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Effects of Dietary Inclusion of Roasted Full-Fat Soybean on Egg Production and Quality, Hematological Parameters, and Cholesterol Level in Layer Chickens

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ABSTRACT

The scarcity and high costs of poultry feed ingredients, such as soybean meal (SBM), present significant challenges for modern poultry production systems in Ethiopia. To explore potential alternatives, this study evaluated the effects of varying inclusion levels of roasted full-fat soybean (FFSB) in layer diets on productive performance, egg quality traits, and selected blood parameters. A 12-week feeding trial was conducted using 120 Bovans Brown hens aged 34-46 weeks, with an average initial body weight of 1.44 ± 0.01 kg. The hens were randomly assigned to five dietary treatment groups (0%, 10%, 15%, 20%, and 25% FFSB), each replicated three times with eight hens per replicate. The control diet contained 20% SBM for comparison. The results showed that hens in the control group exhibited significantly higher hen-day egg production (89.72%), egg mass (54.28 g/hen/day), and body weight gain (314 g) compared with those fed diets containing different inclusion levels of FFSB. However, no significant differences in egg production were observed among the groups fed diets containing different inclusion levels (10-25%) of FFSB. The group fed 10% FFSB exhibited a higher egg mass (38.44 g/hen/day) than those receiving 15% and 25% inclusion levels. The feed conversion ratio (FCR) increased with higher levels of FFSB inclusion, with the 25% FFSB group showing a significantly higher FCR (3.37) compared to the control group (2.06). Full-fat soybean inclusion had no significant influence on most egg quality traits, nor on hematological indices or serum cholesterol levels. The findings indicated that FFSB inclusion in layer feeds at levels up to 25% did not compromise egg quality or hen health. Although higher FFSB inclusion lowered feed costs, reduced egg production offset these savings, making full substitution of SBM economically unprofitable.

Keywords: Diet, Egg production, Egg quality, Full-fat soybean, Inclusion level, Layer

INTRODUCTION

Poultry production plays a critical role in enhancing food security and economic stability in Ethiopia. Meeting consumer demand for meat and eggs heavily depends on the consistent availability of safe and cost-effective poultry feeds. However, the scarcity and rising prices of key feed ingredients, particularly soybean meal (SBM), pose significant challenges to the development of modern poultry production systems (Negash, 2022; Zegeye et al., 2023). This challenge highlights the need to identify sustainable, locally available, and cost-effective feed alternatives. Full-fat soybeans (FFSB) present a promising option, offering protein (37-42%) and energy (18-22% fat) comparable to SBM, while eliminating the additional cost associated with oil extraction (Mihandoost et al., 2021; Karimi et al., 2022; Toomer et al., 2024a). The potential for using FFSB is particularly strong in the Amhara region, which accounts for approximately 39% of Ethiopia's soybean production (CASA, 2023). This substantial output presents a direct opportunity to utilize locally sourced FFSB in poultry feed formulation. However, raw FFSB contains several anti-nutritional factors (ANFs), such as trypsin inhibitors, lectins, and saponins, which can compromise poultry growth performance, feed efficiency, and egg quality by

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interfering with protein digestion (Mishra et al., 2024). Heat treatment methods such as roasting, extrusion, and autoclaving have been used to deactivate ANFs, particularly the trypsin inhibitors that are sensitive to thermal processing (Macisaac et al., 2005; Senkoylu et al., 2005; Karimi et al., 2022).

Dry heating (roasting) provides a practical solution for Ethiopia, which often faces resource limitations and relies on smallholder production systems. This method entails low operational costs and requires minimal infrastructure, making it particularly suitable for these environments (Papanikou, 2020). Previous studies have indicated that heat-treated FFSB can be incorporated into layer diets at inclusion levels of 20-25%, resulting in optimal performance without adverse effects on laying hens (Senkoylu et al., 2005; Lázaro et al., 2006; Toomer et al., 2024b). However, its applicability in Ethiopia has not been thoroughly examined, given the variability in climatic conditions, feed management practices, and breed-specific responses. Additionally, the economic feasibility of incorporating roasted FFSB into layer feed formulations remains unassessed, hindering evidence-based decision-making for smallholder farmers and regional feed mills. Therefore, this study investigated the impact of varying dietary inclusion levels of roasted FFSB on egg production performance, egg quality characteristics, hematological indices, and serum cholesterol levels in Bovans Brown laying hens.

