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Carcass Characteristics and Blood Biochemical Parameters of Cobb-500 and Hubbard Chicken Strains Fed on Commercial and Farm-Formulated Diets

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ABSTRACT

The limits of commercial diets, their quality, and their rising costs are some of the major challenges to broiler production in Ethiopia. The purpose of this investigation was to evaluate carcass yield characteristics and blood biochemical parameters of Cobb-500 and Hubbard chicken strains fed on farm-formulated diets (T1) and three different commercial diets (T2, T3, and T4). A total of 384 mixed-sex day-old chicks (192 per strain) were randomly assigned to four dietary treatments with four replicates, each consisting of 12 broilers. The experiment was set up as a 2 × 4 factorial design, providing each strain with four diets in a completely randomized design. After 42 days of the experiment, one male and one female of each strain from each pen (eight birds per treatment) were slaughtered for carcass yield and hematological analysis. Although diets had a significant impact on live body weight, feed conversion ratio, and feed consumption among the study treatments, they had no significant effect on the mortality rate of the broilers as a whole. There was a significant effect of strains on the weight of eviscerate, dress, thigh, drumstick, breast, neck, back, and eviscerate yield percentage, with Cobb 500 showing higher values than Hubbard broilers. The farm-formulated diet (T1) significantly increased the weight of non-edible offal compared to the commercial diets, except for the weight of crops and lungs, which were similar to those in commercial diet group T4. The Hubbard strain showed a higher least square mean for packed cell volume than the Cobb-500 strain. Sex was found to have no significant impact on the hematological parameters. The farm-formulated diet (T1) also resulted in a higher marginal return rate than that of the commercial diet (T3) in the Cobb-500 strain. These findings suggest that locally sourced farm-formulated diets could be a viable alternative to commercial diets for broiler chickens in the study area.

Keywords: Broiler chicken, biochemical parameter, Carcass trait, Farm-made diet, Haematology, Profitable

INTRODUCTION

The demand for protein bases to feed the world's growing population has significantly boosted the poultry production industry within the meat-producing agriculture sector (Bogale and Engida, 2022; El-Sabrout et al., 2022). Worldwide, commercial systems are used to produce huge quantities of chickens; however, these systems are not widely employed in developing countries like Ethiopia, where they are primarily limited to urban areas (Habte et al., 2017). In the industrialized world, broiler chickens are typically raised for rapid growth and slaughtered between 6 and 8 weeks of age, or when they reach a body weight of 1.8 to 2.2 kg (Musa et al., 2006).

The carcass yield characteristics, including dressed weight, edible giblet weights, and the weights of the breast, drumstick, thigh, back, and shank are all significantly impacted by strain (Marcu et al., 2013). Correspondingly, Pripwai et al. (2014) reported similar results, showing that sex affected the weight of the thighs, the dressed weight, the meat-to-bone ratio, and the wings. The combined weight of edible and inedible offal in chicken carcasses was a significant factor for both producers and consumers (Zawacka et al., 2018). According to Uhlíová et al. (2018), age, sex, strain, and diet are the main factors that affect the carcass and the meat quality of broiler chickens. High packed cell volume (PCV) and high haemoglobin (Hb) are indicators of great feed conversion efficiency. Moreover, recognizing the typical physiological standards in a normal state is crucial for the effective management of broiler chickens (Nyaulingo, 2013). According to Ayo-Enwerem et al. (2017), the response of broilers to their internal and external surroundings, including their feeding, is always reflected in their haematological features.

To increase carcass yield, chicken feed in Ethiopia commonly includes oil seed cakes, milling by-products, and cereal grains (FAO, 2019). However, the rising prices of protein and energy sources have led to increasing feed costs, posing a significant challenge for commercial broiler production in developing countries (Abbas, 2013). Since commercial feeds are expensive and are provided in limited supply, small-scale chicken producers often cannot afford them (Wilson et al., 2021). Consequently, one of the main challenges in broiler chicken production in Ethiopia is feed scarcity and the cost of purchasing and transporting broiler feeds. This issue is further exacerbated by the fact that most cereals used as broiler feed are also staple diets for humans and animals. In Ethiopia, maize, soybean meal, noug seed cake, and wheat short are the primary ingredients used in formulating commercial feed (Mengesha, 2012). As a result, smallholder chicken farmers and others have to purchase expensive commercial rations from manufacturing industries due to the lack of affordable alternative feed formulations for broilers. These chicken feed ingredients are mainly produced in the rural areas of Ethiopia, particularly in the western part of the country. However, these raw materials are transported to Addis Ababa and surrounding towns for processing and ration formulation.

The costs associated with transportation, processing, and service charges contribute to the high purchase price of commercial feed. To achieve sustainable diet production and ensure global feed security, alternative substances are increasingly being incorporated into broiler diets (Morgan and Choct, 2016; Tufarelli et al., 2018). There is growing interest in using alternative feed ingredients, such as near-available resources and local diets, to reduce the economic costs of producing carcass-yield meat (El-Deek et al., 2020). In this study, farm-formulated poultry diets were proposed as a cost-effective alternative to expensive commercial diets for comparison.

However, there is limited information on the effects of different commercial and farm-formulated diets, using locally available ingredients, on the carcass yield and blood profile of broilers. Moreover, insufficient research has been conducted on the carcass yield and blood biochemical of strains in Ethiopia using locally available resources and ingredients. Therefore, this study aimed to assess carcass yield characteristics and blood biochemical parameters of Cobb-500 and Hubbard's chicken strains fed on commercial and farm-formulated diets.

MATERIALS AND METHODS

Ethical approval

All procedures involving animal handling, blood collection, and routine manipulations followed the animal care guidelines and protocols approved by the Institutional Review Board of the College of Veterinary Medicine and Agriculture (CVMA), Ethiopia, Animals Ethics Committee (Approval Number: VM/ERC/01/13/12/2020).

Description of the study site

The broiler feeding experiment was conducted at a poultry farm located on the Nekemte campus of Wollega University, Ethiopia, situated at 10° 0' North latitude and 37° 30' East longitude. The study area has an average annual rainfall of 1998 mm, a relative humidity range of 11% to 31%, and average minimum and maximum temperatures of 8 °C and 30 °C, respectively (NMS, 2019).

