bioactive compounds in casimiroa seed kernels (CSK) has been analyzed for antimicrobial, antioxidant, anticonvulsant, cardiovascular, and anti-inflammatory activity (Elkady *et al.* 2017) that can contribute to the health and performance of broiler chickens. For instance, Ibrahim *et al.* (2019) demonstrated that diabetic rats treated with 500 mg/kg of Casimiroa edulis seed protein experienced a significant reduction in blood glucose levels, from 600 to 117.28 mg/dl, along with improved weight gain, enhanced liver function, and increased antioxidant activity. Moreover, a study based on laying hens fed with nanoencapsulated meal of fruit of Casimiroa edulis at 5 g/kg for one month revealed no adverse cellular effects but promoted cell proliferation, immunity, and enhanced antioxidant activity (Corona *et al.* 2023).

Despite several studies documenting the significant phytochemical composition and pharmacological effects of CSK meals, their impact on productive parameters of broiler chickens—such as growth performance, carcass characteristics, and economic efficiency—has been insufficiently evaluated. Therefore, determining the optimum inclusion levels of CSK meals to enhance these productive traits while minimizing overall costs remains an important area for further research. This study aims to evaluate the effects of incorporating different levels of CSK meals on the growth performance, carcass yield, and profitability of broiler chickens.

2. MATERIALS AND METHODS

2.1. Description of study area

The experiment was conducted in Haramaya University's poultry farm, located 515 km east of Addis Ababa, of Ethiopia. The site is situated at an altitude of 2006 meters above sea level, with coordinates of 9o 41' N latitude and 42^{o} 4' E longitude. The area experiences the mean annual rainfall and temperature were 790 mm and $17^{o}C$ with mean minimum and maximum temperatures of 14 and $23.4^{o}C$, respectively (Mengesha *et al.* 2015).

2.2. Ingredients and Treatment Ration Preparations

The diet used in the current study consisted of a variety of feed ingredients, including maize, wheat shorts, soybean meal, noug seed cake, casimiroa seed kernel (CSK) meal, and salt. Besides, the diet included essential nutrients like; vitamin and mineral premix, methionine, lysine, limestone, and dicalcium phosphate. To obtain the test ingredient, Casimiroa fruit was collected from Casimiroa trees grown in the Eastern Hararghe, specifically in Maya city of Adele woreda, Dengego kebele. Fully ripened Casimiroa fruits were selected for seed collection. The Casimiroa fruit pulp and seed kernels were carefully separated, and the seed coats were removed before soaking. The seed kernels were thoroughly washed with tap water to reduce contamination. Then, to prepare the seeds for inclusion in the diet, they were chopped using a kitchen knife and soaked in cold water for 24 hours. This soaking process helped to reduce the levels of anti-nutritional factors present in the seeds (George *et al.* 2020a). After soaking, the chopped seeds were sun-dried for 4 days (8–10 hours per day). Once completely dried, the seeds were ground to a particle size of 5 mm using a grinding machine, producing the final meal. To maintain its quality, the CSK meal was stored in an airtight container to prevent contamination.

2.3. Experimental House, Birds and Feeding Management.

Prior to the actual experiment, the experimental house underwent thorough cleaning and disinfection. The floor was covered with teff straw to a depth of 7 cm and disinfected using hydrogen peroxide before placing the birds. Each pen was equipped with a 250-watt infrared heat bulb. A circular plastic feeder and drinker were placed in each pen one day prior to introducing the birds. A total of 192 unsexed and day-old broiler chicks (Cobb500) were purchased from Alama Farm PLC in Bishoftu, Ethiopia, and then transported to Haramaya University poultry farm. The broiler experiment was carried out for a total of 42 days. The starter phase was fed until three weeks of age, while the finisher phase started from the 4th up to the 6th week of age. Water was provided at all times, and measured quantities of the experimental ration were offered ad libitum twice a day, at 8:30 am and 5:00 pm, with the expected 20% refusal. The amount of feed refused was recorded each morning to determine feed intake. Bodyweight measurements were taken at the beginning of the experiment and at weekly intervals throughout the trial period, as well as at the end of the feeding trial, using a sensitive balance. The standard biosecurity protocol was strictly followed throughout the entire experiment. The chicks were vaccinated against Newcastle disease (HB1) on day 7, and a booster dose of Lasota was administered via eye drops on day 21. They were also vaccinated against infectious bursal (Gumboro) disease as recommended by the manufacturers.

2.4. Experimental Design and Treatments

The experiment was organized using a completely randomized design (CRD) with four dietary treatments (T1, T2, T3, and T4,) indicating CSK meals inclusion levels of 0%, 1.5%, 3%, and 4.5% respectively in the concentrate mixture. All experimental birds were randomly assigned to these dietary treatments, each had four replications and each replication had 12 birds. Win feed software was used to formulate the treatment rations to be iso-caloric and iso-nitrogenous to meet the nutrient requirement of broilers (NRC 1994). The starter and finisher diets were formulated separately as indicated in the Table 1. Finally, formulated rations were processed at the Haramaya Area Union Animal Feed Processing Centre.

Table 1
The proportion of ingredients (%) for starter and finisher broiler chickens ration

Ingredients	Starter (1–3 weeks)				Finisher (4–6 weeks)			
	T1	T2	T3	T4	T1	T2	T3	T4
Maize grain	47	46.5	46.5	45	58	57.5	56	54.5
Soybean meal	30.25	30.25	30.25	30.25	31.5	31.5	31.5	31.5
Noug seed cake	16.25	16.25	16.25	16.25	4.8	4.8	4.8	4.8
Wheat shorts	3.5	2.5	1	1	2.5	1.5	1.5	1.5
CSKM	0	1.5	3	4.5	0	1.5	3	4.5
Limestone	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
Vitamin premix	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Lysine	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
Methionine	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Dicalcium phosphate	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Salt	0.3	0.3	0.3	0.3	0.5	0.5	0.5	0.5
Total	100	100	100	100	100	100	100	100

CSKM = Casimiroa Seed Kernel Meal; T1 = 0% CSKM, T2 = 1.5% CSKM, T3 = 3% CSKM, T4 = 4.5% CSKM

2.5. Data Collection

2.5.1. Feed intake, body weight changes and mortality rate

Daily feed consumption was calculated by subtracting feed refusals from the feed offered. Bird weights were recorded at the start and on days 7, 14, 21, 28, 35, and 42 by weighing all birds in each pen before feeding. Body weight (BW) gain was determined as the difference between final and initial weights, while average daily gain (ADG) was calculated by dividing BW gain by the total experimental days. FCR was obtained by dividing daily dry matter (DM) intake by ADG (Shawle *et al.* 2016). The performance index was calculated by dividing BW gain by FCR and multiplied by hundred (North 1981). Mortality rate was expressed as a percentage of dead birds relative to the initial population.