MATERIALS AND METHODS

Ethical approval

The animals were handled and cared for following welfare standards and experimental protocols approved by the College of Agriculture and Environmental Sciences Animal and Research Ethics Committee of Bahir Dar University, Ethiopia (Ref. No. 007-2025).

Laboratory chemical analysis and feed formulation

Raw soybeans were roasted in a metal pan over a wood fire and considered adequately processed when the beans reached the locally recognized golden-brown color. They were then cooled in open air at ambient temperature (23$^{\circ}C$) for 24 hours before being ground for feed preparation. Dry matter (DM), crude fiber (CF), total ash (TA), ether extract (EE), and crude protein (CP) were determined according to (AOAC, 2000). The Chemical compositions of the FFSB and SBM are presented in Table 1. The metabolizable energy (ME) was calculated according to the study of Wiseman (1987).

$$\text{ME (kcal/kgDM)} = 3951 + 54.4\,\text{EE} - 88.7\text{CF} - 40.8\,\text{ash}$$

Based on the laboratory analytical data results, five experimental diets were formulated with graded inclusion levels of FFSB at 0%, 10%, 15%, 20%, and 25% FFSB. The diet containing 20% SBM (0% FFSB) was used as a positive control treatment. All the experimental diets were formulated containing a minimum of 15% CP based on the NRC (1994) nutrient requirements for laying hens Table 2. Lysine and methionine were added to all diets to maintain consistent and adequate levels of these limiting amino acids, independent of the varying crude protein content.

Table 1. Chemical composition and calculated metabolizable energy (ME) of soybean meal and full-fat soybean (as-DM basis)

Chemical composition	Soybean meal	Full-fat soybean
Dry matter (%)	89.6	91.21
Crude protein (%)	38.47	32.89
Crud fiber (%)	5.84	8.25
Ether extract (%)	5.27	11.62
Ash (%)	3.06	1.86
ME (Kcal/kg DM)	3,594.83	3,775.57

Study design and management of experimental hens

The experiment was conducted at the Bahir Dar University poultry farm, Ethiopia, using 120 Bovans Brown laying hens aged 34 weeks with an average body weight of approximately 1.44 ± 0.01 kg. The hens were randomly allocated in a completely randomized design into five treatment groups (24 hens per treatment), each subdivided into three replicates of eight hens, and housed in pens (2 m² per pen) bedded with 5 cm of teff (*Eragrostis tef*) straw. The hens were allowed a one-week adaptation period to the experimental diets before data collection, which was carried out over a 12-week period. Ambient temperature (T°) and relative humidity (RH) were recorded daily using a digital thermo-hygrometer (Graph 1), and weekly average temperature-humidity index (THI) values were calculated (Zulovich and DeShazer, 1990).

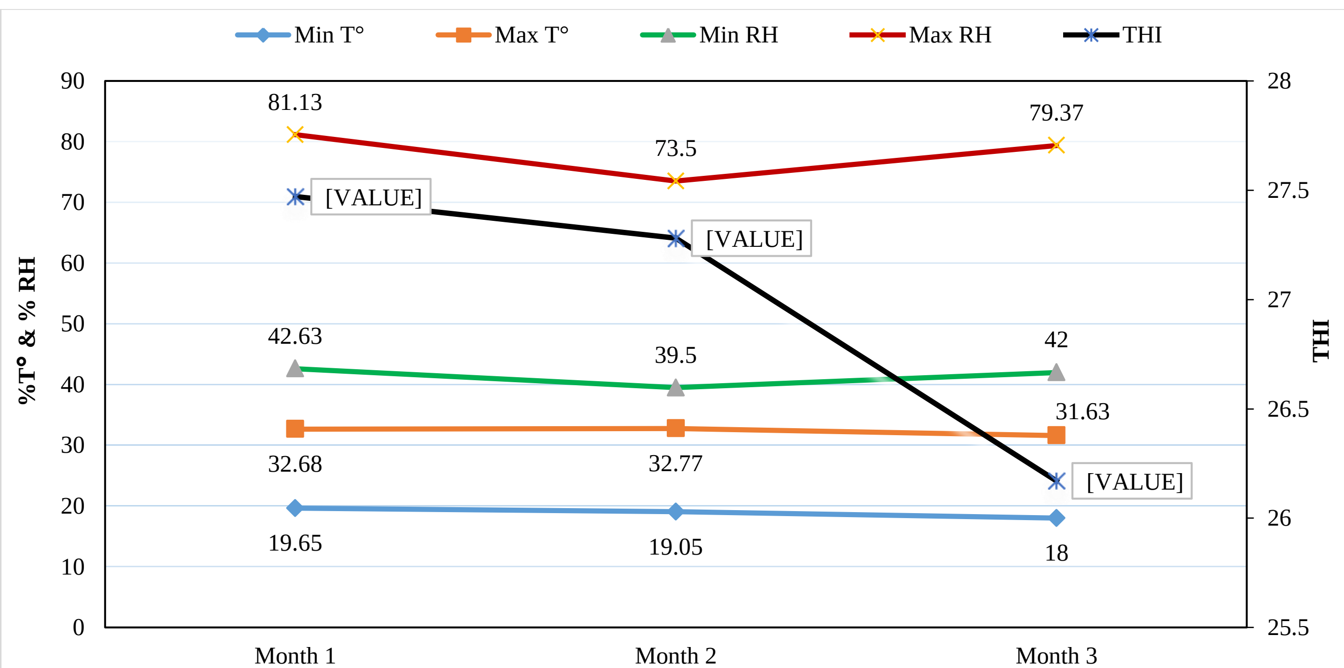
$$\text{THI layers} = 0.60\text{ T max} + 0.40\text{ T min}$$

