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Full Length Research Paper

Effects of Fish Meal Inclusion in Broiler Diet on Growth Performance and Carcass Characteristics of Koekoek Chicken

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Abstract

This study aimed to evaluate weight gain, carcass traits, and economic efficiency of Koekoek chickens fed fish meal as a partial replacement for soybean meal. The offal was obtained from Koka Fish Reservoir and Ellen Lake, and it was cooked, sun-dried, and included in the diets. A total of 120 chickens were randomly selected and assigned to four treatments (T1: 5 %, T2: 10 %, T3: 15 %, T4: 20 % fish meal) in a complete randomized design with two replications of 15 chicks each. The feeding trial was commenced for 48 days, followed by carcass evaluation of two chicks per replication. Results revealed that inclusion of fish meal diet had a significant effect on average daily weight gain and final weight ($p < 0.0001$) and FCR ($p < 0.02$) among treatments. Chickens fed on T1 and T2 consumed more daily dry matter (91.7 vs 89.8) and organic matter (18.7 vs 18.3) g/chick/day, respectively. Thus, chickens fed on T1 and T2 achieved a higher average daily weight gain, slaughter weight, drumstick, thigh, wing, total carcass weight, and total edible components. Chickens fed T3 and T4 diets exhibited lower average daily weight gain (16.2 g/day in both treatments) despite having the highest daily intakes of calcium (1.12 and 1.14 g/day) and phosphorus (0.65 and 0.79 g/day), respectively. Chickens fed on a T4 diet had the lowest intake (295.8 kcal/day) of metabolizable energy. The total edible offal and dressing % were not significantly ($p > 0.05$) affected among dietary treatments. Economically, the production cost incurred for T1 (325.8 Birr) was higher than that of T2 (307.1 Birr), while their relative net income was higher. Therefore, inclusion of fish meal up to 10 % (T2) in grower diets is recommended to optimize both performance and profitability of the broilers.

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1. Introduction

Ethiopian village poultry production is an essential part of rural livelihood, helping to generate cash, improve household nutrition, and provide food security (Desta, 2021). In the country, poultry farming is a financially viable business considering its shorter production cycles and lower capital requirements for small-scale farming (Ramukhithi *et al*., 2023). This sector is mostly defined by smallholder, scavenging-based systems that use indigenous chicken breeds (Birhanu *et al*., 2023). Scavenging poultry rearing plays an important role in converting house hold leftover (food), grains, wastes, worms, and insects into valuable and quality protein (Singh *et al*., 2022). Currently, village poultry production system faces persistent annual feed deficits due to frequent seasonal variability, shortage of rainfall, and the onset of prolonged drought periods for crop cultivation (Markos *et al*., 2024). These challenges expose rural poultry's scavenging ability and further intensify competition for grains for food system. Despite low input and limited management, village poultry provide eggs, meat, and manure, and play socio-cultural roles in rural communities across the country (Belay and Oljira, 2019).

In addition, the prevalence of diseases are most important issue affecting small-holder poultry business besides absences of scavenging feed resources supplementation (Getahun *et al*., 2025). The shortage of poultry feed resources in terms of quantity and quality, high marketing price, and variability remain unresolved challenges to boost egg and meat productivity (Kleyn and Ciacciariello, 2021). The primary cause for this is that the majority of conventional chicken feed ingredients, such as maize and soybeans, are staple foods for humans (Babatunde *et al*., 2021). Thus, the competition between livestock and human food systems would increase, thereby increasing the cost of chicken feed on the market (Zegeye *et al*., 2023).

As a result, the issue of poultry feed source is particularly severe and unresolved for Ethiopian small-scale commercial poultry farmers both now and in the future (Abera *et al*., 2024). As a result, dependence on crop residues and agro-industrial by-products is steadily increasing to balance food-feed systems (Salo *et al*., 2025). Moreover, commercially produced diets are unaffordable, especially when it comes to the protein sources for exotic and upgraded poultry breeds (Wilson, 2021). This economic barrier restricts reliance on exotic poultry productivity and discourages small-scale farmers from pursuing new business ventures and sources of income (Bounds and Zinyemba, 2018).

In Ethiopia, poultry production has untapped potential due to a variety of underutilized, natural, industrial, and agricultural resources in different agro-ecologies if processed and utilized for commercial production, besides a wide range of agricultural processing residues, agro-industrial by-products, and aquatic leftover resources, which are potential for poultry sector productivity improvements (Melesse *et al*., 2013; Ababor *et al*., 2023). Hence, these leftovers are generally not suitable for human consumption. Thus, it is important to process and transform leftovers into nutritionally valuable feed resources for poultry feeding (Limeneh *et al*., 2022). So, searching for alternative feed resources and strategic use of those by-products could lower feed costs, reduce competition with humans for grains, and enhance the sustainability of poultry farming in rural communities (Alhotan, 2021; Getahun *et al*., 2025). Moreover, underutilized agricultural and aquatic by-product conversion into high-quality protein source feeds may increase the supply of reasonably priced animal-source food, promoting food and nutrition security (Ababor *et al*., 2023). Accordingly, previous studies indicated that cost-efficient utilization of potential agricultural and agro-industrial by-products in animal feeding systems should be emphasized to alleviate feed scarcity and promote more resilient production systems (Tolera, 2007; Nurfeta, 2010).