2.5.4. Carcass traits and slaughter procedure

At the end of feeding trial, 64 birds (16 per treatment and 4 per replication each comprising two males and two females) were selected for carcass evaluation based on body weights closest to the group average. The birds were subjected to a 12-hour fasting period to ensure their crops were emptied (Ari *et al.* 2013). Pre-slaughter weights were taken, and after slaughter and bleeding, de-feathering was carried out using a de-feathering machine. The dressed carcass weight was then measured after the removal of blood and feathers. Dressing percentage was calculated in accordance with the procedure outlined by FAO (2001). To determine the eviscerated carcass weight, the combined weight of non-edible offal (blood, feathers, lower legs, head, kidneys, lungs, pancreas, crop, proventriculus, small intestine, caeca, large intestine, cloaca, and urogenital tracts) were subtracted from the dressed carcass weight. Finally, the eviscerated percentage was calculated as a proportion of the slaughter weight (FAO 2001). All the eviscerated carcass (drumstick, thigh, breast, wings, back, neck meat), edible offal (heart, gizzard, and liver), and the aforementioned non-edible offal components were individually weighed using a sensitive balance. Then, their percentage was calculated relative to the pre-slaughter weight (Kekeocha 1985). The length of gastrointestinal tract (GIT) parts (small intestine, large intestine, and caeca length), were measured using a measuring tape. Finally, abdominal fat was measured by weighing the fat removed from the proventriculus to the cloaca.

2.5.5. Chemical analysis of the feed

To ensure the formulated ration met nutritional requirements of broiler chickens, representative sample from each dietary treatment was taken and the chemical composition analysis was carried out in Haramaya University animal nutrition laboratory. The diets were analysed for their dry matter (DM), crude fibre (CF), ash, ether extract (EE), calcium, and phosphorus contents. Nitrogen (N) was determined according to the Kjeldahl procedure (AOAC, 2011). Then, crude protein (CP) was calculated as N × 6.25. Calcium and phosphorus were also measured by using atomic absorption spectroscopy and spectrophotometry, respectively (AOAC 2011). The metabolizable energy (ME) content of the experimental diets was calculated by adopting the equation proposed by Wiseman (1987) as follows: ME (Kcal/kg DM) = 3951 + 54.4 EE − 88.7 CF − 40.8 ash

2.5.6. Production and economic efficiency analysis

The economic efficiency of feeding rations containing different levels of CSK meals was evaluated using the European Broiler Index (EBI) and the Production Efficiency Factor (PEF) (Marcu *et al.* 2013).

$$\mathrm{EBI} = \frac{\text{Viability } (\%) * \text{Daily weight gain } (\text{g})}{\text{FCR (kg feed/kg gain)} * 10}$$

$$\mathrm{PEF} = \frac{\text{Viability } (\%) * \text{Body weight } (\text{Kg})}{\text{Age at depleted } (\text{days}) * \text{FCR}} * 100$$

Where: Liveability (%) = chicks alive at the end of the period (%), Age (day) = the age of the chick at slaughter, Body weight = final body weight

Partial budget analysis (PBA) was performed to evaluate the economic advantage of the different treatments by using the procedures of (Upton 1979). Hence, PBA was to evaluate the economic benefits of incorporating Casimiroa fruit seed kernel meals into broiler chicken diets. The analysis considered feed costs, assuming similar chick purchase prices, and carcass selling prices based on average live weight across treatments. Labor and vaccination costs were deemed constant for treatments (Shapiro *et al.* 1994). Feed cost per bird was calculated by multiplying feed consumption by cost per kilogram. Variable costs were the difference between feed expenses for each diet and live bird prices Upton 1979; Shapiro *et al.* 1994). Net income (NI) was determined by subtracting total variable costs (TVC) from total rate of returns (TRR): NI = TRR − TVC. Changes in net income (ΔNI) were calculated as ΔNI = ΔTRR - ΔTVC, where ΔTRR and ΔTVC represent changes in returns and costs, respectively. The marginal rate of return (MRR) quantified the increase in ΔNI per unit of additional expenditure: MRR = ΔNI / ΔTVC.

2.6. Statistical Analysis

Data were processed and analysed using one-way ANOVA and General Linear Model (GLM) procedures in the statistical analysis system of JMP pro. 17.2 version software program. When analysis of variance showed significance, treatment means were separated using the Tukey test. A probability level (P) of 0.05 was used to determine differences among the treatment means, which were significantly different ($P < 0.05$). The mean values and the standard errors of the means (SEM) were reported. Statistical models set for data analysis were as follows: $Y_{ijk} = \mu + T_i + E_{ij}$, where: Y_{ijk} = represents the j^{th} observation in the i^{th} treatment levels, μ = overall mean of a response variables, T_i = the fixed effect of i^{th} CSK meal inclusion levels (i = 0, 1.5, 3, 4.5) in the response variables and E_{ij} = error term. To determine effects of sex and sex-treatment interactions on carcass characteristics two-way ANOVA ware performed.

3. RESULTS

3.1. Chemical Composition of Ingredients and Experimental Ration

The laboratory analysis results for the experimental diets and main feed ingredients are presented in Table 2. As anticipated, the four treatment rations were nearly isocaloric and isonitrogenous. Among the tested ingredients, Casimiroa seed kernel (CSK) meal exhibited the highest metabolizable energy (3571.26 kcal/kg DM), surpassing wheat shorts, soybean meal, and noug seed cake, and was comparable to maize grain. Furthermore, CSK had the highest calcium content and the lowest crude fiber content relative to the other major feed ingredients. Notably, its crude protein content (12.48%) was significantly higher than that of maize grain (9.45%), indicating that CSK could serve as a cost-effective alternative to expensive energy-rich feed ingredients.

Table 2
Chemical composition of the main ingredients and the ration (based on DM%)

Ingredients	DM%	CP	CF	EE	Ash	Ca	P	ME (Kcal/kg DM)
Maize	90.32	9.45	4.16	3.76	4.67	0.07	0.46	3595.72
Wheat shorts	90.94	15.35	9.67	3.48	4.74	0.16	0.60	3089.19
Soybean meal	93.31	39.44	8.62	4.21	5.97	0.34	0.56	3171.72
Noug seed cake	92.06	30.45	16.48	7.41	10.8	0.33	0.58	2451.46
CSKM	89.08	12.48	2.94	0.96	4.19	1.01	0.11	3571.26
Starter phase								
T1	89.58	21.87	8.43	4.89	7.57	0.39	0.45	3160.89
T2	89.83	22.03	8.18	4.75	8.15	0.62	0.48	3150.67
T3	89.15	21.91	7.99	4.57	8.12	0.68	0.51	3159.62
T4	88.77	21.96	7.95	4.39	8.31	0.65	0.37	3145.13
Finisher phase								
T1	87.64	19.67	8.03	4.38	6.60	0.47	0.31	3207.96
T2	88.74	19.74	7.98	4.28	6.54	0.34	0.38	3209.30
T3	88.31	19.92	7.99	4.53	6.91	0.73	0.31	3206.81
T4	88.54	20.01	8.05	4.59	7.02	0.81	0.42	3200.38