The experiment was conducted under natural daylight conditions without artificial lighting, with the open-sided house allowing adequate sunlight and ventilation throughout the day (approximately 12-13 hours of light). All hens were vaccinated at the rearing farm before arrival against common poultry diseases such as Newcastle disease, infectious bursal disease, and fowl pox; hence, no additional vaccinations were administered during the study. Layers were inspected upon arrival to confirm health status and were monitored daily for health and behavior under standard hygiene and biosecurity practices. Feed and water were provided on a pen basis, with each pen equipped with its own feeder and drinker. Feed was offered twice daily (morning at 8:00 AM and afternoon at 2:00 PM), and refusals were collected and weighed the following day, while clean drinking water was supplied *ad libitum* throughout the experimental period.

Table 2. Ingredient proportions and chemical composition of dietary treatments for Bovans Brown layers (34-46 weeks of age)

Feed ingredient (%)	T1	T2	T3	T4	T5
White maize grain	54	55	50	50	50
Full-fat soybean	-	10	15	20	25
Soybean meal	20	-	-	-	-
Noug seed cake	11	20	20	15	10
Bone meal	4	4	4	4	4
Limestone	9	9	9	9	9
L-lysine-HCL	0.5	0.5	0.5	0.5	0.5
DL-Methionine	0.5	0.5	0.5	0.5	0.5
Vitamin and mineral Premix	0.5	0.5	0.5	0.5	0.5
Salt	0.5	0.5	0.5	0.5	0.5
Analyzed nutrients					
Dry matter (%)	91.04	92.29	92.03	92.33	92.16
Crude protein (%)	16.03	15.05	15.42	15.59	16.29
Crud fiber (%)	5.06	7.61	8.46	6.75	6.06
Ether extract (%)	1.29	3.96	5.70	6.28	7.08
Ash (%)	11.07	10.83	11.58	12.85	12.86
ME (Kcal/kg DM)	3,120.25	3,049.87	3,038.40	3,169.94	3,275.12

HCl: Hydrochloride salt form; T1: 0% FFSB; T2:10% FFSB; T3: 15% FFSB; T4: 20% FFSB; T5: 25% FFSB. Per kilogram of premix: Vitamin A: 6,000,000 IU; Vitamins B1: 3000 mg; Vitamins B2: 4000 mg; Vitamins B6: 3000 mg; Vitamins B12: 8 mg; Vitamins E: 40,000 mg; Vitamins K: 1200 mg; Niacin: 30 mg; Folic acid: 1000 mg; Biotin: 300 mg; Ca-pantothenate: 10,000 mg; Iron: 25 000 mg; Copper: 1200 mg; Manganese: 4000 mg; Zinc: 4000 mg; Iodine: 400 mg; Selenium: 30 mg; Cobalt: 200 mg.



Graph 1. Average minimum and maximum temperature (T°), average minimum and maximum relative humidity (RH), and temperature-humidity index (THI) during the three experimental months.

Production performance parameters

Daily feed intake (FI) per replicate was calculated as feed offered minus refusal. Body weight (BW) was measured individually at trial start and end, with body weight change (BWC) per replicate derived from initial and final differences. Eggs were collected twice daily per pen to record production, and the hen-day egg production (HDEP) rate was calculated as the average percentage per replicate (Hunton, 1995).

$$\text{HDEP (\%)} = \frac{\text{No of eggs collected per day}}{\text{No of hens present that day}} \times 100$$

Daily egg weight per replicate was measured immediately after collection, with average egg weight (EW) calculated as total weight divided by egg count. Egg mass (EM) per pen was determined using the formula published by North (1984). $\text{EM} = \text{HDEP (\%)} \times \text{EW}$

Feed conversion ratio (FCR) was calculated per replicate as total feed intake divided by total egg mass produced.