Therefore, access to agro-industrial by-products for commercial poultry farms is increasing annually across urban and peri-urban centers (Feyisa *et al*., 2024). However, the use of commercial diets for rural and scavenging poultry production is minimal due to the high prices of commercially formulated feeds. Nevertheless, the advantages of having a range of agricultural leftovers, agro-industrial by-products, especially from businesses that process wheat and edible oil, and fish farming, are not well assessed for their capacity to be successfully incorporated into formulations for the production of livestock feed, including poultry (Diriba and Urge, 2020). Additionally, the majority of smallholder farmers do not rely on using leftovers as feed supplies compared to concentrate feeds. The main reason for this under-utilization is a lack of technical expertise and understanding regarding feed formulation and utilization (LIVES, 2014).

Fish meal is the most promising alternative feed source that might be used as a supplemental protein source feed for livestock production (Hardy and Tacon, 2002). In the Rift Valley region, fish by-products like gut, head, skin, scales, eyes, gills, and gonads are relatively accessible and is recognized for their exceptional nutrient profile that deserves attention as a livestock protein source (Negesse and Tera, 2010). On the contrary, large amounts of fish by-products are wasted as leftovers, especially non-edibile offals close to nearby water bodies when fish are harvested and processed by fishermen (Jayathilakan *et al*., 2012). These by-products have a tendency to build up near watercourses if properly handled, which can result in pollution, foul aromas, and possible environmental contamination (Olsen *et al*., 2014).

Fish by-products or leftovers are also used as valuable alternative agricultural inputs, such as organic fertilizers, ingredients for livestock feed (fish meal), or soil conditioners, instead of thrown away as waste (Jayathilakan *et al*., 2012). Hence, processing of fish by-products into fish meal also lowers environmental risks while encouraging resource recycling and sustainable agriculture (Campanati *et al*., 2022). Therefore, processing of fish by-products as fish meal is a source of a highly concentrated protein source feed that provides essential amino acids, particularly methionine and lysine, which are often deficient in plant-based feed ingredients, especially for poultry production (Leeson, 2008; Alagawany *et al*., 2021). Fish meal inclusion in poultry diets can significantly enhance growth performance by providing a balanced nutritional profile for the best possible muscle growth and egg productivity (Kolawole and Mustapha, 2023). Thus, fish meal provisions have a significant nutritional impact on broiler feeding and increase farming profitability by growing muscle mass quickly (Abasubong *et al*., 2025). Particularly in starting broiler diets, it boosts development, feed efficiency, and gastrointestinal health by providing a highly digested protein, vital amino acids, omega-3 fatty acids, vitamins, and minerals (Thanabalan and Kiarie, 2021). However, excessive amounts of fish meal supplementation might alter meat quality and necessitate antioxidant preservation.

Therefore, integration of fish meal and agro-industrial by-products into poultry feeding systems, besides replacing plant proteins, offers various broader benefits, including environmental sanitations, as well as nutritional qualities in feeding (Georganas *et al*., 2023). So, fish meal can serve as a suitable substitute, as it is an excellent source of lysine, methionine, tryptophan, and other trace minerals (Niu *et al*., 2016). Incorporation of fish leftovers as fish meal into chicken diets may also lessen rivalry with human food, minimize production costs, increase profitability, and further lessen the environmental effects of waste disposal (Abasubong *et al*., 2025). However, greater knowledge and technical proficiency in ration formulation and feed usage are necessary for effective utilization of potential feed resources. Therefore, this study was conducted to evaluate the fish meal and specific agro-industrial by-products in replacing soybean meal in poultry feeding in commercial farms to improve weight gain, carcass yield, and economic returns. These help to produce evidence that can guide the development of sustainable, cost-effective ration formulation procedures suited to the requirements of Ethiopia's smallholder poultry farmers in Ethiopia.

2. Materials and Methods

2.1. Description of the Study Area

The experimental trial was carried out in the Bora district of the East Shoa Zone of the Oromia region, Ethiopia. The district lies approximately 110 km southeast of Addis Ababa and 50 km southwest of Adama, along the Addis Ababa–Hawassa main road. The Bora district is found in an altitude range of 1,500 - 1,800 meters above sea level. The area has an average yearly temperature range from 13.4 - 28 °C, with maximum daily temperatures reaching up to 28°C. The area receives a mean annual rainfall ranging from about 500 to 800 mm (RVMLZ, 2008). The total area of the studied district is about 53,977 ha, of which 27,550 ha was cultivated land, 2,743 ha allocated for forest, 3,123 ha for grassland, 1,073 ha for water body and the land uses for other purpose was 3,054 ha. Koka reservoir (255 km^2) and Ellen Lake (54 ha) are the two main water bodies found in the district used for irrigation and fishery. Koka reservoir is also used for recreation, while the primary purpose is for hydroelectric power generation. The people in the area grow a variety of crops for home consumption and sale, mainly maize, wheat, haricot bean, and teff. Crop grains offered besides grain-wastes are used for free scavenging poultry, including home wastes. The studied area has livestock populations of 89,964 cattle, 46,044 sheep, 57,130 goats, 581 mules, 8,072 donkeys, and 38,992 chickens (indigenous and cross-bred) kept under extensive backyard rearing practices (BLDHA, 2019).

2.2. Fish Meal Preparation

Before the collection of fish offal, fishing (fish harvesting) and filleting activities were observed at the landing site of Koka and Ellen Lake. Fishing cooperatives and individuals harvest fish to supply fresh and dried flesh to hotels and households. Fishermen use hooks and nets for fishing methods, and fish are fleshed and filleted immediately near water bodies based on daily catch availability. After fishing, they discard fish offal and other by-products and leave behind along the shoreline of lakes. After steady observations, we prepare plastic bowls for handling the fish offal after filleting. People involved in fish filleting were instructed to fillet on clean stony ground to avoid adulteration with the soils and other contaminants. The offal's not suitable for human consumption, such as gut, head, skin, scale, eyes, gills, and gonads of catfish, tilapia, and barbus was collected and boiled for 20 minutes to inactivate bacteria and parasites (Negesse and Tera, 2010) (Figure 1).