Experimental diet and treatment

Broilers were fed three commercial diets and one farm-formulated diet in two feeding phases, both of which were isoprotein and isocaloric, 21 days for the starter phase and 21 days for the finisher phase. The commercial diets, labeled A, B, and C, were randomly selected from different manufacturers in Ethiopia. Commercial diets are formulated to be complete, containing balanced levels of protein and calories. The farm-formulated diet (T1) was prepared using locally available feed ingredients such as maize grain, noug seed cake, wheat shorts, soybean meal, and common salt. Limestone, dicalcium phosphate, vitamin premix, L-lysine, and DL-methionine were also added to the diets (Table 1). All diet plans were formulated using Win Feed 2.84 software based on the nutritional recommendations for broilers and the chemical composition of the ingredients (Table 2). The formulated diets were to meet the isocaloric (3100–3200 kcal/ME per kg DM) and isoproteins (18–22% CP) nutrient requirements of broiler chickens (NRC, 1994).

Table 1. Percentage composition of feed ingredients in starter and finisher diets

Phase	Ingredients (%)	Treatments			
		T1	T2	T3	T4
Starter	Maize grain	52.5	51.5	52.5	50
	Soybean meal	22	15	17.5	25
	Noug seed cake	12	10	12	-
	Wheat short	10	-	15.5	-
	Mineral	0.5	0.25	0.1	0.75
	Vitamin premix	0.5	0.25	0.1	0.75
	Limestone powder	1	1	0.5	0.5
	Di-calcium phosphate	0.5	0.25	0.2	-
	L-lysine	0.25	0.25	0.2	-
	DL-methionine	0.25	0.25	0.2	-
	Common salt	0.5	0.25	0.5	-
	Meat and bone	-	5	0.7	-
	Groundnut	-	-	-	9
	Wheat bran	-	16	-	14
	Total	100	100	100	100
Finisher	Maize grain	54.5	52	53.5	50
	Soybean meal	21	16	18	25
	Noug seed cake	10	11	12	-
	Wheat short	11	-	14	-
	Mineral	0.5	0.25	0.1	0.75
	Vitamin premix	0.5	0.25	0.1	0.75
	Limestone powder	1	1	0.5	0.5
	Di-calcium phosphate	0.5	0.25	0.2	-
	L-lysine	0.25	0.25	0.2	-
	DL-methionine	0.25	0.25	0.2	-
	Common salt	0.5	0.25	0.5	-
	Meat and bone	-	5	0.7	-
	Groundnut	-	-	-	8
	Wheat bran	-	13.5	-	15
	Total	100	100	100	100

T1: Farm-formulated diet, T2, T3, and T4: Commercial diets from different sources (A, B, and C), %: Percentage, Vitamin premix: Poultry booster soluble powder, Amoxicillin soluble powder, and Amprolium soluble powder

Experimental broilers and management

This experiment was conducted over 42 days, comprising 21 days for the starter phase and 21 days for the finisher phase. Three hundred and eighty-four mixed-sex day-old chicks (192 per strain), procured from Alema (Cobb-500 strain) and Elere Farms (Hubbard strain) located at Bishoftu, were used for the experiment. Upon arrival, the chicks were kept in 32 separate deep-litter pens, each with five cm of wood shavings (sawdust) litter underneath. Before the chicks arrived, the 2.5 x 1.5 m^2 deep litter floor housings (pens) containing the broilers were thoroughly cleaned, disinfected, and covered with sawdust litter material. All the pens were provided with drinkers, feeders, and a brooding unit (with a 230-watt bulb) placed at the centre of the house. At the hatchery, the chicken received vaccinations against Newcastle (UK, Indonesia, and Korea) and Gumboro (USA strain), as well as against Marek's disease (Turkey, USA, and Europe strains) at 7 and 21 days of age. Throughout the trial, diets were given *ad libitum* up to the end of the experiments. Clean, cold, and fresh drinking water was also available at all times.

Experimental design and treatments

The experiments involved two broiler strains (Cobb 500 and Hubbard) and four treatment diets (one farm-formulated and three commercial diets), assigned to pens in four replicates of 12 chicks each. The study followed a 2 × 4 factorial design, which provided each strain with four diet distributions in a completely randomized design (CRD). Treatment for each of the two strain groups consisted of 48 chick-feeding experiments.

Live body weight and feed consumption

Feed consumption for the broiler chickens was determined by subtracting the amount of feed refused from the amount offered. Refusals were collected and weighed daily, before fresh feed was provided, after removing any contaminants. The quantity of feed provided every three days was adjusted to ensure that all groups of broilers had *ad libitum* access to feed. For every pen, the feed that was provided and refused was recorded. The feed conversion ratio (FCR) was calculated by dividing the mean daily intake of feed by the average daily body weight (Lawrence and Fowler, 1998). The mortality rate was determined by dividing the number of deceased broilers by the total number of broilers at the start of the experiment and multiplying by 100 to express it as a percentage.

Carcass yield characteristics of broilers

At the end of the 42-day finisher period, one male and one female from each pen were slaughtered for carcass characterization, totaling 32 males and 32 females per treatment. Before slaughter, the chickens were randomly selected, weighed, and fasted for 12 hours while having unrestricted access to water to relieve their digestive tracts. To determine the slaughter weight, the chickens' body weights were measured before slaughter. Cervical dislocation, a sharp knife incision to the throat, and five minutes of bleeding were the methods used for slaughtering (Ncobela et al., 2016). After bleeding, the carcass was scalded in hot water (60 °C) for 45 seconds before de-feathering and eviscerating; the feathers were removed starting from the tail, wing sides, legs, back, and neck regions of the scalded chicken. The carcass was then eviscerated, hung over the evisceration line, and given fifteen minutes to drain before being weighed. The weight of the slaughtered carcass was measured following the removal of the inedible viscera. The eviscerated bodies were separated into six sections including the breast, thigh, drumstick, wings, neck, and back, and their weights were measured. Information on the weight of the back, neck, breast, drumstick, thigh, liver, wing, gizzard, and all other non-edible offal, including the digestive tract (crop, proventriculus, gizzard, small and large intestines) as well as the pre-slaughter live weight was recorded. Additionally, noted were the visceral organs, which included the weight of the lungs, heart, kidneys, and shank. The individual parts of the total non-edible (TNE) offal, such as the heads, shanks, crops, kidneys, heart, lungs, intestines, and abdominal fat were also noted. The total weight of the back, neck, drumsticks, thighs, wings, breast, and edible offal (liver, heart, and gizzard) was used to calculate the weight of all the carcass parts. A cut of each carcass was used to determine the weights of the breast, thigh, drumstick, and wings. The dressing percentage was determined following FAO (2001).