Egg quality parameters

A total of 30 eggs (six per treatment, two per replication) were randomly sampled at two-week intervals for quality analysis, with replicate means calculated from sample averages for each parameter. Eggs were weighed individually, then carefully cracked onto a flat tray, and the shells were separated and weighed. Shell thickness was measured using a digital caliper after removing the shell membranes, by taking readings at three points on each egg at the air cell (broad end), equator (middle portion), and sharp end. The mean value of these three measurements was recorded as the average shell thickness for each egg. Yolk color was assessed using a Roche color fan, while albumen and yolk heights were determined with a tripod micrometer. The Haugh unit (HU) for each replicate was then calculated using the formula described by Haugh (1937), where h is albumen height (mm), and W is the weight of the egg (g)

$$\text{HU} = 100 \log 10 \,(\text{h} + 7.57 - 1.7\text{w}0.37)$$

Measurements of blood parameters and economic analysis

At the end of the experiment, approximately 3 mL of blood was collected from the wing veins of 15 randomly selected hens (three hens per treatment). The hematology analysis was performed with an automated hematology analyzer (BC- 5800, Mindray, China) after blood samples were deposited in K3-EDTA heparinized tubes, and serum samples were analyzed for total cholesterol (COL), low-density lipoprotein (LDL), and high-density lipoprotein (HDL) after being separated by centrifuging (3,000 rpm, 15 minutes).

The economic viability of incorporating graded levels of roasted full-fat soybean (FFSB) into the diets of Bovans Brown layers was evaluated by calculating the net return per hen. The analysis followed the method of Upton (1979) for partial budget analysis, using feed formulation costs and local market egg prices. Total feed intake was multiplied by the corresponding ingredient costs to calculate feed cost:

$$\text{Feed cost/hen} = \text{Total Feed Intake(kg)} \times \text{cost of diet (USD/kg)}$$

To calculate egg revenue, the total egg output per hen was multiplied by the local market price of eggs in Bahir Dar, Ethiopia, during the time of the study.

$$\text{Income/ hen} = \text{Total egg produced} \times \text{price per egg (USD)}$$

Subsequently, the net return per hen was derived as the total egg revenue minus the total feed cost:

$$N\text{et retern/ hen} = \text{income per hen} - \text{feed cost per hen (USD)}$$

Statistical analysis

All data were analyzed by one-way analysis of variance (ANOVA) using the general linear model (GLM) procedure of SAS (version 9.4, SAS Institute Inc., Cary, NC), where a significant treatment effect was identified ($p < 0.05$). Treatment means were separated using the least significant difference (LSD) test according to the following model: $Yij = \mu + Ti + eij$

Where Yij is the response variable, μ is the overall mean, Ti is the fixed (feed) effect of the i^{th} dietary treatment (level of FFSB), and eij is the random error associated with the j^{th} observation (individual hen) within the i^{th} treatment.

RESULTS

Egg production performance

Hens fed the control diet exhibited significantly higher HDEP, egg mass, and body weight change compared with those fed diets containing roasted FFSB (Table 3; $p < 0.05$). Among the FFSB-fed groups, no significant differences were observed in mean HDEP or body weight change ($p > 0.05$). However, hens fed the 10% roasted FFSB diet produced a higher egg mass than those receiving 15% and 25% inclusion levels ($p < 0.05$), while the 20% group showed intermediate values that were not significantly different from either. A significant difference in FCR was observed among the treatment groups ($p < 0.05$), with hens fed the control diet showing the lowest FCR. As the level of roasted FFSB increased, the FCR gradually rose, with the 25% FFSB group exhibiting a numerically higher FCR than the 10-20% FFSB groups.

Egg quality

No significant differences ($p > 0.05$) were observed in most external and internal egg quality parameters among the treatment groups, except for eggshell weight and yolk color (Table 4). Eggshell weight was significantly higher in hens fed the 10% roasted FFSB diet compared with those on the control, 15%, and 20% FFSB inclusion levels ($p < 0.05$), while a slight improvement in yolk color was noted at the 25% FFSB inclusion level.