T1, T2, T3 and T4 = 0, 1.5, 3 and 4.5 level comprise Casimiroa Seed Kernel Meal rations, respectively, ME = Metabolizable energy, Kcal = Kilocalorie, Kg = Kilogram, P = Phosphorous, Ca = Calcium, EE = Ether extract, CF = Crude fiber, CP = Crude protein, DM = Dry matter

3.2. Feed Intake, Growth and Performances

Feed intake, nutrients utilization and growth performances of broiler chicken at different stages of development is presented in Table 3. Feed intake, body weight changes, mortality rate, and performances index of the chicken during the starter phase were similar across dietary treatments with varying level of CSK meals. The most efficient feed conversion ratio (FCR) ($p < 0.05$) was observed in birds fed with T3, followed by T2. During the finisher phase of feeding management, and the entire period, inclusion of CSK meal significantly influenced ($p < 0.05$) all performance parameters except feed intake and mortality rate. Similarly, birds which fed on the T3 diet demonstrated superior final body weight, weight gain, and average daily gain compared to T4 while showing no significant differences from T2 and T1. Moreover, birds under T3 exhibited a significantly better FCR ($p < 0.05$) compared to other treatments and achieved the highest performance index ($p < 0.05$) during both the finisher and overall periods.

Table 3
Performances of broilers fed on ration comprising different levels of CSK meals

Parameters	**Treatments**				**SEM**	**P-Value**
Starter Phase (1–21 days)	**T1**	**T2**	**T3**	**T4**		
Initial body weight (g/bird)	42.65	41.68	43.73	42.21	0.79	0.350
Feed intake (g/bird)	1047.49	1011.42	1003.73	970.35	22.13	0.16
Final body weight (g/bird)	507.07	500.81	509.96	435.6	19.04	0.051
Body weight gain (g/bird)	464.42	459.12	466.23	393.39	18.87	0.051
Average daily gain (g/day)	22.12	21.86	22.20	18.73	0.90	0.051
Daily feed intake(g/bird)	49.88	48.16	47.79	46.21	1.05	0.161
Feed conversion ratio	2.26^{ab}	2.21^{ab}	2.16^{b}	2.48^{a}	0.072	0.040*
Performance index	19.65	20.58	21.56	16.61	1.17	0.057
Mortality (%)	2.08	4.17	2.08	2.08	2.17	0.873
Finisher Phase (21–42 days)						
Initial body weight (g/bird)	507.07	500.81	509.96	435.6	19.04	0.051
Feed intake /Chick (g/bird)	2761.88	2800.35	2665.83	2725.2	48.26	0.288
Final body weight (g/bird)	1759^{ab}	1785.85^{a}	1903.83^{a}	1580.9^{b}	46.80	0.003*
Body weight gain (g/bird)	1251.9^{ab}	1285.2^{ab}	1393.87^{a}	1145.3^{b}	34.90	0.002*
Average daily gain (g/day)	59.61^{ab}	61.19^{ab}	66.37^{a}	54.53^{b}	1.66	0.002*
Daily feed intake(g/bird)	131.52	133.35	126.94	129.77	2.30	0.288
Feed conversion ratio	2.21^{a}	2.18^{a}	1.91^{b}	2.39^{a}	0.06	0.001*
Performance index	20.55^{b}	21.05^{b}	27.44^{a}	17.83^{b}	1.10	0.0004*
Mortality (%)	6.25	2.08	4.17	2.08	2.17	0.495
Entire Period (1–42 days)						
Initial body weight (g/bird)	42.65	41.68	43.73	42.21	0.79	0.350

T1, T2, T3 and T4 = 0, 1.5, 3 and 4.5 level comprise casimiroa seed kernel meal rations, respectively. ^{a,b,c} *= Means within a row with different superscripts are significantly different (p < 0.05), SEM = Standard error of mean*

Parameters	Treatments				SEM	P-Value
Starter Phase (1–21 days)	**T1**	**T2**	**T3**	**T4**		
Feed intake /Chick (g/bird)	3809.36	3811.77	3669.56	3695.54	61.84	0.275
Final body weight (g/bird)	1759 ^{ab}	1785.85^{a}	1903.83^{a}	1580.8^{b}	46.80	0.003*
Body weight gain (g/bird)	1716.4^{ab}	1744.17^{a}	1860.1^{a}	1538.7^{b}	46.67	0.003*
Average daily gain (g/day)	40.87^{ab}	41.53^{a}	44.29 ^{a}	36.63^{b}	1.11	0.003*
Daily feed intake(g/bird)	90.70	90.76	87.37	87.99	1.47	0.2753
Feed conversion ratio	2.22 ^{a}	2.19 ^{ab}	1.97 ^{b}	2.41^{a}	0.05	0.000*
Performance index	20.30^{b}	20.92^{b}	25.73^{a}	17.44^{b}	0.87	0.0002*
Mortality (%)	8.33	6.25	6.25	4.17	2.55	0.726

T1, T2, T3 and T4 = 0, 1.5, 3 and 4.5 level comprise casimiroa seed kernel meal rations, respectively. ^{a,b,c} *= Means within a row with different superscripts are significantly different (p < 0.05), SEM = Standard error of mean*

3.3. Carcass Parameters

3.3.1. Carcass yield

Carcass yield components of broilers fed on diets containing different levels of CSK meals is shown Table 4. There were no significant differences (p > 0.05) in live weight, dressed weight, eviscerated weight, and percentages of drumstick, wings, and neck among birds under different dietary treatments. Whereas inclusion of CSK meal significantly affected carcass, thigh, and breast percentages (p < 0.05) in which birds under T3 had exhibited superior performances as compared with T1 and T4. There were no significant effects (p > 0.05) of sexes and sex-by-treatment interactions.

3.3.2. Edible offal and abdominal fat weight

The total giblet, gizzard, liver, heart, skin weights, and abdominal fat (AF) percentage is presented in Table 5. There was no significant difference (p > 0.05) in weight among the total giblet, gizzard, and skin while the inclusion of CSK meal in the ration significantly (p < 0.05) affected the average weights of liver, and heart percentage (T1 = T2 = T3 < T4). Broilers which fed on T1 diet had a higher abdominal fat percentage than those in T3 and T4 diets. Sex had a significant effect (p < 0.05) on abdominal fat percentage, in which female birds exhibited higher AF values than males while it had no significant effect (p > 0.05) on the remaining edible offal parameters.

3.3.3. Non-edible offal

Table 6 is shown non-edible components (ceca, crop, lung, spleen, proventriculus, small and large intestines). Except lung and small intestine (SI) weights, all other non-edible offal parameters were not significantly influenced (p > 0.05) by the inclusion of CSK meal in the broiler ration Lung weight was significantly higher (p < 0.05) in T3 while the smallest SI weight was recorded by those birds fed on T1 and T4 diet (Table 6). There were no significant differences (p > 0.05) in non-edible offal weight with respect to sex and interaction between sex and treatment.