$$\text{Dressing Percentage (\%)} = \frac{\text{Dressed Weight (g)}}{\text{Slaughter Weight (g)}} \times 100$$

According to FAO (2001) guidelines, the dressing percentage was calculated as follows: The dressed weight was computed by summing the weights of the drumsticks, thighs, wings, breast, back, neck, heart, liver, gizzard, feet, head, and viscera (including lungs, pancreas, and intestines). The eviscerated weight was obtained by subtracting the weights of the head, viscera, and feet from the dressed weight. The eviscerated percentage was then calculated by dividing the eviscerated weight by the slaughter weight and multiplying by 100.

$$\text{Eviscerated yield (\%)} = \frac{\text{Eviscerated weight}}{\text{Slaughter Weight}} \times 100$$

Evaluation of the haematological and serum biochemical tests of broilers

The blood and serum biochemical profiles were evaluated at the end of the experimental period (Day 42 of the study). Blood samples were collected from two randomly selected chickens per replication (one female and one male). Five millilitres of blood were drawn from immobilized chickens via the wing veins. Following conventional protocols outlined by Davice and Lewis (1991), half of the blood sample was transferred to vacutainer glass tubes containing ethylenediaminetetraacetic acid (EDTA) for haematological analysis. The remaining blood was placed in the second set of vacutainer glass tubes without EDTA for serum biochemical analysis. The haematological indices assessed included packed cell volume (PCV), red blood cells (RBC), white blood cells (WBC), haemoglobin (Hb), mean corpuscular volume (MCV), mean corpuscular haemoglobin (MCH) and mean corpuscular haemoglobin concentration (MCHC). Likewise, the concentrations of creatinine, glucose, cholesterol, and total protein in the serum were determined. For serum analysis, the samples were stored at -20 °C. RBC and WBC were counted using a hemocyte meter (Irizaary-Rovira 2004). The values obtained for RBC, Hb, and PCV were used to calculate MCV, MCHC, and MCH, which were computed as described by Irizaary-Rovira (2004).

Partial budget analysis

The partial budget analysis was conducted following the method outlined by Upton (1979) to determine the economic benefit of feed and chicken production. The total variable cost (TVC) for each treatment was calculated by summing the expenses related to feed, veterinary care, labor, and other services incurred during the experimental period for each treatment. Marginal revenue (MR) was calculated by subtracting the total feed cost from the total revenue (MR = TR + TFC). Total return (TR) was computed as the difference between the buying price and the sale price. In other words, the selling price minus their buying price equals TR. The following is how net return (NR) was computed by deducting TVC from TR: TR – TVC = NR. The changes in net return were calculated as follows: ΔTR – ΔTVC = ΔNR. The increase in net return (NR) corresponding to each extra unit of expenditure (ΔTVC) was measured by the marginal rate of return (MRR), which is represented as a percentage.

$$\text{MRR\%} = \frac{\Delta \text{NR}}{\Delta \text{TVC}} \text{X100}$$

Chemical analysis of diets

The dry matter, crude protein, ether extract, crude fiber, and ash of the feed samples used in the study were evaluated in compliance with AOAC (1990). Atomic absorption spectroscopy and the spectrophotometer method were used at Haramaya University Laboratory to assess the levels of calcium and phosphorus, respectively (AOAC, 1998). Using the Wiseman (1987) equation, the metabolized energy values were indirectly determined from the ether extracts (EE), crude fiber (CF), and ash to determine the metabolizable energy of the diets.

Table 2. Chemical feed composition of commercial and farm-formulated diets (percentage on dry matter base)

Phase	DM	CP	CF	EE	Ash	Ca	P	ME (Kcal/kg DM)
Starter (1–21 days)								
T1	89.38	14.64	4.32	5.89	6.96	0.97	0.60	3604.22
T2	91.07	15.37	3.42	5.69	7.17	0.86	0.65	3665.03
T3	90.42	16.18	5.68	5.48	10.52	1.04	0.60	3316.29
T4	89.76	14.22	5.45	5.72	6.93	0.42	0.25	3495.99
Finisher (22–42 days)								
T1	89.43	14.37	4.90	6.16	6.89	0.92	0.58	3570.21
T2	91.11	14.89	4.32	5.91	6.80	0.74	0.62	3612.45
T3	90.62	15.77	5.81	5.79	9.31	1.01	0.61	3370.37
T4	89.80	13.89	5.92	5. 88	5.88	0.40	0.24	3505.61

T1: Farm-formulated diet, T2, T3, T4: Commercial diets from different sources, %: percentage, DM: Dry matter, CP: Crude protein, EE: Ether extract, CF: Crude fiber, Ca: Calcium, P: Phosphorous, ME: Metabolisable energy, Kcal: kilocalorie, kg: Kilogram

Statistical data analysis

The Statistical Analysis System (SAS) version 9.4 and the General Linear Model (GLM) techniques were used to analyze the data (SAS, 2016). Duncan's multiple range tests were utilized to separate treatment means (Duncan, 1955). The statistical models for feed consumption and body weight were expressed as following formula.

$Y_{ijk} = \mu + B_i + F_j + (B*F)_{ij} + \varepsilon_{ijk}$

Where Y_{ijk} is the response variable, μ is an overall mean, B_i is the fixed effect of the strains (i: Cobb 500 and Hubbard), F_j is the fixed effect of the j^{th} feed-type (j: farm-formulated, commercial diets 1, 2, and 3), $(B*F)_{ij}$ is the interaction effect between chicken strains and feed treatment diets, and ε_{ijk} is the random error term. For carcass yield and blood profile analyses, the statistical model used was as following formula.

$Y_{ijk} = \mu + B_i + F_j + S_k + \varepsilon_{ijk}$

Where Y_{ijk} is the response variable i, j, k; μ is the overall mean, Bi is the effect of the strains (i: Hubbard and Cobb 500); F_j is the effect of feed type (j: farm-formulated diet, commercial diets 1, 2, and 3); S_k is the effect of sex (k: male and female); and ε_{ijk} is the random error component.