Blood analysis

Similarly, no significant differences were found in hematological parameters across dietary treatments. This included all measured white blood cell (WBC) counts (heterophils, lymphocytes, monocytes, eosinophils) and red blood cell (RBC) parameters (hemoglobin, hematocrit; $p > 0.05$). Total cholesterol, HDL, and LDL levels were also unaffected by increasing FFSB inclusion (Table 5; $p > 0.05$).

Economic analysis

The economic returns of FFSB inclusion in layer diets, evaluated using partial budget analysis based on egg sales and feed costs, are presented in Table 6. Hens fed the control diet achieved significantly higher net return compared with those fed diets containing roasted FFSB (Table 6; $p < 0.05$).

Table 3. Effect of full-fat soybean inclusion on egg production performance of Bovans Brown layer

Parameters	T1	T2	T3	T4	T5	SEM	P-value
HDEP (%)	89.72^{a}	63.57^{b}	57.03^{b}	57.27^{b}	57.81^{b}	3.451	<0.0001
Egg weight (g)	60.48^{a}	60.45^{a}	60.12^{ab}	60.52^{a}	57.43^{b}	0.454	0.1719
Egg mass (g/hen/day)	54.28^{a}	38.44^{b}	34.257^{c}	34.65^{bc}	33.14^{c}	2.157	<0.0001
Final BW (kg)	1.743^{a}	1.552^{b}	1.489^{b}	1.441^{b}	1.444^{b}	0.035	0.0107
Initial BW (kg)	1.429^{a}	1.446^{a}	1.439^{a}	1.437^{a}	1.427^{a}	0.012	0.9927
BWC (g)	314^{a}	106^{b}	49^{b}	4^{b}	17^{b}	0.036	0.0111
Feed intake (g/hen/day)	112.03^{a}	117.17^{a}	113.93^{a}	112.30^{a}	110.04^{a}	1.216	0.4789
FCR	2.06^{b}	3.07^{a}	3.34^{a}	3.27^{a}	3.37^{a}	0.139	0.0006

Means within the same rows with different $^{a\text{-}c}$ Superscripts are significantly different ($p < 0.05$). Whereas values with similar superscripts do not differ significantly ($p > 0.05$); T1: Control (20% SBM); T2: 10% FFSB; T3: 15% FFSB; T4: 20% FFSB; and T5: 25% FFSB inclusion level; SEM: Standard error of mean; HDEP: Hen-day egg production; BW: Body weight; BWC: Body weight change; FCR: Feed conversion ratio.

Table 4. Effect of full-fat soybean inclusion on egg quality parameters of Bovans Brown layer

Parameters	T1	T2	T3	T4	T5	SEM	P-value
Egg index	78.331^{a}	78.456^{a}	78.381^{a}	78.203^{a}	77.669^{a}	0.245	0.8554
Sample EW(g)	59.917^{a}	61.429^{a}	61.363^{a}	59.092^{a}	59.183^{a}	0.435	0.2964
Eggshell weight (g)	7.687^{c}	8.337^{a}	7.933^{bc}	7.787^{bc}	8.100^{ab}	0.075	0.0261
Eggshell thickness (mm)	0.357^{a}	0.360^{a}	0.352^{a}	0.352^{a}	0.362^{a}	0.003	0.6871
Albumen height (mm)	8.446^{a}	9.396^{a}	8.779^{a}	8.650^{a}	8.913^{a}	0.112	0.0965
Albumen weight (g)	36.754^{a}	38.613^{a}	38.558^{a}	36.858^{a}	36.613^{a}	0.374	0.2964
HU (%)	91.804^{b}	96.207^{a}	93.176^{ab}	93.072^{ab}	94.385^{ab}	0.537	0.1345
Yolk weight (g)	15.417^{a}	14.479^{a}	14.871^{a}	14.446^{a}	14.471^{a}	0.177	0.3380
Yolk index	0.462^{a}	0.472^{a}	0.479^{a}	0.469^{a}	0.472^{a}	0.003	0.3723
Yolk color	1.00^{c}	1.54^{b}	1.83^{ab}	1.83^{ab}	2.13^{a}	0.1205	0.0089

Means within the same rows with different $^{a\text{-}c}$ Superscripts are significantly different ($p < 0.05$). Whereas values with similar superscripts do not differ significantly ($p > 0.05$); T1: Control (20% SBM); T2: 10% FFSB; T3: 15% FFSB; T4: 20% FFSB; and T5: 25% FFSB inclusion level; SEM: Standard error of mean; EW: Egg weight; HU: Haugh unit.