Fig. 1. Fish offal's cooking to reduce microbial load in the process of fish meal preparation

Before formulation, fish offals were cooked and sun-dried for 2 - 3 days to minimize moisture to prevent further bacterial multiplication during storage and make for easy milling. Then, offals were thinly and evenly spread and exposed to sunlight at an open dry place using a plastic sheet as a drying material.

2.2.1. Ingredients, nutritional compositions, and experimental ration

Nutritional compositions of feed ingredients used in ration formulation are presented in Table 1. Compared to soybean meal, fish meal contained higher levels of crude protein (CP), ether extract (EE), calcium (Ca), phosphorus (P), and metabolizable energy (ME), while its crude fiber (CF) content was comparatively lower (Table 1).

Table 1. Nutritional compositions of feedstuff used in ration formulation on DM % basis.

	Nutrients								
Ingredients	**DM%**	**CP**	**EE**	**CF**	**Ash**	**NFE**	**Ca**	**P**	**ME(kcal/kgDM)**
Fish meal	94.2	51.8	15.8	3.0	25.3	23.2	4.0	1.2	3513.4
Soybean roasted	91.9	46.7	4.55	9.01	10.3	25.8	0.2	0.6	2972.1
Wheat bran	93.1	10.7	4.41	11.2	9.4	61.9	0.1	1.3	2813.5
Maize grain	91.5	10.7	3.38	12.4	10.5	57.9	0.1	0.3	2609.3

DM: Dry matter; CP: crude protein; CF: crude fiber; EE: ether extract; NFE: nitrogen free extract;

Ca: calcium; P: phosphorus; ME: Metabolizible Energy

Experimental rations were prepared from locally available feedstuff like maize, wheat bran, roasted soybean, fish meal, limestone, and salt as to local standard formula of Alema Koudijs broiler feeding stages (Schimmel, 2016). Soybean was roasted for five minutes to deactivate trypsin inhibitors, coarse ingredients were ground and homogenized, and diets were formulated using Feed Win software to meet broiler requirements, resulting in rations with ~21 % CP and 13.2 MJ/kg DM, and ME recommended for broilers (Ekreen *et al*., 1997). Additionally, methionine and premix were excluded from experimental feedings of T2, T3, and T4 due to high cost and limited availability for smallholder farmers, and were expected to be replaced with fish meal (Table 2).

Table 2. The proportion of feed ingredients (%) used for experimental chicks and management.

Ingredients	T1	T2	T3	T4
Maize	51.6	52	52	52
Soybean meal	15	10	5	0
Wheat bran	16	26	26	26
Fish meal	5	10	15	20
Lime stone	1	1	1	1
Nouge cake	10	-	-	-
Methionine	0.1	-	-	-
Premix	1	-	-	-
Salt	0.3	1	1	1
ME (kcal/kg)	3225.9	3226.8	3193.5	3160.1
CP	19.87	19.80	21.43	22.97
Total	100	100	100	100

Sources (Leeson and Summers, 2009).

2.3. Experimental Design

The experimental design used for this feeding trial was a complete randomized design (CRD) consisting of four dietary treatments with two replications. All the chickens were assigned randomly to one of the four dietary treatments. Each treatment was classified in two replications of 15 chickens, and each replication with three pens assigned with five (5) chickens in each pen (Table 3). Additionally, male and female chicks were proportionally assigned to treatment pen and replications, whereas randomized for sex group among the three pens in one replication.

Table 3. Experimental design of the feeding trial

Dietary treatments	Inclusion rate of fish offal	Replications		
		1	2	Total
1	5 %	15	15	30
2	10 %	15	15	30
3	15 %	15	15	30
4	20 %	15	15	30
Total		60	60	120

2.3.1. Experimental animal handling and feeding trial

A total of 150 Koekoek day-old chickens were purchased from the Debre Zeit Agricultural Research Center and handled under uniform management conditions at the experimental site before the experimental trial. All procedures followed Hawassa University's ethical guidelines for animal welfare and use in research (HU-E.C/06/2022).

Health management included the provision of anti-coccidiostats and oxytetracycline in drinking water. Also, chickens were vaccinated against Newcastle disease at 7 and 21 days of age (Abdoshah *et al*., 2022). They were housed in a deep litter poultry house constructed by a volunteer farmer using local building materials for poultry production purposes. After the brooding age, a total of 120 chickens (equal performing) were randomly selected from 150 chickens, individually weighed using a digital balance of 5 kg with ± 20 g precision, leg-tagged, and transferred to experimental pens measuring 1m × 180 cm. The pens were partitioned with mesh wire and covered with a 5 cm layer of sawdust litter, which was replaced with dry, clean sawdust as needed to maintain hygiene.

During the two-week brooding period, chickens were fed commercial starter feed and provided with water ad-libitum. Following brooding, the feeding trial commenced, and chickens in each replication were fed in groups. The amount of feed offered and refusals was collected and measured daily per individual bird to determine feed intake. Except treatments diet variation, all management conditions were similarly provided, including floor space, light, temperature, ventilation, and relative humidity for each of the groups in replications. The feeding trial continued for a total duration of 48 days.