Table 4
Carcass yield components of broilers fed ration containing different levels of CSK meals

	Treatments						Sex		T*Sex	
Parameters	T1	T2	T3	T4	SEM	P value	M	F	P-Value	P-Value
Live wt (g)	1763.63	1789.5	1846.38	1632.25	55.06	0.068	1793.81	1722.06	0.205	0.812
Dressed wt (g)	1618.63	1664.9	1719.75	1504.13	55.24	0.065	1654.13	1599.56	0.333	0.817
Dressing%	91.76	92.97	93.17	92.11	0.58	0.279	92.18	92.82	0.285	0.219
Eviscerated wt (g)	1311.38	1390.5	1445.88	1259.63	44.95	0.053	1373.94	1329.75	0.335	0.989
Eviscerated %	74.44	77.80	78.29	77.17	1.06	0.072	76.58	77.27	0.525	0.365
Carcass %	63.12^{b}	66.15^{ab}	66.76^{a}	64.92^{b}	0.92	0.049*	65.04	65.43	0.675	0.475
Drumstick%	10.57	10.59	10.63	10.43	0.22	0.570	10.65	10.46	0.418	0.220
Thigh%	11.12^{b}	11.42^{ab}	12.29^{a}	11.03b	0.26	0.007*	11.61	11.22	0.146	0.712
Breast%	26.49^{b}	29.65 ab	29.74^{a}	27.48b	0.55	0.004*	28.13	28.55	0.450	0.832
Wings%	4.21	4.21	4.08	4.37	0.11	0.340	4.19	4.24	0.669	0.654
Back %	7.53	7.55	7.29	8.12	0.22	0.074	7.46	7.78	0.150	0.678
Neck %	3.02	3.14	3.03	3.29	0.11	0.296	3.03	3.21	0.125	0.123

*$^{a, b, c}$ = Means within a row with different superscripts are significantly different ($p < 0.05$), SEM = Standard error of the mean, T1, T2, T3 and T4 = 0, 1.5, 3 and 4.5 level comprise casimiroa seed kernel meal rations, respectively. M = Male, F-Female, T*S = Treatment-sex interaction, g = gram*

Table 5
Edible offal and abdominal fat weight of broilers fed ration containing different levels of CSK meals

	Treatments						Sex		T*Sex	
Parameters	T1	T2	T3	T4	SEM	p-Value	M	F	p-Value	p-Value
Total giblet	80.25	81.50	82.88	86.63	1.63	0.058	83.75	81.88	0.262	0.715
Gizzard (g)	32.5	32	32.88	31.63	0.92	0.786	32.44	32.06	0.688	0.566
Liver wt (g)	40.00^{b}	41.38^{ab}	41.63^{ab}	45.13^{a}	1.03	0.012*	42.56	41.50	0.310	0.604
Heart wt (g)	7.75^{b}	8.13^{b}	8.38^{b}	9.88^{a}	0.36	0.002*	8.75	8.3125	0.235	0.844
Skin wt (g)	107.88	115.75	113.88	108	6.95	0.798	111.5	111.25	0.972	0.996
AF%	1.43^{a}	1.23^{ab}	0.86^{b}	0.85^{b}	0.10	0.004*	0.98^{b}	1.21^{a}	0.024*	0.113

*Edible offal (TG + skin), TG = (Gizzard + Heart + Liver), $^{a, b, c}$ = Means within a row with different superscripts are significantly different ($p < 0.05$), SEM = Standard error of the mean, T1, T2, T3 and T4 = 0, 1.5, 3 and 4.5 level comprise casimiroa seed kernel meal rations, respectively. M = Male, F-Female, T*S = Treatment-sex interaction, g = gram, AF = abdominal fat weight*

Table 6
Non-edible offal weight of broilers fed ration containing different levels of CSK meals

	Treatments						Sex		T*Sex	
Parameters	T1	T2	T3	T4	SEM	P - value	M	F	p-Value	p-Value
Spleen wt (g)	2.25	3.25	2.75	2.25	0.30	0.076	2.63	2.63	1.00	0.260
Kidney wt (g)	10.50	10.63	11.50	9.63	0.58	0.178	10.75	10.38	0.521	0.457
Lung wt (g)	9.00 ^{b}	11.38 ^{ab}	13.38 ^{a}	10.63 ^{ab}	0.78	0.005*	11.5	10.69	0.306	0.543
Crop wt (g)	14.38	12.00	12.00	12.38	0.79	0.129	13.25	12.13	0.167	0.999
Pro. wt (g)	9.5	10.38	10.75	9.75	0.84	0.708	10.31	9.88	0.606	0.584
SI wt (g)	76.5^{b}	87.25^{a}	90.5^{a}	78.5^{b}	3.59	0.002*	81.31	85.06	0.307	0.247
SI length (cm)	183.38	190.38	187.00	186.00	4.86	0.098	182.31	186.06	0.448	0.432
LI wt (g)	2.88	3.38	3.5	2.75	0.37	0.418	2.94	3.31	0.323	0.510
LI length(cm)	9.00	10.75	9.25	9.38	0.47	0.059	9.44	9.75	0.509	0.144
Ceca wt (g)	12.13	12.00	13.25	11.88	0.99	0.750	12.69	11.94	0.458	0.203
Ceca length(cm)	18.15	18.13	18.88	17.13	0.61	0.988	18.13	18.00	0.839	0.269

*^{a,b,c} = Means within a row with different superscripts are significantly different ($p < 0.05$), SEM = Standard error of the mean, T1, T2, T3 and T4 = 0, 1.5, 3 and 4.5 level comprise casimiroa seed kernel meal rations, respectively. M = Male, F-Female, T*S = Treatment-sex interaction, g = gram, cm = centimetre, Pro.= proventriculus, SI = small intestine, LI = large intestine*

3.4. Production Efficiency and Partial budget analysis

European broiler index (EBI) and production efficiency factor (PEF) among the treatment groups during starter and finisher phases of broiler feeding management are presented in Table 7. There was no significant difference ($p < 0.05$) in EBI and PEF among dietary treatment groups during starter feeding management phase. Whereas EBI and PEF value during the finisher phase was significantly higher ($p < 0.05$) in T3 as compared with T1, T2 and T4 dietary treatments while T1, T2 and T4 exhibited similar EBI and PEF values. Throughout the entire periods, birds fed on T3 had higher ($p < 0.05$) EBI and PEF values compared to T4 while these values recorded under the later experimental diet, were similar with T1 and T2. The highest net profit was obtained from selling meat produced from birds fed on T3 diet with a net profit of 113.41 ETB, followed by T2 and T1 with net profits of 92.31 and 71.47 ETB respectively (Table 8). Whereas, the least profit was earned from the birds consumed T4 ration. High marginal rates of return were observed in T3, followed by T2, and then T1.