RESULTS AND DISCUSSION

Live body weight and feed consumption

The effects of diet and strain on feed consumption and living body weight are presented in Table 3. The findings show that strain significantly affected live body weight (LBW) and feed conversion ratio (FCR), but no significant influence on broiler mortality rate (MR) or feed consumption was observed (FC, $p < 0.05$). Cobb 500 broilers outperformed Hubbard broilers in terms of feed conversion ratio and live body weight. Diet had a significant impact on live body weight, feed conversion ratio, and feed consumption, but did not affect the mortality rate ($p < 0.05$). In terms of live body weight, the farm-formulated diet (T1) was comparable to the commercial diet (T4). Similarly, broilers fed with commercial diets T2 and T3 exhibited comparable live body weight and feed conversion ratios, with T2 and T3 showing the best feed conversion ratios (FCR) among the treatments. For the total number of broilers, there was no significant interaction between strain and diet affecting live body weight, feed consumption, feed conversion ratio, or mortality rate.

In comparison, the Hubbard strain had an average live body weight of 1583.43g, overall, while the Cobb-500 strain achieved the highest live body weight at 1975.77g. Cobb 500 broilers also demonstrated a superior feed conversion ratio of 2.43 compared to Hubbard's 3.05. This indicates that Cobb 500 broilers are more efficient in converting feed to meat, as reflected by their lower FCR. The observed variations can be attributed to sex, strains, nutrition, genetics, and environmental factors. At six weeks of age, Cobb-500 broilers consistently maintained a higher live body weight compared to Hubbard broilers. These findings are consistent with those of Udeh et al. (2011), who reported similar results for final body weights at eight weeks of age: Anak (1855 g), Arbor Acre (1880 g), Ross (1812.50 g), and Marshal (1645 g).

Consequently, after six weeks, the live body weight of 2455.58g achieved with diet treatment T2 was lower than the final body weights in previous studies. Mezgebu et al. (2020) reported that the male Sasso T44 broilers' final body weights at 20 weeks of age in Nekemte ranged from 2755.98 g to 3907.42 g. This difference was attributed to the length of feeding and the variation in dietary ingredients. The higher live body weight of the broilers led to an increase in their intake, which in turn produced the highest overall superiority in feed consumption with diet T3 (4515.55g). Among all treatments, T2 and T3 exhibited the highest FCR. Similarly, Alagawany et al. (2021) revealed that FCR was enhanced when lemongrass essential oil was added to quail diets over a maximum of five weeks.

Table 3. Least squares mean for performance and percentage mortality of broilers in overall 42 days of age

Effect and level	LBW (g/bird)	FC/Chick(g/bird)	FCR	MR%
RMSE	860.99	207.14	0.38	0.35
R^2	0.32	0.78	0.85	0.00
Strain				
Cobb500	1975.77[a]	4071.65	2.43[b]	14.06
Hubbard	1583.43[b]	4007.90	3.05[a]	13.02
P-Value	<.0001	0.3926	0.0001	0.7677
Diet				
T1	1102.76[b]	3596.23[c]	3.70[a]	11.46
T2	2455.58[a]	4122.38[b]	1.86[c]	15.63
T3	2175.57[a]	4515.55[a]	2.25[c]	14.58
T4	1384.48[b]	3924.93[b]	3.06[b]	12.50
P-Value	<. 0001	<. 0001	<. 0001	0.8318
Strain* Diet				
Cob*T1	1224.99	3609.07	3.29	13
Cob*T2	2659.31	4080.25	1.65	17
Cob*T3	2404.49	4529.89	2.06	15
Cob*T4	1614.28	4067.40	2.74	13
Hub*T1	980.53	3583.40	4.10	10
Hub*T2	2251.84	4164.52	2.08	15
Hub*T3	1946.65	4501.22	2.44	15
Hub*T4	1154.69	3782.46	3.58	13
P-Value	0.8011	0.3521	0.5069	0.9933

[a,b,c] Different superscripts within the same column are significantly different at $p < 0.05$, T1: Farm-formulated diet, T2, T3, T4: Commercial diets from different sources, %: Percentage, LBW: Live body weight, FC: Feed consumption, FCR: Feed conversion ratio, MR: Mortality rate, g: Gram: RMSE: Root mean square error, R^2: Coefficient of determination, Cob: Cobb-500, Hub: Hubbard

Carcass yield characteristics of broiler chickens

The effects of strain, sex, and diet treatments on the carcass yield of the chickens are detailed in Table 4. The results of the current study indicate that the chickens' strain significantly affected several measurements including thigh weight (TW), drumstick weight (DrW), breast weight (BrW), neck weight (NW), back weight (BaW), dressed weight (DW), eviscerate yield percentage (EY %), and eviscerate weight (EW). For Cobb 500 and Hubbard, there was no significant effect on slaughter weight (SW), carcass weight (CW), dressing percentage (DP), or wing weight (WW), respectively ($p < 0.05$).

When compared to Hubbard strains, the Cobb-500 strain demonstrated the maximum weight for the drumstick, thigh, back, and breast. This is because of the genetic makeup of the strains and their greater capacity for feed intake, feed conversion efficiency, and adaptation to environmental factors. These findings aligned with those of Biazen et al. (2021) who noted that chickens with a higher slaughter weight had heavier breast, wing, neck, and back weights. Similarly, Mirosław et al. (2021) provided additional evidence on the impact of breed, origin, and diet on slaughter yield and meat quality. Therefore, consumers often prefer chickens with high yields of desirable parts such as breast muscle, drumsticks, and thighs, as these are considered the most valuable carcass sections in broilers raised for meat production (Faria et al., 2010).

Subsequently, comparing the eviscerated weight (1570.25 g) and dressed weight (1815.28 g) of the strains, the Cobb 500 chickens outperformed those of the Hubbard strain. The Cobb-500's larger body size contributes to its higher live and dressing weights, indicating superior carcass yield and visceral weights. The strain variations in the carcass yield and growth performance of broiler chickens make this significant. The study's findings are consistent with those of Fernandes et al. (2013). As the results indicated, there was a variation in the proportion of breast, thigh, drumstick, neck, and back among the strains. This result was similar to previous reports (Ibrahim, 2019; Biazen et al., 2021). The Cobb-500 strain showed higher breast weight compared to the Hubbard strain, attributed to genotype, feeding capacity, and environmental adaption. Compared to meat from other regions of the chicken carcass, breast meat frequently has a higher economic value (Eltazi et al., 2014). This is because there are no bones in the chicken's body and the breast meat has content collection meat. These findings concurred with those of Biazen et al. (2021) and Marapana (2016). In terms of eviscerated percentage, the Hubbard strain (61%) was lower than the Cobb-500 (67.85%), consistent with findings reported by Tesfaye et al. (2013).