2.3.2. Growth performances and feed conversion efficiency

The initial and final live body weights were recorded and used to determine the weight gain performances during the feeding trial period. Daily live body weight gain of each chicken was recorded until the end of the experimental period on a weekly basis. Average daily weight gain (ADWG) was calculated by subtracting the initial live weight from the final weight and then dividing the total live weight gain by the total number of days across the experimental period (g/day), and feed conversion ratio (FCR) was determined as the ratio of feed intake to body weight gain using the formula of Emmerson (1997).

$$\text{Average daily weight gain (ADWG)} = \frac{\text{Final live weight-Intial live weight}}{\text{Number of the expermental day}}$$

FCR = Weight of dry feed fed (g) / live weight gain of chicks (g)

2.3.3. Evaluations of carcass characteristics

After the feeding trial, two chickens (one male, one female) per replication, four per treatment, sixteen in total, were fasted for eight hours, slaughtered humanely, efficiently bleed and weighed. Blood, feathers, shanks and claws, head, lungs, heart, spleen, pancreas, crop, proventriculus, kidneys, intestines, and abdominal fat were recorded as non-edible offal. Edible offal included skin, liver, and gizzard. Carcass components were further divided into back (thorax + lumbar), 2 thighs, 2 drumsticks, 2 wings, and breast. Dressing percentage was calculated as the proportion of dressed carcass weight relative to live body weight at the slaughtering.

2.4. Feed Ingredients and Partial Budget Analysis

Chemical composition of feeds used for ration formulations was analyzed at the Animal Nutrition Laboratory of Hawassa University. Feed samples were assessed for dry matter (DM), crude fiber (CF), crude protein (CP), ether extract (EE), and ash content following the procedures described by AOAC (2005). Calcium (Ca) and phosphorus (P) concentrations were ascertained for feeding at the Debre Zeit Agricultural Research Center using an atomic absorption spectrometer. Metabolizable energy (ME) of feed ingredients was calculated according to the method of Wiseman (1987) as follows:

$$\text{ME (kcal/kg DM)} = 3951 + 54.4\ \text{EE} - 88.7\ \text{CF} - 40.8\ \text{Ash}$$

A partial budget analysis was investigated following the procedure described by Upton (1979) to evaluate changes in total return using fish meal as a partial replacement for soybean in broiler diets. Total variable costs (TVC) included the costs of chickens, feed, and health management for each treatment group. Total return (TR) was calculated from the sale prices of chickens from feeding trials and the purchase price of the chickens as the initial costs. Net income (NI) was determined by subtracting total variable costs from total return:

The change in net income (ΔNI) is expressed as the difference between the change in total return (Δ TR) and total variable cost (Δ TVC).

$\Delta NI = \Delta TR - \Delta TVC$

2.5. Statistical Analysis

Body weight gains and feed conversion ratio (FCR) were analyzed using a repeated-measure, while nutrient and energy intake, carcass production characteristics for diets and sex effects were analyzed using ANOVA of SAS Ver. 9.4 (SAS, 2012). Tukey's HSD test test was used to compare treatment means, with significance declared at $p < 0.05$. Data analysis was done using model:

$$Yij = \mu + \alpha i + Aj + eij$$

Where;

Yij = response variable.

μ = general mean,

αi = the effect of dietary treatments (T1, T2, T3 and T4),

Aj = the effect of sex (1: male, 2: female) and

eij = random error,

3. Results

3.1. Nutritional Compositions of the Experimental Diets

The nutritional compositions of feed ingredients used and analyzed (on % DM basis) for experimental diets are presented in Table 4. Crude protein (CP) content ranged from 19.0 to 20.4 %. Based on the investigation, there were no significant variations ($p > 0.05$) observed between the calculated and analyzed CP values for T1 and T2, confirming proper formulation for standard broiler diet. Ether extract (EE) content increased slightly from T1 to T4, while calcium (Ca) and phosphorus (P) concentration increases consistently with greater amount of partially replaced fish meal in the experimental diets (Table 4).

Table 4. Nutritional compositions of the experimental fed diets on % DM basis

Diets	Nutrients								
	DM%	CP	EE	CF	Ash	NFE	Ca	P	ME(kcal/KGDM)
T1	92.5	20.4	7.3	8.94	10.9	51.3	0.79	0.52	3115.8
T2	92.8	20.4	8.3	9.38	10.3	52.7	0.96	0.64	3149.4
T3	91.9	19.8	11.4	9.61	10.8	50.7	1.23	0.71	3277.9
T4	92.7	19.0	11.1	9.79	10.5	53.4	1.57	0.78	3255.5

DM: Dry matter; CP: crude protein; CF: crude fiber; EE: ether extract; NFE: nitrogen free extract; Ca: calcium; p: phosphorus; ME: Metabilisible Energy; T1: fed with 5 % fish meal; T2: fed with 10 % fish meal; T3: fed with 15 % fish meal; T4: fed with 20 % fish meal

3.2. Experimental Diet Composition and Feed Intakes

The effect of experimental diet levels of partially replaced fish meal on the daily feed intake of grower Koekoek chickens is listed in Table 5. The inclusion of fish meal in the chicken diet had shown significant variation of feed intake ($p < 0.05$) for DM, CP, Ca, and P. Chicks fed on treatment diets of T1 and T2 had higher feed intake for DM, CP, P, and ME than those kept on T3 and T4 ($p < 0.05$). The inclusion of fish meal in the diets of T3 and T4 had the highest Ca and P minerals. However, chickens fed on T3 and T4 recorded lower DM and CP compared to T1 and T2. The inclusion effect of fish meal had a non-significant effect ($p > 0.05$) on crude fiber (CF) intake among treatments. On the other hand, chickens fed on T4 diets had the lowest intake of ME compared to other treatments (Table 5).