Table 7
Production efficiency of broilers fed different levels of CSK meals

Parameters		Treatments					
Production efficiency		T1	T2	T3	T4	SEM	P- value
Starter (1–21)	EBI	95.84	95.47	101.72	75.20	7.55	0.123
	PEF	104.65	104.11	111.22	83.19	7.96	0.125
Finisher (22–42)	EBI	253.21^{b}	274.68^{b}	332.37^{a}	226.17^{b}	12.60	0.0005*
	PEF	355.92^{b}	381.80^{ab}	454.03^{a}	312.04^{b}	17.64	0.0008*
Entire period (1–42)	EBI	168.78^{ab}	178.76^{ab}	210.72^{a}	146.99^{b}	10.57	0.0083*
	PEF	172.98^{ab}	183.02^{ab}	215.68^{a}	151.01^{b}	10.75	0.0084*

EBI = European broiler index, PEF = Production efficiency factor, [a, b, c] Means within a row with different superscripts are significantly different, T1, T2, T3 and T4 = 0, 1.5, 3 and 4.5 level comprise casimiroa seed kernel meal rations, respectively, SEM = standard error of the mean

Table 8
Profitability analysis for broilers fed different levels of CSK meals

Parameters	Treatments			
Cost	T1	T2	T3	T4
Chicken cost (ETB)	93.00	93.00	93.00	93.00
Total feed consumed/chicken (kg)	3.809	3.812	3.670	3.696
Per unit feed cost (ETB)	42.89	42.58	42.25	41.85
Total feed cost/ chicken (ETB)	163.38	162.32	155.06	154.66
Total cost / chicken (ETB)	256.38	255.32	248.06	247.66
Income				
Average of eviscerated wt (kg) / chicken	1.31	1.39	1.45	1.26
Price/kg of carcass (supermarket) (ETB)	250	250	250.00	250.00
Total return / chicken (ETB)	327.85	347.63	361.47	314.91
Net return/chicken (ETB)	71.47	92.31	113.41	67.25
Marginal rate of return	0.22	0.27	0.31	0.21

T1, T2, T3 and T4 = 0, 1.5, 3 and 4.5 level comprise casimiroa seed kernel meal rations, respectively, ETB = Ethiopian birr

4. DISCUSSION

4.1. Chemical composition

The treatment diets contained metabolizable energy and protein levels that met the nutritional requirements for both starter and finisher broilers (NRC, 1994). Additionally, the rations provided adequate calcium and phosphorus, with concentrations aligning with recommendations: 1% Ca and 0.45% P for the starter phase, and 0.9% Ca and 0.35% P for the finisher phase (NRC, 1994)

4.2. Feed Intake and Growth Performance traits

In this study, it was shown that CSK meal (T3) utilized at 3% level in the finisher phase and the entire feeding periods, significantly improves final body weight, body weight gain and average daily gain; these findings are consistent with Abu Hafsa and Ibrahim (2018). The authors reported increased final body weight, body weight gain, and feed conversion ratio (FCR) with no change in feed intake in broiler birds fed with diet incorporated with 20 g/kg of grape seed over 42 days. Similar to the present result, earlier findings of Ibrahim *et al.* (2019) reported that diabetic rats treated with 500 mg/kg of CSK meal protein gained 93 g more weight than those treated with 10 mg/kg of the standard drug glibenclamide. The existence of complex bioactive compounds like coumarins and flavonoids in CSK meal are likely responsible for these enhancements (Tun *et al.* 2020). These compounds are known for their pharmacological properties, including antibacterial, antimicrobial, and antioxidant effects (Elkady *et al.* 2017; Widelski *et al.* 2018; Nath and Aravindkumar, 2021). In addition, Duskaev *et al.* (2020) and Obianwuna *et al.* (2024) have reported that diets rich in coumarin and flavonoids have enhanced the broilers' gut health via the activation of beneficial microbes, inhibition of pathogenic ones, enhancement of the efficacy of nutrient absorption, and improvement of the general gastrointestinal system, thus leading to enhanced growth performances.

In this current study, the trends of enhanced FCR observed up to 3% CSK meal inclusion level in all phases indeed agree with those of Saleem *et al.* (2024), who stated the better FCR towards increasing level of mango seed kernel meal from 10–30 g/kg and lower at higher level (40 g/kg) in broiler rations. The FCR improvement might be related to the flavonoids present in CSK meal, due to Nath and Aravindkumar (2021) reported flavonoids are strong antioxidants that reduce oxidative stress in broilers, which enhances growth rate and feed conversion efficiency. They argued that flavones might enhance the binding of growth hormone to hepatic growth hormone receptors and stimulate insulin-like growth factor levels to positively regulate the growth of broilers. Furthermore, Obianwuna *et al.* (2024) stated that flavonoids improve gut health by enhancing nutrient absorption and villi height. Tan *et al.* (2022) also reported the statement by adding that flavonoids induce fat metabolism via stimulating fat degradation and inhibiting adipogenesis which implicates their action in better body composition and FCR improvement.

In general, the existence of significant differences in broiler growth performances at the 3% inclusion level of CSK meal (T3) during the finisher phase and entire feeding periods indicated that the optimum benefits of CSK meal are achieved at moderate levels. According to Adetunji *et al.* (2020), a balanced diet with a balanced fiber content enhances gut health and nutrition absorption throughout the starter and finisher stages supported current findings. However, the considerable decrease in growth performance at the highest inclusion (4.5% CSK meal) level during the finisher and the entire period may be related to the existence of certain anti- nutritional factors. According to Elkady *et al.* (2017), complete CSK meal contains 53.73 mg/g concentration of tannins which might have hindered the bioavailability of nutrients. In the same line, Azizi *et al.* (2018) observed that the body weight decreased progressively after the addition of more than 5% dried apple pomace in the diets for the broilers. In accordance with the present study, Abu Hafsa and Ibrahim (2018) reported improved growth performance and constant feed intake at moderate levels of grape seed inclusion (20 g/kg) but decreased at higher levels of grape seed over the 42-day duration.

4.3. Carcass Traits

Improved carcass weight percent, including breast and thigh muscles, at 1.5 and 3% inclusion levels of CSK, might be attributed to high concentrations of valuable bioactive compounds such as unsaturated fatty acids and flavonoids, and other essential nutrients. These results are supported by Tareen *et al.* (2017), who found similar enhancement with a 3% inclusion level of palm kernel meal in broiler diets. In the same vein, Saleem *et al.* (2024) confirmed similar results when including 30 g/kg mango seed kernel meals in broiler rations. The study showed the potentials of locally available fruit seed kernels to stimulate muscle growth, augment feed efficiency, and improve general meat production in broiler chickens. Unsaturated fatty acids, accounting for nearly 94.2% of the fatty acid composition in CSK meals (Elkady *et al.* 2017), would likely be responsible for metabolic processes that facilitate the development of lean muscle mass. As DeLany *et al.* (1999) mentioned, a high concentration of unsaturated fatty acids, such as linoleic acid, makes a particularly significant contribution to the enhancement of lean muscle mass and muscle development in the abdominal area. This is probably due to its role in increasing lipid metabolism and suppressing fat deposition. Also, flavonoids are another significant bioactive compound found in CSK meals at a concentration of 14.4 mg/g on a dry weight basis (Elkady *et al.* 2017), which is an additional benefit by acting as natural antioxidants. These are found to prevent lipid oxidation and improve the quality of meat in general. By decreasing oxidative stress, flavonoids allow for a higher proportion of lean cuts in breast and thigh muscles, which have high interest in poultry production. This agrees with the observed carcass composition improvement in the current study.