For males and females, sex significantly affected slaughter weight, carcass weight, eviscerate yield percentage, dressing percentage, and back weight. However, the effect of sex was not significant on eviscerate weight, dressed weight, wing weight, thigh weight, drumstick weight, breast weight, or neck weight. In this study, male broilers had a greater carcass weight (1868.14g) compared to female broilers (1589.92g). As expected, a larger carcass yield was found in broiler chickens with higher growth potentials or higher live weight, which is comparable to the results of Cruz et al. (2018). The males weighed more in the slaughter, carcass, and back, and the females weighed more in the dressing than their male counterparts. This is due to the hormonal differences between the sexes and feed intake capacity. The dressing percentage for males (70.91%) was lower than for females (77.05%). These variations are influenced by genetics, strain, sex, and dietary factors. The dressing percentage observed in the present study was higher than the 53.7–56.7% reported by Melkamu (2017) for Sasso chickens slaughtered at 56 days of age, reflecting differences due to age and diet.

Regarding eviscerates yield percentage and dressing percentage, diet treatments did not show significant effects. However, other carcass yields were significantly influenced by diet treatment. The weight of the carcass was different depending on the diet treatment, showing that there were significant variations in the yield of the carcass part. This is because different dietary treatments contain different ingredients, which affect carcass yield. These results align with those of Ikusika et al. (2020) and Sanka et al. (2021), who reported a significant influence of the rearing system on carcass yields. Similarly, compared to other dietary treatments in the study, the broiler strains fed on the commercial diet (T2) exhibited greater slaughter, carcass, eviscerates, and dressed weights. This is because the profiles of amino acids and crude proteins of meat and bone meal are higher than those of other diet treatments. In contrast to other dietary treatments, the broiler strain in the farm-formulated diet (T1) showed reduced weights of slaughter, carcass, eviscerate, and dressing. This reduction is likely due to the lower content of meat and bone meal in the farm formulations derived from locally available resources. Therefore, the chickens fed T2 and T3 had the largest yields of carcass components (breast, thigh, and drumstick), while the broilers fed the farm-formulated diet had the lowest carcass yields.

In terms of back weight and wing weight, broilers consuming the farm-formulated diet (T1) had weights comparable to those fed the commercial diet (T4). However, dietary treatments in the current investigation resulted in significantly different weights for the slaughter, dressed, eviscerated, and breast broilers, consistent with findings reported by Seid et al. (2020). These results, on the other hand, contrast with those reported by Shawle et al. (2016). Significant differences in drumstick and thigh weights were observed across the dietary treatments. Variations in age, strains, and dietary composition typically account for these differences. The findings contradicted those reported by Chala et al. (2022). In addition, Marapana (2016) states that some factors, including strain, sex, length of feed withdrawal before processing, distance of hunger before slaughter, the birds' travel distance from the farm to the slaughter plant, their life span, and their rearing system, can all impact dressing percentage and relative meat yield in different carcass parts.

Table 4. The live weight and carcass traits of slaughtered broiler chickens at 42 days of age

Effect and level	SW(g)	CW(g)	EW(g)	DW(g)	EY%	DP	WW(g)	TW(g)	DrW(g)	BrW(g)	NW(g)	BaW(g)
RMSE	384.77	326.61	152.39	170.23	11.66	13.56	8.19	41.44	40.89	75.37	9.83	39.11
R^2	0.64	0.54	0.71	0.69	0.24	0.26	0.31	0.48	0.49	0.60	0.65	0.69
Strains												
Cobb500	2418.14	1786.13	1570.25^{a}	1815.28^{a}	67.85^{a}	75.57	78.12	276.81^{a}	255.53^{a}	431.45^{a}	87.70^{a}	324.86^{a}
Hubbard	2232.96	1671.94	1330.27^{b}	1570.34^{b}	61.00^{b}	72.27	75.81	232.38^{b}	204.7^{b}	388.55^{b}	72.17^{b}	252.95^{b}
P-Value	0.0591	0.1673	<. 0001	<. 0001	0.0223	0.2875	0.2639	<. 0001	<. 0001	0.0265	<. 0001	<. 0001
Sex												
M	2478.23^{a}	1868.14^{a}	1473.95	1721.10	61.25^{b}	70.91^{b}	77.77	258.55	233.11	411.62	80.16	299.34^{a}
F	2172.86^{b}	1589.92^{b}	1426.57	1664.52	67.61^{a}	77.05^{a}	76.16	250.64	227.20	408.38	79.70	278.47^{b}
P-Value	0.0024	0.0012	0.2186	0.1889	0.0332	0.0465	0.4353	0.4483	0.5649	0.8639	0.8521	0.0370
Diets												
T1	1633.99^{c}	1249.08^{c}	1132.79^{c}	1359.20 ^{c}	69.04	76.60	72.19^{b}	204.38^{b}	182.62^{b}	291.72^{c}	63.38^{b}	233.21^{b}
T2	2844.15^{a}	2042.40^{a}	1634.62 ^{a}	1874.20 ^{a}	59.27	68.03	76.61^{b}	270.87^{a}	249.57^{a}	510.35^{a}	90.15^{a}	335.74^{a}
T3	2600.56^{a}	1907.09^{ab}	1573.84^{ab}	1840.20^{b}	61.41	71.92	85.14^{a}	260.78^{a}	237.63^{a}	467.05^{a}	84.97^{a}	318.29^{a}
T4	2223.49^{b}	1717.56^{b}	1459.79 ^{b}	1697.63^{b}	67.97	79.13	73.92^{b}	282.35^{a}	250.81^{a}	370.88^{b}	81.24^{a}	268.38^{b}
P-Value	< 0.0001	< 0.0001	< 0.0001	< 0.0001	0.0521	0.0628	0.0002	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001

^{a,b,c} Different superscripts within the same column are significantly different at $p < 0.05$, T1: Farm-formulated diet, T2, T3, T4: Commercial diets from different source, SW: Slaughter weight, CW: Carcass weight, EW: Eviscerate weight, DW: Dressed weight, EY %: Eviscerate yield percentage, DP: Dressing percentage, WW: Wing weight, TW: Thigh weight, DrW: Drumstick weight, BrW: Breast weight, NW: Neck weight, BaW: Back weight, RMSE: Root-mean-square error, and R^2: Coefficient of determination.