Table 5. Chemical composition of the treatment diets

Nutrients (g/chick/day)	Treatments					
	T1	T2	T3	T4	SE	*p*-value
Dry matter	91.74	89.75	84.24	84.2	0.65	0.002
Crude protein	18.67	18.29	16.68	16.96	0.13	0.001
Crude fiber	3.91	4.04	3.88	3.95	0.03	0.07
Calcium	0.78	0.92	1.12	1.43	0.01	0.001
Phosphorus	0.51	0.61	0.65	0.79	0.00	0.0001
Metabolizible energy (kcal/chick/day)	309.02	304.58	300.48	295.75	2.21	0.05

T1: fed with 5 % fish meal; T2: fed with 10 % fish meal; T3: fed with 15 % fish meal; T4: fed with 20 % fish meal; SE: standard error

3.3. Growth Performances and Feed Conversion Ratio

Growth performance of Koekoek chicks (male and female) fed with various levels of fish meal diets is presented in Figure 3. The growth rates can generally be accelerated by the absorption of major and trace nutrients by different organs, soft tissues, and bones. As shown in Figure 3, both sexes showed an increasing trend of body weight gain as age advanced. There were no significant differences in body weight gain between the two sexes during the first two weeks of the experiment. However, starting from the third week of the experiment and onwards, male chicks attained higher body weight gain than females (Fig. 2).

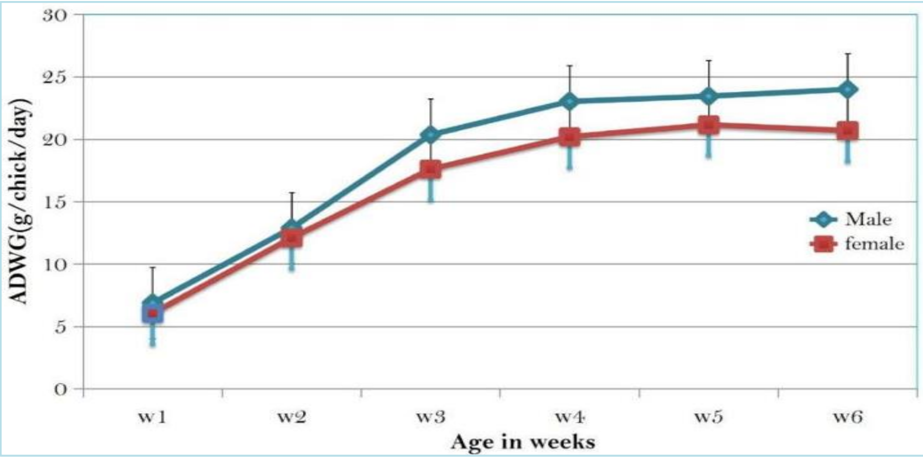

Fig. 2. Growth rate trend of Koekoek chickens across six weeks of age fed on partially replaced fish meal diets.

Average daily weight gain (ADWG) and feed conversion ratio (FCR) of Koekoek chicks fed with various levels of fish meal diets are presented in Table 6. The inclusion levels of fish meal diets had a significant effect on ADWG and final body weight ($p < 0.0001$) and FCR ($p < 0.02$). Chickens fed on T1 had the highest ADWG followed by T2, while the lowest ADWG was reported for T3 and T4. Correspondingly, feed intake for T1 and T2 was higher than that of the T3 and T4 treatment groups. Feeding efficiency of chickens fed on T1 and T2 achieved higher ADWG with better FCR values compared to T3 and T4 (Table 6).

Table 6. Growth performance and feed conversion ratio of Koekoek chicks fed on partially replaced fish meal.

Parameters	Treatments					
	T1	**T2**	**T3**	**T4**	**SE**	**p-value**
Initial weight (g/chick)	115.3	114.8	115.5	114.7	0.37	*0.35*
Final weight (g/chick)	1024.3	982	892.8	895.4	11.88	<0.0001
Total gain (g/chick)	909.6	866.4	778.1	779.5	-	-
ADWG (g/chick/day)	19.0	18.1	16.2	16.2	0.222	<0.0001
Feed intake (g/chick)	4760.5	4642.2	4400	4360.7	-	-
FCR (g feed/g gain	5.2	5.4	5.6	5.6	0.154	0.02

ADWG: average daily weight gain; FCR: fed conversion ratio; T1: fed with 5 % fish meal T2: fed with 10 % fish meal; T3: fed with 15 % fish meal, T4: fed with 20 % fish meal

The relationship between ADWG and FCR over the experimental period is illustrated in Figure 4. Regardless of dietary treatment, ADWG was significantly influenced by age ($p < 0.001$) whereas ADWG and FCR were increased with increasing age across 48vdays of feeding trails (Fig 3). However, there is no significant variations were observed for FCR across 6 week of age ($p > 0.05$). Thus, ADWG was best estimated by the linear equation of $Y = 3.18x + 6.20$, with a strong positive correlation ($R^2 = 0.84$). Similarly, FCR was better estimated by linear equation of $Y = 0.30x + 5.40$, exhibiting a very high correlation coefficient ($R^2 = 0.97$).