In the current study, inclusion of CSK meal up to 3% in broiler diets had no adverse effects on liver or heart weights, indicating as it is optimum inclusion level. According to Bone (1979), changes in organ weights specifically liver and heart weights, usually occur due to heightened metabolic activity aimed at detoxifying the body. Absence of the weight change of these organs in this study indicated the diets were free from toxic substances or anti-nutritional factors up to 3% CSK meal inclusion (T3). At the inclusion level of 4.5% CSK meal, however, an increase in the weight of liver and heart was observed. This effect is consistent with the finding of George *et al.* (2020), who also noticed the same effects at high inclusion rates of avocado seed kernel meal on broiler organ weights. The increased size of the heart and liver at higher levels of CSK meal inclusion may be attributed to the presence of tannins in the seeds. This agrees with Bawa *et al.* (2006) and Abu and Tanimowo (2012), who attributed increased organ weights to the presence of antinutritional factors that would influence organ growth.

The content of abdominal fat can be decreased as the level of CSK meals increases because casimiroa seed kernel meals contain high amounts of alpha-linolenic acid and amino acids. Elkady *et al.* (2017) and Ibrahim *et al.* (2019) revealed that the seed kernels of Casimiroa edulis are rich in the alpha-linolenic acid and essential amino acids. Chickens with diets high in alpha-linolenic acid tended to have lower deposits of abdominal fat, unlike those on diets high in saturated fatty acids (Kartikasari *et al.* 2018). Amino acids may also prevent visceral fat through inhibition of hepatic fatty acid synthase activity and activation of glycogenesis, thus significantly reducing fat accumulation (Loizzo *et al.* 2018). The abundance of abdominal fats presents in female birds indicates a higher tendency of fat deposition when compared to males due to metabolic and hormonal changes, as reported by Tumova and Teimouri (2010) and Silva (2012). In line with this, de Souza Khatlab *et al.* (2018) stated that females show greater amounts of gene expression in the context of fatty acids and lipid production than male.

Increased lung weight observed in broiler birds fed 1.5, 3 and 4.5% inclusion levels of CSK meal probably attributed to the metabolic activity of the broilers. In their findings, Namakparvar *et al.* (2014) report, larger lungs improve the flow of oxygen needed for metabolic functions. On the other hand, the small intestine weight of the current study is similar with the works of Al-Marzooqi (2019) who reported increased small intestine weight in broiler chickens to achieve greater body weight. The weight of small intestine in broilers is believed to link with more efficient feed digestion and a greater surface area for nutrient absorption for enhancing overall nutrient uptake.

4.4. Production Efficiency and Profitability Analysis

The Performance and economic feasibility assessment through European Broiler Index (EBI) and Production Efficiency Factor (PEF), was positively influenced by body weight change, feed conversion ratio (FCR), average daily gain (ADG), and survival rate (Marcu *et al.* 2013). The maximum value of EBI and PEF were obtained at the 3, 1.5 and 0% inclusion levels of CSK meal, respectively. These values of EBI and PEF obtained during the present study agreed with work of Tolmir *et al.* (2014). On the other hand, current values are lower when compared to those obtained by Bhamare *et al.* (2016). These declines are probably linked to the factors like growth performance and management conditions. In general, the EBI and PEF values in this study offer valid information about practices of broiler farm management.

According to the partial budgeting of the current study, broilers that received 4.5% CSK meal registered the minimum net return of 67.25 ETB per bird compared to other inclusion levels. On the other hand, birds which fed on the 3% CSK meal attained the highest net return of 113.41 ETB per bird. Moreover, the birds which fed on 3% CSK meal diet showed the highest marginal rate of return relative to the unit cost of production. Therefore, the current study indicated that a ration containing 3% CSK meal is more profitable than higher inclusion levels under the current study's feeding management.

5. CONCLUSION

The results of this study indicated that inclusion of CSK meal up to 4.5% in Cobb 500 broiler diets had no adverse effects on the health condition of the birds. Whereas the optimum inclusion of CSK meal was 3%, in which the highest feed conversion ratio, body weight gain, carcass yields, highest net profit, and marginal rate of return were recorded. Therefore, this study recommended including CSK meal at a 3% level in Cobb 500 broiler diets to obtain maximum growth, carcass yields, and economic performance.

Declarations

6.1. Funding

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6.2. Conflicts of Interest or Disclosure Statement

The authors declare that there was no conflict of interest or no potential conflict of interest was reported by the author(s).

6.3. Data Availability Statement

The data used in this study are available from the corresponding author upon request to interested.

6.4. Ethical Approval

All procedures involving animal care and management were in accordance with the guidelines for the treatment of animals in behavioural research and teaching (ScienceDirect and Behavior, 2012)

6.5. Contributions of the Authors

Mohamedjuhar Musa carried out conceptualization, research, formal analysis, data gathering, data analysis, writing the original draft, reviewing, and editing. Mengistu urge played roles in planning, supervision, directing, reviewing, and revising. Whereas Biazen, Sileshi, Meseret, and Misba played the conceptualization, supervision, review, and editing roles. The publishable version of the manuscript has been read and approved by all authors.