Table 5. The non-edible offal weights of slaughtered broiler chickens at 42 days of age

Effect and level	HEW (g)	CRW (g)	LUW(g)	SHW (g)	SIW (g)	LIW(g)	KW(g)	AFW (g)	PRW (g)
RMSE	10.43	1.91	1.62	11.68	9.13	2.30	1.95	4.37	0.99
R^2	0.52	0.15	0.04	0.46	0.42	0.38	0.16	0.25	0.53
Strain									
Cobb500	65.35^a	10.13	9.98	70.93^b	71.10	14.52	9.61	24.42	6.99
Hubbard	52.41^b	9.31	10.37	80.36^a	72.07	13.68	9.26	26.47	6.86
P-Value	<.0001	0.0896	0.3450	0.0021	0.6722	0.1471	0.4897	0.0664	0.5926
Sex									
M	60.21	9.78	10.36	75.24	72.13	14.48	9.67	25.42	7.14
F	57.55	9.66	9.99	76.05	71.04	13.71	9.19	25.47	6.71
P-Value	0.3114	0.8039	0.3680	0.7819	0.6340	0.1830	0.3271	0.9625	0.0902
Diet									
T1	45.67^b	8.96	10.29	66.76^b	63.54^b	12.51^b	8.66^b	23.08^b	5.62^c
T2	67.05^a	10.56	10.42	88.90^a	80.39^a	16.10^a	8.70^b	28.83^a	8.25^a
T3	61.56^a	10.06	10.06	79.01^a	77.36^a	15.27^a	10.38^a	25.71^{ab}	7.30^b
T4	61.25^a	9.31	9.9	67.91^b	65.06^b	12.51^b	9.98^a	24.16^b	6.53^{bc}
P-Value	< 0.0001	0.0885	0.8232	< 0.0001	< 0.0001	< 0.0001	0.0272	0.0029	< 0.0001

[a,b] Different superscripts within the same column are significantly different at $p < 0.05$, T1: Farm-formulated diet, T2, T3, and T4: Commercial diets from different sources, HEW: Head weight, CRW: Crop weight, LUW: Lung weight, SHW: Shank weight, SIW: Small Intestine weight, LIW: Large Intestine weight, KW: Kidney weight, AFW: Abdominal Fat weight, PRW: Proventicuas weight, RMSE: Root-mean-square error, and $R^{2:}$ Coefficient of determination

Table 6. The edible offal weights of slaughtered broiler chickens at 42 days of age

Effect and level	GW (g)	HW (g)	LW (g)	SkW (g)
RMSE	6.97	1.42	4.08	23.51
R^2	0.74	0.42	0.84	0.78
Strain				
Cobb500	56.44^{a}	12.41	53.13^{a}	160.19^{a}
Hubbard	40.68^{b}	12.67	37.33^{b}	142.92^{b}
P-Value	<.0001	0.4599	<.0001	0.0047
Sex				
M	48.57	12.68	45.85	154.45
F	48.55	12.40	44.61	148.66
P-Value	0.9916	0.4348	0.2289	0.3289
Diet				
T1	35.41^{c}	10.67^{b}	39.21^{c}	97.03^{c}
T2	56.62 ^{a}	13.49^{a}	49.28^{a}	198.81^{a}
T3	53.48^{ab}	13.41^{a}	48.02^{ab}	184.43^{a}
T4	48.74^{b}	12.60^{a}	44.43^{b}	125.94^{b}
P-Value	< 0.0001	< 0.0001	< 0.0001	< 0.0001

^{a,b,c} Different superscripts within the same column are significantly different at $p < 0.05$, T1: Farm-formulated diet, T2, T3, and T4: Commercial diets from different sources, GW: Gizzard weight, HW: Heart weight, LW: Liver weight, SkW: Skin weight, RMSE: Root-mean-square error, and R^2: Coefficient of determination.

Edible offal of the slaughter

The effects of chicken strain, sex, and diet treatment on edible offal are summarized in Table 6. The Cobb 500 strain exhibited significantly higher weights of gizzard, liver, and skin compared to the Hubbard strain, while the heart weight showed no significant difference between the two strains ($p < 0.05$). Therefore, the Hubbard strain's greater susceptibility to these effects could indicate a limited capacity for feeding-related adaptation. This finding is in agreement with Biazen et al. (2021), who observed similar differences in these parameters across chicken breeds. The weight of the edible offal was not significantly affected by the sex of the chickens. This result indicated that there was no difference between the sexes between treatments. These findings were similar to those of Biazen et al. (2021).

The present study revealed that there was a significant effect of diet treatment on the gizzard, heart, liver, and skin weight of the broiler chickens ($p < 0.05$). This difference was due to feed intakes, sex, strains, feed conversion ratio, and environmental conditions. Except for the gizzard weight, the finding on edible offal weight was similar to that reported by Mosebework et al. (2018). These similarities are likely due to dietary treatment ingredients, genotype, and climatic factors.

Non-edible offal of the slaughter

The effects of chicken strain, sex, and diet treatment on non-edible offal are depicted in Table 5. The results reveal that there was no significant strain effect on crop weight (CRW), lung weight (LUW), small intestine weight (SIW), large intestine weight (LIW), kidney weight (KW), abdominal fat weight (AFW), and proventriculus weight (PRW), while a significant effect was observed for head weight (HEW) and shank weight (SHW, $p < 0.05$). The least-square means obtained for HEW were higher for Cobb 500 when compared with those of Hubbard, while SHW values were significantly higher for Hubbard than for Cobb 500. The sex of the broiler chickens did not significantly affect non-edible offal ($p > 0.05$).

The study demonstrated a significant effect of diet treatment on the weights of the head, shank, small and large intestines, kidney, abdominal fat, and proventriculus, except for crop and lung weight ($p < 0.05$). Likewise, broiler strains consuming the farm-formulated diet (T1) exhibited weights for the shank, small and large intestines, and abdominal fat similar to those consuming the commercial diet (T4). Additionally, the farm formulation was similar to the commercial diet (T2) about kidney weight. The broiler strain chickens receiving the commercial diet (T2) had a higher abdominal fat weight among dietary treatments. Therefore, the abdominal fat weight in the farm-formulated diet (T1) was similar to that of the commercial diet (T4) consumed among the treatments for the broilers. The accumulation of unnecessary fat on carcasses, particularly in the abdomen, was the main concern of broiler farmers in the previous studies. This finding highlights the issue of excessive abdominal fat, which is often rejected by consumers and considered waste. Although the statistical results indicated a significant difference in abdominal fat weight among treatments, T2 had the highest abdominal fat weights compared to other dietary groups. This result suggests that the farm-formulated diet (T1) was more effective in reducing abdominal fat compared to any commercial diet. These results are consistent with the findings of Tamasgen et al. (2021). Conversely, the effect of dietary treatments on the small intestine and proventriculus weights was not supported by Mirosław et al. (2021). The weight of the large intestine varies significantly among treatments based on the diets, which aligns with Abera et al. (2016).