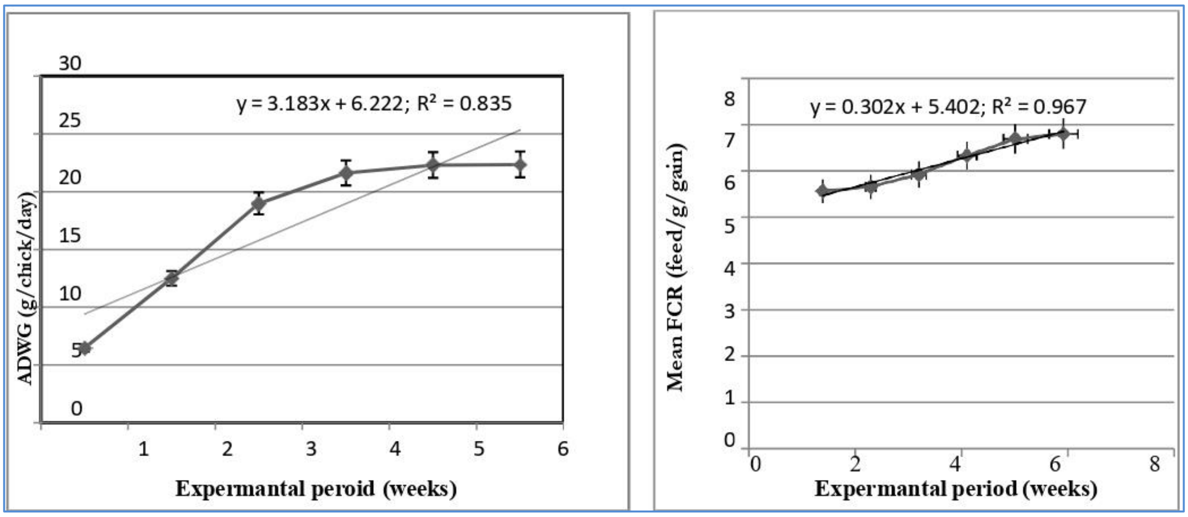

Fig. 3. Relationship between ADWG and FCR during the experimental period

3.4. Carcass Production and Characteristics

3.4.1. Total edible component (TEC)

The study showed that dietary fish meal inclusion effects on total edible carcass components and edible offal ($p < 0.05$). Chickens fed on T1 had the highest slaughter weight, breast, drumsticks, thighs, wings, back, total carcass weight, and overall edible yield followed by T2, with values significantly greater ($p < 0.001$) than chickens fed on T3, and T4. Similarly, male chickens surpass females in each component of the carcass weight. The inclusion of fish meal diet level across the treatments influences most carcass traits. However, it had a non-significance ($p > 0.05$) effect on skin, gizzard, liver, toes, and dressing percentage except for T1 (Table 7).

Table 7. Effect of diet and sex on total edible component of chicks fed on inclusions of fish meal

Parameters	Sex			Treatments					*p*-value	
	Male	Female	SE	T1	T2	T3	T4	S.E	Diet	Sex
Slaughter weight (g)	974.6	830.7	38.2	1052	953.8	918.5	791.2	11.1	0.001	<0.001
Breast (g)	98.1	84.5	6.3	116.2	90.5	78.5	79.7	3.3	0.001	0.003
Drumstick (g)	83.4	69.1	4.4	92.7	77.2	70.0	65[c]	2.1	0.001	0.001
Thighs (g)	86.9	68.8	4.8	95.8	78.5	70.2	66.5	4.1	0.004	0.002
Wings (g)	41.5	34.6	2.3	46.8	38. 5	35.0	32.3	1.6	0.001	0.003
Back (g)	71.4	59.9	3.5	76.8	65.0	62.7	58.0	3.7	0.035	0.01
Total carcass*	414.3	345.5	20.9	461.5	382.7	348.2	327.0	11.2	0.001	0.001
Skin	58.5	46.3	3.5	60.5	53.0	46.5	49.5	4.5	0.23	0.03
Gizzard	39.3	32.6	1.8	39.5	37.3	33.0	34.0	2.4	0.28	0.03
Liver	24.6	19.3	1.1	23.3	23	21	20	1.8	0.56	0.02
TEC***	536.6	443.6	24.4	584.7	496.0	449.4	430	12.5	0.001	0.001
Dressing%	53.0	51.7	0.7	55.4	53.8	53.1	54.4	1.5	0.584	0.20

TEC: Total edible component (total carcass+ edible offal); SE: stander error

3.4.2. Total non-edible offal (TNEO)

Dietary fish meal inclusion and sex effect on total non-edible offal of Koekoek chickens are summarized in Table 8. Chickens fed on lower fish meal diet (T1) had higher mean weights for most non-edible offal. However, these differences were non-significant ($p > 0.05$), except for blood and anus ($p < 0.05$). Treatment result had a substantial effect ($p < 0.05$) on sex for most non-edible offals like blood, feathers, head, shank and claws, proventriculus, lungs, small intestine, stomach, and total non-edible yield, with males exhibiting higher values than females (Table 8).

Table 8. Fish meal inclusion and sex effect on total non-edible offal of Koekoek chicks

Parameters	Sex			Treatments					p-value	
	Male	Female	SE	T1	T2	T3	T4	SE	Diet	sex

Blood	39.3	27.0	1.41	41.2	28.7	33.0	29.8	2.00	0.01	0.001
Feather	66.3	58.8	2.22	65.5	68.5	57.5	59.2	3.14	0.13	0.05
Head	38.9	30.5	1.40	35.7	34.7	33.3	35.0	1.99	0.84	0.003
Shank claw	58.8	40.8	1.83	56.7	49.5	47.3	45.8	2.60	0.07	0.001
Esophagus	2.1	1.6	2.12	1.9	2.25	1.6	1.6	0.30	0.45	0.18
Crop	10.4	7.5	1.16	9.8	10.5	7.8	8.0	1.65	0.65	0.12
Pereventriculus	6.3	5.4	0.23	5.5	5.8	5.5	6.5	0.33	0.19	0.03
Spleen	1.7	1.4	0.16	1.9	1.9	1.3	1.3	0.23	0.16	0.31
Pancreases	1.8	1.7	0.27	1.5	1.8	1.9	1.9	0.39	0.90	0.95
Kidney	8.4	7.1	0.50	6.3	9.3	7.3	8.3	0.71	0.08	0.12
Heart	5.9	5.0	0.36	5.8	6.0	5.0	5.0	0.52	0.44	0.13
Lung	7.3	5.7	0.43	7.0	7.0	6.0	6.0	0.61	0.49	0.04
small intestine	37.6	25.1	2.56	30.0	33.7	29.5	32.3	3.62	0.83	0.01
Large intestine	14.9	12.8	2.01	12.2	13.0	18.2	12.0	2.85	0.41	0.50
Abdominal fat	15.3	22.0	3.45	23.7	19.7	16.5	14.5	4.88	0.58	0.20
Cloacae	8.2	6.8	0.50	8.8	8.5	6.3	6.5	0.71	0.07	0.07
Bile	1.6	1.5	0.2	1.5	1.9	1.3	1.4	0.98	0.36	0.67
TNEC	313.7	231	19.5	321	262	236.0	270.0	27.57	0.25	0.02