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References

1. Abd El Hack ME, Alagawany M, Patra A, Abdel-Latif M, Ashour EA, Arif M, Dhama K (2019) Use of brewers dried grains as an unconventional feed ingredient in the diets of broiler chickens. *Advances in Animal and Veterinary Science*, 7(3): 218-224. http://dx.doi.org/10.17582/journal.aavs/2019/7.3.218.224
2. Abu AO, Tanimowo DA (2012) Effect of b- mannase supplementaion and feed presentation on carcass characteristics and macro-mineral Digestibility of growing rabbits fed palm kernel cake-based diets. *Nigerian Journal of Animal Production*, 39(2): 83-89. http://dx.doi.org/10.51791/njap.v39i2.723
3. Abu Hafsa S, Ibrahim S (2018) Effect of dietary polyphenol-rich grape seed on growth performance, antioxidant capacity and ileal microflora in broiler chicks. *Journal of Animal Physiology and Animal Nutrition* 102:268–275. https://doi.org/10.1111/jpn.12688
4. Adetunji MA, Adegbenro M, Ojambati OG, Aletor VA (2020) Growth performance and cost implication of broiler chickens fed fortified composite cassava stump meal-based diets. *Animal Research International,* 17(2): 3631–3639. https://www.ajol.info/index.php/ari/article/view/199321
5. Agustin JA, Soto M, Famiani F, Cruz-Castillo JG (2017) In Situ Characterization of Fruits and Seeds of a Number of White Sapote (*Casimiroa edulis Llave and Lex*.) Accessions in *Mexico. HortScience*,52(12):1849-1852.https://doi.org/10.21273/HORTSCI12432-17
6. Ahlawat TR, Patel NL, Patel CR, Agnihotri R (2016) White Sapote (*Casimiroa edulis* Llave and Lex). In: Ghosh SN (ed) Underutilized Fruit Crops: Importance and Cultivation, 1st edn. Narendra Publishing House, Singapore, pp 1353-1367
7. Al-Harthi MA (2002) Efficacy of vegetable diets with antibiotics, and different types of spices or their mixtures on performance, economic efficiency and carcass traits of broilers. *Journal of Animal and Poultry Production*, 27(2): 819-831. https://doi.org/10.21608/jappmu.2002.253333
8. Al-Marzooqi W, Al-Maskari ZAS, Johnson EH, Al-Kharousi K, Mahgoub O, Al-Saqri NM, Tahir YE (2019) Comparative evaluation of growth performance, meat quality and intestinal development of indigenous and commercial chicken strains. *International Journal of Poultry Science*, 18:174-180. https://doi.org/10.3923/ijps.2019.174.180
9. AOAC (Association of Official Agricultural Chemists) (2011) *Official Methods of Analytical Chemist, 18th edition*. published by AOAC International, North Frederick Avenue, Gaithersburg, Maryland, USA.
10. Ari MM, Ayanwale BA, Ogah DM (2013) Effects of alkali treatment of soya bean on carcass traits intestinal morphology and cooking yield of broilers. *Traka Journal of Science*, 2:189-196.
11. Awaad AS, Maitland DJ, Moneir S (2007) New alkaloids from *Casimiroa edulis* fruits and their pharmacological activity. *Chemistry of Natural Compounds*, 43:576-580. https://doi.org/10.1007/s10600-007-0196-9
12. Azizi M, Seidavi A, Ragni M et al (2018) Practical applications of agricultural wastes in poultry feeding in Mediterranean and Middle East regions: Part 1: Citrus, grape, pomegranate and apple wastes. *World Poultry Science Journal*, 74(3):1-10. https://doi.org/10.1017/S0043933918000478
13. Bawa GS, Orumuyin M, Agbaji AS, Ladan Z, Okekeifi UO (2007) Effects of different methods of processing neem seeds on performance of young growing rabbits. *Pakistan Journal of Nutrition*, 6: 212-216. https://doi.org/10.3923/pjn.2007.212.216
14. Bone FJ (1979) Anatomy and Physiology of Farm Animals. Reston, USA.
15. Bhamare KS, Dildeep V, Senthil MS, Chavan SJ (2016) Nutritive evaluation of cashew apple waste in broilers. International Journal of Nature and Science, 7(3):629-632
16. Corona LRD, Rodríguez MEM, Pérez LMA et al (2023) Immunostimulant effects of diet supplementation with yellow (*Pouteria campechiana*), white (*Casimiroa edulis*), and black (*Diospyros digyna*) sapote nanocapsules on laying hens: in vitro and in vivo study. *Tropical Animal Health Production,* 360(55):1-14. https://doi.org/10.1007/s11250-023-03778-y

17. De Souza Khatlab A, Del Vesco AP, Gasparino E, de Oli-veira Neto AR (2018) Gender and age effects on the expression of genes related to lipid metabolism in broiler liver. *Czech Journal of Animal Science,* 63(3): 103–109. https://doi.org/10.17221/41/2017-CJAS
18. DeLany JP, Fawn B, Truett AA, Scimeca JA, West DB (1999) Conjugated linoleic acid rapidly reduces body fat content in mice without affecting energy intake. *American Journal of Physiology,* 276(4): R1172-9. https://doi.org/10.1152/ajpregu.1999.276.4.R1172
19. Duskaev G, Rakhmatullin S, Kvan O (2020) Effects of Bacillus cereus and coumarin on growth performance, blood biochemical parameters, and meat quality in broilers. *Veterinary World*, 13(11):2484–2492. https://doi.org/10.14202/vetworld.2020.2484-2492
20. El-Deek AA, Al-Harthi MA, Attia YA, Hannfy MM (2003) Effect of anise (*Pimpinella anisum*), fennel (*Foeniculum vulgare*) and ginger (*Zingiber officinale Roscoe*) on growth performance, carcass criteria and meat quality of broilers. *Archive for Poultry Science,* 67(2):92-96. https://doi.org/10.1016/S0003-9098(25)00075-X
21. Elkady WM, Ibrahim EA, Gonaid MH, El Baz FK (2017) Chemical profile and biological activity of Casimiroa edulis non-edible fruit's parts. *Advanced Pharmaceutical Bulletin,* 7(4):655-660. https://doi.org/10.15171/apb.2017.079
22. FAO (Food and Agricultural Organization) (2001) *Food Balance Sheet*: A hand Book. Rome, Italy.
23. FAO (Food and Agricultural Organization) (2022) FAOSTAT database: Food and Agriculture Organization of the United Nations. Retrieved from http://www.fao.org/faostat/en/#home
24. Genanew TZ, Zegeye A, Banjaw BT (2022) Characterization and optimization of Casimiroa (*casimiroa edulis*) fruit juice using Response Surface Methodology (RSM). *International Journal of Agricultural Science and Food Technology*, 8(2): 090-100. https://doi.org/10.17352/2455-815X.000150
25. George OS, Allison GH, Ekine OA (2020b) Performance and biochemical parameters of broiler chickens fed avocado (*Perseaamericana*) seed meal-based diet. *Nigerian Journal of Animal Production* 47 (3):188–193. https://doi.org/10.51791/njap.v47i3.154
26. George OS, Kingsley C, Ekine OA (2020a) Effects of dietary inclusion of avocado seed meal (*Persea americana*) on the carcass yield and haematological profile of broiler chickens. *Nigerian Journal of Animal Production*, 47(2):82-88. https://doi.org/10.51791/njap.v47i2.102
27. Guaiume EA (2007 Effects of reduced protein, amino acid supplemented diets on production and economic performance of commercial broilers fed from hatch to market age. Dissertation, University of Missouri-Columbia, USA
28. Ibrahim N, Hawary SE, Mohammed M, Ali S, Kandil Z, Refaat E (2019) Chemical compositions and hypoglycemic activities of the protein and mucilage of Casimiroa edulis (*Llave and Lex*) seeds and fruits. *Journal of Applied Pharmaceutical Science,* 9(10): 084–091. https://doi.org/10.7324/JAPS.2019.91011
29. Kartikasari, LR, Hertanto BS, Nuhriawangsa AM (2018) Carcass and cut yields of broiler chickens fed diet containing purslane meal rich in omega-3 fats. International Symposium on Food and Agro-biodiversity (ISFA) 2017. IOP Publishing Conference Series: Earth and Environmental Science. https://doi.org/10.1088/1755-1315/102/1/012088
30. Kekeocha CC (1985) *Introduction to poultry keeping*. In: Poultry Production Hand Book. Pfizer Corporation, Nairobi, pp 1-15
31. Loizzo MR, Falco T, Bonesi M, Sicari V, Tundis R, Bruno M (2018) Ruta chalepensis L. (*Rutaceae*) leaf extract: chemical composition, antioxidant and hypoglicaemic activities. *Natural Product Research*, 32(5):521-528. https://doi.org/10.1080/14786419.2017.1326491
32. Makinde OJ, Ajibade AJ, Opoola E, Sikiru AB, Okunade SA (2021) Potential of Entada africana Guill. and Perr. seed meal as feed ingredient in the diet of broiler chickens. *Tropical and Subtropical Agroecosystems*, 24(79): https://doi.org/10.56369/tsaes.3747