Haematological and serum biochemical study

The impact of chicken strain, sex, and diet treatment on serum biochemical and haematological parameters is shown in Tables 7 and 8. The results of the study revealed that the chicken strain had a significant effect on packed cell volume (PCV, $p < 0.05$). No significant differences were observed for red blood cells (RBC), white blood cells (WBC), haemoglobin (Hb), and mean corpuscular volume (MCV), mean corpuscular haemoglobin (MCH), and mean corpuscular haemoglobin concentration (MCHC). Compared to the Cobb-500 strain, the Hubbard strain had a higher least square mean for the packed cell volume. Sex had no significant impact on the haematological parameters.

Table 7. The haematological parameters of broiler chickens at 42 days of age

Effect and level	PCV (%)	RBC ($*10^6$/dl)	WBC ($*10^3$/dl)	Hb (g/dl)	MCV (fl)	MCH (pg)	MCHC (g/dl)
RMSE	0.90	0.23	12.87	1.19	5.98	1.76	1.34
R^2	0.42	0.15	0.66	0.27	0.07	0.19	0.24
Strain							
Cobb500	8.80[b]	3.13	329.19	14.71	135.92	44.99	33.79
Hubbard	9.39[a]	3.21	324.20	14.57	134.79	44.55	33.32
P-Value	0.0111	0.1488	0.1259	0.6281	0.4526	0.3271	0.1641
Sex							
M	9.07	3.13	328.51	14.74	135.95	45.08	33.65
F	9.13	3.20	324.88	14.54	134.76	44.47	33.47
P-Value	0.7962	0.2322	0.2646	0.4886	0.4269	0.1709	0.5968
Diet							
T1	8.57[bc]	3.05	315.78[b]	13.91[b]	133.28	45.14[ab]	34.06[a]
T2	8.41[c]	3.17	337.24[a]	14.74[ab]	136.58	45.46[a]	33.95[a]
T3	9.32[ab]	3.24	348.02[a]	15.69[a]	136.40	44.89[ab]	33.81[a]
T4	10.10[a]	3.21	305.74[b]	14.21[b]	133.28	43.60[b]	32.41[b]
P-Value	<. 0001	0.0910	<. 0001	0.0005	0.3851	0.0228	0.0027

[a,b,c] Different superscripts within the same column are significantly different at $p < 0.05$, T1: Farm-formulated diet, T2, T3, T4: Commercial diets from different sources, %: Percentage, PCV: Packed cell volume, RBC: Red blood cells, WBC: White blood cells, Hb: Haemoglobin, MCV: Mean corpuscular volume, MCH: Mean corpuscular haemoglobin, MCHC: Mean corpuscular haemoglobin concentration, one deciliter (dL): 10^{-10} liters, one femtoliter (fL): 10^{-15} liters, one pictogram (Pg): 10^{-12}, g: Gram, RMSE: Root-mean-square error and R^2: Coefficient of determination.

Table 8. The serum biochemical parameters of broiler chickens at 42 days of age

Effect and level	TP (g/dl)	GLU (mg/dl)	CHO (mg/dl)	CRT (mg/dl)
RMSE	0.61	25.77	15.38	0.13
R^2	0.14	0.06	0.16	0.04
Strain				
Cobb500	3.17	208.13	137.41	0.07
Hubbard	3.26	216.94	138.06	0.11
P-Value	0.5830	0.1770	0.8657	0.1500
Sex				
M	3.31	215.16	142.05[a]	0.09
F	3.12	209.91	133.42[b]	0.09
P-Value	0.2325	0.4185	0.0287	0.9050
Diet				
T1	3.03	212.11	139.72	0.08
T2	3.54	207.44	141.34	0.09
T3	3.00	214.96	129.59	0.09
T4	3.28	215.63	140.28	0.10
P-Value	0.0557	0.8011	0.1209	0.9776

[a,b] Different superscripts within the same column are significantly different at $p < 0.05$, T1: Farm-formulated diet, T2, T3, and T4: Commercial diets from different sources, mg: Milligrams, TP: Total protein GLU: Glucose, CHO: Cholesterol, CRT: Creatinine, one deciliter (dL): 10^{-10} liters, g: Gram, RMSE: Root-mean-square error and R^2: Coefficient of determination.

There was a significant response to diet treatment in the packed cell volume, white blood cells, and haemoglobin, mean corpuscular haemoglobin, and mean corpuscular haemoglobin concentration ($p < 0.05$). However, there was no significant response observed in the mean corpuscular volume and red blood cells of the broiler chicken strains. These results are similar to those of Gana et al. (2019) and Oluwafemi et al. (2021), and highlight that factors such as species, age, sex, environment, nutrition, infection, and physiological conditions (Hrabčáková et al., 2014) can influence hematological variables.

Similarly, broilers consuming the farm-formulated diet (T1) exhibited higher packed cell volume compared to those on a commercial diet (T2) and were similar to those on commercial diets (T4) concerning white blood cells, mean corpuscular volume, and mean corpuscular hemoglobin concentration.

The white blood cell counts for broilers fed commercial diets (T2 and T3) were significantly higher and comparable to those observed in other treatments. These results might have played a role in the broilers' enhanced performance in both diets, as white blood cells play a crucial role in resisting diseases and fighting infections (Soetan et al., 2013). Furthermore, the study revealed that the mean corpuscular haemoglobin concentration for the farm formulation diet (T1) was comparable to that of the commercial diets (T2 and T3), aligning with the findings of Aikpitanyi and Egweh (2020).

The farm formulation (T1) also showed similar levels of hemoglobin to the commercial diets (T4) although the hemoglobin (Hb), packed cell volume (PCV), and white blood cell (WBC) values for the farm formulation were within the normal range; the commercial diets resulted in higher values for these parameters. This suggests that commercial diets might offer more effective nutrient utilization, enhancing blood formation due to their nutrient composition. This observation is consistent with the findings of Mulatu et al. (2019).