TNEC: Total non-edible components; T1: fed with 5 % fish meal; T2: fed with 10 % fish meal; T3: fed with 15 % fish meal; T4: fed with 20 % fish meal

3.5. Economic Performance Analysis

Partial economic investigation of chickens fed on varying inclusion levels of fish meal diets are presented in Table 9. The low inclusion of fish meal in the chicken ration of T1 incurred the highest production costs (95% of soybean and 5% fish) and yielded the lowest net income ($p < 0.001$) compared with T2. Chickens fed on a diet of T2 (10% fish meal) return more muscle mass. Because balanced mineral availability increases appetite for consumption and conversion efficiency. In contrast, T3 and T4 had lower production costs and achieved lower net income due to high amount of oil presence decreases appetite and affects metabolic systems to degrade fats. On the other hand, increasing fish meal lowers feed costs (since soybeans are more expensive), whereas decreasing fish meal raises feed costs in proportion to net income. Therefore, average inclusion of fish meal diet enhances profitability at advanced costs (Table 9).

Table 9. Partial economic analysis of chickens fed on varied amounts of fish meal diets

Variables	Treatments T1	T2	T3	T4	S.E	p-value
Price of chicken, Birr/chick (VC)	100	100	100	100	-	-
Price of feed, Birr /kg (VC)	157.9	149.1	148.5	148.1	0.01	< 0.0001
Healthy cost, Birr/chick (VC)	16	16	16	16	-	-
Total feed consumed, kg/chick (VC)	4.8	4.6	4.4	4.4	0.01	<0.0001
Price of feed consumed, Birr (VC)	51.9	42.0	37.4	35.1	0.01	<0.0001
Total input cost (TIC)	325.8	307.1	301.9	299.2	0.01	< 0.001
Sale of chick, Birr/chick (TR)	525	513	435	432.5	-	-
Net Income (NI) = (TR-TIC)	199.2	205.9	133.1	134.3	0.14	< 0.001

VC: variable cost; TIC: total input cost; TR: total revenue; NI: net income

4. Discussion

4.1. Nutrient and Energy Contents of the Experimental Fed Diets

The study showed that crude protein (CP) content of the experimental fed diets was within the recommended ranges of 19 - 20 % for grower and finisher broilers, respectively, as suggested by El-Deek *et al.* (2020). Ether extract (EE) content increased slightly from T1 to T4 with higher levels of fish meal inclusion, indicating a gradual improvement in dietary energy density might be due to better oil (fat) content of fish meal. Similarly, calcium (Ca) and phosphorus (P) concentrations rose linearly with increasing fish meal levels.

These was consistent with the findings of Tera *et al.* (2008) and El-Deek *et al.* (2020), reflecting the higher mineral contribution of fish meal to support bone development and overall metabolic functions. Metabolizable energy (ME) content also increased with higher fish meal inclusion, remaining within the recommended 3200 kcal ME/kg DM for broilers (El-Deek *et al.*, 2020). Nutrient improvements likely contributed to the observed differences in growth performance, feed intake, and feed conversion efficiency among treatments, highlighting the importance of fish meal inclusion in optimizing broiler production.

The crude protein (CP) content of fish meal in % DM basis in this study (51.8 %) was lower than 70 % reported by Negussie and Alemu (2005) for Ethiopian fish meal. This variations in CP contents might be due to differences in preparation methods (Jacob, 2013; Liu *et al*., 2021). Fish meal composition also varies depending on the species used, processing methods of fish meal and fish ecotype, and whether fillets were removed prior to processing (Hilmarsdottir *et al*., 2020). The fat content observed in the current study was higher than the 3.4–11.3 % reported by Wisenfeld *et al*. (2005) for good-quality fish meal. However, it was lower than 21.6 % reported by Tera (2008), possibly due to incomplete fat recovery during processing. Crude fiber (CF) values were consistent with those reported by Wolde *et al*. (2011). Calcium content in this study was lower than the 6–6.08 % reported by Tera et al. (2009). Previous studies, including Tera et al. (2009), have suggested that such variations in ingredient composition and processing procedures can directly affect feed intake, growth performance, and carcass traits, highlighting the importance of ingredient quality in poultry nutrition.

4.2. Feed Intake of Chickens

Feed intake is a key factor in influencing poultry performance and serves as an important indicator of feed nutritive value (Barzegar *et al*., 2020). The replacement of soybean with varying levels of fish meal led to significant differences in nutrient intakes, with chickens fed T1 and T2 showing higher dry matter (DM), crude protein (CP), and metabolisable energy (ME) intakes. These results are consistent with Ponce and Gernat (2002), who reported increased feed intake in broilers when tilapia by-product meal was included up to 6 % in the diet, while higher inclusion levels depressed intake. The lower feed intake observed in T3 and T4 may be associated with higher phosphorus (P) and calcium (Ca) and EE (amounts of oil in feed) levels, which can reduce feed consumption (Berihun *et al*., 2023). This study report also aligns with Isika et al. (2006), who noted that elevated mineral intake, particularly of P and Ca, can impair nutrient digestibility and limit overall feed intake and conversion efficiency.