33. Mammo M (2012) Feed resources and chicken production in Ethiopia. *World Poultry Science Journal,* 68(3): 491-502. https://doi.org/10.1017/S0043933912000591

34. Marcu A, Vacaru-Opris I, Dumitrescu G, Ciochina LP, Marcu A, Nicula M, Pet I, Dronca D, Kelciov B, Maris C (2013) The influence of genetics on economic efficiency of broiler chicken's growth. *Animal Science and Biotechnology,* 46(2):333-346.

35. Mengesha K, Sharma JJ, Tamado T, Lisanework N (2015) Effect of plant spacing and weeding frequency on weed infestation, yield components, and yield of common bean (*Phaseolus vulgaris* L.) in Eastern Ethiopia. *East African Journal of Sciences.* 9 (1): 1-14.

36. Mottet A, Tempio G (2017) Global poultry production: Current state and future outlook and challenges. *World Poultry Science Journal,* 73(2):245-256. https://doi.org/10.1017/S0043933917000071

37. Namakparvar R, Shariatmadari F, Hossieni SH (2014) Strain and sex effects on ascites development in commercial broiler chickens. *Iranian Journal of Veterinary Research,* 15(2):116-121. https://doi.org/10.22099/ijvr.2014.2349

38. Nath S, Aravindkumar K (2021) Role of flavonoids in poultry nutrition. *Acta Scientific Veterinary Sciences,* 3(12), 88–91. https://doi.org/10.31080/ASVS.2021.03.0259

39. North MO (1981) *Commercial chicken production and manual, 2nd Ed*. AVI Publishing Company Inc, USA, pp 95–101.

40. NRC (National Research Council) (1994) *Nutrient requirements of poultry*. *9th revised edition.* National Academy Press, Washington, DC, USA.

41. Obianwuna U, Chang X, Oleforuh-Okoleh V, Onu P, Zhang H, Qiu K, Wu S (2024) Phyto biotics in poultry: Revolutionizing broiler chicken nutrition with plant-derived gut health enhancers. *Journal of Animal Science and Biotechnology,* 15:169. https://doi.org/10.1186/s40104-024-01101-9

42. Saleem K, Hayat Z, Latif HRA, Tariq Z, Riaz T, Ullah S, Jamil S, Rehman S, Azam M (2024) Growth performance and gut microbiota of broilers administered different levels of mango seed kernel extract. *Brazilian Journal of Poultry Science,* 26(2):001-008. http://dx.doi.org/10.1590/1806-9061-2023-1843

43. Satheesh N (2015) Review on Distribution, Nutritional and Medicinal Values of *Casimiroa edulis Llave*- an Underutilized Fruit in Ethiopia. *American-Eurasian Journal of Agriculture and Environmental* Sciences, 15(8):1574-1583. http://dx.doi.org/10.5829/idosi.aejaes.2015.15.8.9585

44. Shapiro BI, Mohamed-Saleem MA, Reynolds L (1994) Socio-economic constraints to strategic sheep fattening: evidence from the Ethiopian highlands. In: Small ruminant research and development in Africa, Proceedings of the second biennial conference of the African Small Ruminant Research Network, Tanzania 7-11, December 1992, pp 9-14.

45. Shawle K, Urge M, Animut G (2016) Effect of different levels of Lepidium sativum L. on growth performance, carcass characteristics, hematology, and serum biochemical parameters of broilers. *Springer Plus*, 5:1441. http://dx.doi.org/10.1186/s40064-016-3118-0

46. Tan Z, Halter B, Liu D, Gilbert ER, Cline MA (2022). Dietary Flavonoids as Modulators of Lipid Metabolism in Poultry. Frontiers Physiology. 25(13):863860. https://doi.org/10.3389/fphys.2022.863860

47. Tareen MH, Wagan R, Siyal FA, Babazadeh D, Bhutto ZA, Arain MA, Saeed M (2017) Effect of various levels of date palm kernel on growth performance of broilers. *Veterinary World,* 10(2): 227-232. http://dx.doi.org/10.14202/vetworld.2017.227-232

48. Tolmir N, Milosevi N, Ceroni C, Skrbi Z, Maslovari M (2014) The effect of feeding programmes on broiler performance and production efficiency. *Proceedings of the International symposium on Animal Science,* 2014: 224-230.

49. Tumova E, Teimouri A (2010) Fat deposition in the broiler chicken. review: *Scientia agriculturae bohemica,* 41:121–128.

50. Tun K, Aminah N, Kristanti A, Aung H, Takaya Y (2020) Natural products isolated from Casimiroa. *Open Chemistry*, 18(1):778-797. https://doi.org/10.1515/chem-2020-0128

51. Upton M (1979) Farm management in Africa: the principle of production and planning. *Oxford University Press*, Oxford, pp 282–298
52. Valero M, Salmero MC (2003) Antibacterial activity of 11 essential oils against Bacillus cereus in tyndallized carrot broth. *International Journal of Food Microbiology*, 85(1-2):73-81. https://doi.org/10.1016/s0168-1605(02)00484-1
53. Widelski J, Luca SV, Skiba A, Chinou I, Marcourt L, Wolfender JL, et al (2018) Isolation and antimicrobial activity of coumarin derivatives from the fruit of Peucedanum luxurians Tamamsch. *Molecules,* 23(5):1222. https://doi.org/10.3390/molecules23051222
54. Wiseman J (1987) *Feeding of non–ruminant livestock*. Butterworth and Co.Ltd., London, UK.
55. Zampiga M, Calini F, Sirri F (2021) Importance of feed efficiency for sustainable intensification of chicken meat production: implications and role for amino acids, feed enzymes and organic trace minerals. *World's Poultry Science Journal*, 77(3): 639–659. https://doi.org/10.1080/00439339.2021.1959277