The effects of diet and strain on creatinine, glucose, cholesterol, or total protein were not statistically significant. However, sex had a significant impact on cholesterol levels but no significant effect on total protein, glucose, or creatinine ($p < 0.05$). Cholesterol levels and total protein were lower than those reported in previous studies, consistent with the findings of Alagbe et al. (2019) and Oluwafemi et al. (2021). In the present study, blood glucose levels were within normal ranges in broiler treatments, with values of 212.11, 207.44, 214.96, and 215.63 for T1, T2, T3, and T4, respectively. Thus, the current results, which ranged from 200 to 500 mg/dL, were comparable to the blood glucose levels in healthy birds (Campbell, 2012). The creatinine levels observed in this study are consistent with the findings reported by Aikpitanyi and Egweh (2020).

Partial budget analysis

The effects of diet treatment and strain on the partial budget analysis are presented in Table 9. The partial budget analysis of the total feed consumed per bird (kg) led to the following rankings: T3 > T2 > T4 > T1 for both the Cobb 500 and Hubbard strains. For the Cobb 500 broiler strain, T2 had the best net return, followed by T3, T4, and T1. The highest marginal rate of return was also found in T2, followed by T4, T1, and T3. However, T3 also showed a high marginal rate of return, which was followed by T4, T2, and T1. Additionally, T3, T2, T4, and T1 all showed high values for net returns in the Hubbard broiler strain.

The highest net returns were observed in broiler chickens fed the T2 diet in the Cobb500 strain, followed by T3, T4, and T1. For the Hubbard strain, T3 resulted in the highest net returns, with T2, T4, and T1 following in that order. Variations in net return were due to the differences in feed cost, feed consumption efficiency, strain type, and the selling price of individual broiler chickens in each treatment. Among the experimental diets, the most profitable diets were T2 for Cobb 500 broilers and T3 for Hubbard broilers, respectively, based on net return and marginal rate of return. These findings are in alignment with those reported by Alemayehu et al. (2019) and Tamasgen et al. (2021). The higher net returns observed for Cobb 500 (T2) and Hubbard (T3) compared to the farm-formulated diet (T1) highlight the profitability of these commercial diets. This profitability is linked to the higher carcass weight achieved with these diets. The results of the study corroborate those of Abd El-Hack et al. (2018), who suggested that pigeon peas could boost growth and meat yield in addition to lowering feeding costs without compromising performance. However, Solomon et al. (2017) claimed that the cost of manufacturing each experimental meal with toasted Cajan was comparable to the cost of the diet prepared on a farm. This is not supported by the results of the current investigation. The results of the present study showed that the high income generated by the commercial diets of Cobb 500 (T2) and Hubbard (T3) increased as a result of increased weight gain and carcass weight, with no adverse effects on the chickens' performance. The greatest economic benefit was obtained when broilers were fed higher levels of a commercial diet than the farm-formulated diet. However, the farm-formulated diet (T1) had a higher marginal rate of return than that of a commercial diet (T3) in the Cobb 500 strain.

Table 9. Effects of commercial and farm-formulated diets on economic analysis of two broiler chickens at 42 days of age

Parameter \ Treatments	T1	T2	T3	T4
Partial Budget Cost (Birr)				
Cobb 500 strain				
Day old chick cost (Et. Birr)	52	52	52	52
Total feed consumed/bird (kg)	3.61	4.08	4.53	4.07
Per unit feed cost (Et. Birr)	30.75	37.08	33.38	34.35
Total feed cost (birr/bird)	111.01	151.29	151.21	139.81
Revenue (Et. Birr)				
Average carcass weight (kg)	1.36	2.16	1.85	1.77
Carcass price (supermarket)	260	260	260	260
Total return (Et. Birr)	353.6	561.6	481	460.2
Net return/bird (Et. Birr)	242.59	410.31	329.79	320.39
Marginal rate of return %	218.53	271.21	218.10	229.85
Hubbard strain				
Day old chick cost (Et. Birr)	57.50	57.50	57.50	57.50
Total feed consumed/bird (kg)	3.58	4.16	4.50	3.78
Per unit feed cost (Et. Birr)	30.75	37.08	33.38	34.35
Total feed cost (birr/bird)	110.09	154.25	150.21	129.84
Revenue (Et. Birr)				
Average carcass weight (kg)	1.14	1.92	1.96	1.66
Carcass price (supermarket)	260	260	260	260
Total return (Et. Birr)	296.4	499.2	509.6	431.6
Net return/bird (Et. Birr)	186.31	344.95	359.39	301.76
Marginal rate of return %	169.23	223.63	239.26	232.41

T1: Farm-formulated diet, T2, T3, and T4: Commercial diets from different sources, %: Percentage, kg: Kilogram, ET. Birr: Ethiopian Birr

CONCLUSION

The result revealed that the farm-formulated diet had effects on the live body weight, feed consumption, and feed conversion ratio comparable to those of the commercial diet in the T4 group. Notably, the farm-formulated diet demonstrated a higher marginal return rate than the commercial diets in T3 group for the Cobb-500 strain. Additionally, the farm-formulated diet showed advantages in several haematological parameters in broiler chickens. Farm-formulated diets were comparable with commercial diets in the T4 group for carcass yields, wing weight, and back weight. Consequently, the Cobb-500 strain had a greater result in carcass yield compared to the Hubbard strain during the experimental study. Overall, farm-formulated diets, which utilize locally available resources, offer a viable and cost-effective alternative to more expensive commercial diets. Therefore, it is feasible to generate a commercial diet for broiler chickens, as an alternative diet, using the feed ingredients that are accessible in the farming locations.

DECLARATIONS

Availability of data and materials

The data of the current study are available upon reasonable request.

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Author’s contributions

Bikila Negari created and planned the experiments, collected data, analyzed and interpreted the results, wrote the manuscript, and confined the report. Yesihak Yusuf, Demissu Hundie, Negassi Ameha, Kefelegn Kebede, Biazen Abrar, and Diriba Diba created and planned the experiments, performed the experiments, and provided materials, reagents, analysis tools, or data. All the authors read and approved the final version of the manuscript.

Competing interests

The authors declare that there are no competing interests.

Ethical considerations

The ethical concerns of plagiarism, permission to publish, misconduct, data fabrication, double publication, and redundancy have all been reviewed by each author.

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