4.3. Effect of Fish Meal Inclusions on Growth Performance and Feed Conversion Efficiency

The highest average daily weight gain (ADWG) was observed at 5 % fish meal inclusion (T1, commercial feed). Additionally, chicks feed on diet of T2 showed higher muscle mass than T3 and T4 treatments. These results are consistent with Donald and William (2002), who suggested that fish meal inclusion up to 8 % generally enhances productive performance in broilers. However, higher inclusion levels of 15% and 20% (T3 and T4) resulted in lower ADWG which might be a direct reflection of lower feed intake compared to T1 and T2. These was also similarly reported by findings of Negesse and Tera (2010), and Karimi (2006), who reported that excessive fish meal inclusion can depress growth rates. Chickens fed on T1 and T2 also exhibited the most efficient feed conversion, likely due to the higher growth rate at this inclusion level. These indicated that faster growth rate is typically associated with improved feed utilization, and ADWG and feed efficiency have been reported to be highly correlated (Berihun *et al*., 2023). The efficiency of mineral utilization may be the reason for FCR disparities. In terms of body weight increase per gram of feed ingested, chickens with medium CP and minerals have a greater feed conversion efficiency (Ogbuewu *et al*., 2023). This suggested that CP and above-threshold minerals have a detrimental conversation efficiency.

4.3.1. Carcass production and characteristics

The slaughter carcass weight was strongly influenced by sex, with males being heavier than females (Benyi *et al*., 2015). This difference may be attributed to the effects of androgens in males, which promote muscle development, as well as higher feed intake compared with females (Yuan *et al*., 2024). Correspondingly, Wolde *et al*. (2011) indicated that males generally achieve higher slaughter weights, while females tend to deposit more fat due to sex hormone effects. The highest total carcass weight and individual carcass components (breast, drumsticks, thighs, wings, and back) were observed in chickens fed the diet containing 5 % and 10% fish meal. This was likely due to greater protein deposition at this inclusion level. According to Negesse and Tera (2010), higher carcass yield reflects improved nutrient bio-availability for anabolic processes, as true muscle development results from protein accumulation (Choi *et al*., 2023). These results correspond with the higher growth rates and improved feed conversion efficiency observed in chickens fed 5% fish meal. This implies that optimal nutrient intake supports both efficient weight gain and superior carcass development (Shastak and Pelletier, 2023).

From an economic perspective, partial budget analysis indicated that increasing fish meal inclusion reduced overall production costs in broiler diets, as fish meal is a less expensive protein source than soybean. This cost reduction translated into higher net income, highlighting the economic feasibility of using fish meal as a protein source in the ration. While the 5% fish meal diet (T1) delivered the best growth and carcass outcomes, though it incurred higher costs. The low feed intake of T3 and T4 may be attributed to the high mineral availability in fish meal, which can suppress appetite, thereby reducing weight gain and feed conversion efficiency (Alabi & Adedokun, 2025). Moreover, 10% inclusion reduces expenses and improves output from feeding. These findings are consistent with Tera et al. (2009) and Negesse and Tera et al. (2010), who reported that including fish meal up to 13% in growing chicken diets was cost-effective. Conversely, the 20% fish meal diet (T4) reduced production costs but resulted in lower growth performance. Muscle development may be adversely affected by broiler diets that contain high amounts of fish meal (Wang *et al*., 2023). In excess of fish meal can lower palatability and raise dietary mineral load, which can suppress feed intake, decrease weight gain, and limit feed conversion efficiency (Lall & Kaushik, 2021). Furthermore, imbalances in minerals and amino acids at high inclusion rates may impede optimal broiler growth by impairing metabolic efficiency and nutrient use (Adedokun & Olojede, 2019; Zampiga *et al*., 2021). Therefore, considering both biological performance and economic efficiency, a 10 % fish meal inclusion (T2) offered moderate benefits, maintaining satisfactory growth, carcass traits, and feed efficiency while reducing costs. Overall, results suggest that strategic replacement of soybean with fish meal can enhance profitability. However, maintaining adequate growth performance in broilers, as observed in the higher weight gain, feed efficiency, and carcass yield of chickens fed an optimal fish meal levels.

5. Conclusions

The inclusion of fish meal in broiler fed diets had a significant impact on growth performance, feed efficiency, carcass characteristics, and economic outcomes. Chickens fed 5 % fish meal (T1) exhibited the highest average daily weight gain, improved feed conversion ratio, and heavier carcass weights and individual carcass components (breast, drumsticks, thighs, wings, and back). However, higher inclusion levels (15–20 %) of fish meal diets reduced performance. Males outperformed females in slaughter weight and muscle development. Although 5% inclusion maximized weight gain, production costs were higher, while 10% fish meal provided a cost-effective balance, maintaining satisfactory growth, carcass traits, and feed efficiency. Therefore, incorporating locally prepared fish meal in grower chicken rations up to 10 % (T2) is cost-effective, does not adversely affect growth or carcass traits, and can partially or fully replace plant protein sources for broiler diets.

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Author contributions

MG and KA: Conceptualization, methodology, data curation, validation, formal analysis, visualization, writing–original draft, writing–review and editing.

AN, AE and GD: Conceptualization, writing–original draft, writing–review and editing. In conclusion, all authors read and approved the final version for submission.

Availability of data

The data supporting the results of the study can be available when requested.

Ethics approval

The study adhered to the ethical guidelines of animal experimentation approved by the Hawassa University Animal Welfare and Ethical Committee, 2001 (ref. No: HU-E.C/06/2022).

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