Table 5. Effect of full-fat soybean inclusion on blood hematology and chemistry of Bovans Brown layer

Parameters	T1	T2	T3	T4	T5	SEM	P-value
WBC ($\times 10^3/\mu L$)	40.265^a	37.390^a	38.300^a	40.215^a	38.910^a	0.9058	0.9250
HT ($\times 10^3/\mu L$)	11.548^a	14.343^a	15.832^a	19.156^a	13.121^a	1.0682	0.2604
LYM ($\times 10^3/\mu L$)	26.114^a	20.017^a	20.392^a	19.631^a	23.791^a	1.2842	0.5736
MON ($\times 10^3/\mu L$)	0.4021^c	1.8707^a	1.3360^{ab}	0.6635^{bc}	0.9088^{bc}	0.1932	0.0533
EO ($\times 10^3/\mu L$)	2.201^a	1.122^a	0.741^a	0.764^a	1.089^a	0.3126	0.6783
RBC ($\times 10^6/\mu L$)	2.5700^a	2.4050^a	2.4950^a	2.5400^a	2.5650^a	0.0673	0.9763
HGB (g/dL)	8.850^a	8.400^a	8.150^a	8.750^a	8.450^a	0.3895	0.9927
HCT (%)	32.250^a	30.900^a	31.450^a	29.745^a	31.750^a	0.6878	0.8930
PLT ($\times 10^3/\mu L$)	5.500^a	7.500^a	5.500^a	8.000^a	11.500^a	1.3921	0.3906
HDL (mg/dL)	22.50^a	11.00^a	16.50^a	15.50^a	20.50^a	3.5895	0.9463
LDL (mg/dL)	33.50^a	23.00^a	28.50^a	39.50^a	40.50^a	6.2911	0.9175
COL (mg/dL)	131.00^{ab}	99.00^{ab}	76.50^b	134.50^a	100.00^{ab}	8.4719	0.1742

Means within the same rows with similar superscripts did not differ significantly (P > 0.05); T1: Control (20% SBM); T2: 10% FFSB; T3: 15% FFSB; T4: 20% FFSB; and T5: 25% FFSB inclusion level; SEM: Standard error of mean; WBC: White blood cell count; HT: Heterophil; LYM: Lymphocytes; MON: Monocytes; EO: Eosinophils; RBC: Red blood cell count; HBG: Hemoglobin; HCT: Hematocrit; PLT: Platelets; HDL: High-density lipoprotein; LDL: Low-density lipoprotein; COL: Cholesterol.

Table 6. Economic return of Bovans Brown layers fed graded levels of full-fat soybean

Variable	T1	T2	T3	T4	T5	SEM	P-value
Total egg (number/hen)	80.87^a	56.99^b	51.31^{bc}	47.19^c	51.41^{bc}	3.321	<0.0001
Total feed consumed (kg/hen)	10.08^a	10.55^a	10.25^a	10.11^a	9.91^a	0.109	0.4789
Total feed cost per head (USD)	3.52^a	3.41^{ab}	3.24^{bc}	3.16^{bc}	3.06^c	0.055	0.0217
Total return (USD)	6.53^a	4.60^b	4.14^{bc}	3.81^c	4.15^{bc}	0.268	<0.0001
Net return (USD)	3.00^a	1.19^b	0.90^b	0.65^b	1.09^b	0.233	0.0001

Means within the same rows with different $^{a\text{-}c}$ Superscripts are significantly different ($p < 0.05$). Whereas values with similar superscripts do not differ significantly ($p > 0.05$); T1: Control (20% SBM); T2: 10% FFSB; T3: 15% FFSB; T4: 20% FFSB; and T5: 25% FFSB inclusion level; SEM: Standard error of mean.

DISCUSSION

The inclusion of FFSB in the layer diet decreased the HDEP compared to the control group, though egg weight remained unaffected. These results align with earlier findings by de Faria et al. (1995), who reported that substituting SBM with 5 to 10% roasted FFSB in layer rations reduced egg-laying rates during 33-50 weeks of age, without altering egg weight. Karimi et al. (2022) demonstrated that replacing SBM with 25-100% roasted or autoclaved FFSB had no significant impact on average egg weight.

The observed disparity in egg production and body weight change between hens fed the control diet and those receiving varying levels of FFSB may stem from differences in nutritional composition (Table 1) and residual anti-nutritional factors (ANFs), particularly trypsin inhibitors (TI) that persist in FFSB even after processing. This interpretation is consistent with early findings by Ari et al. (2012) and Erdaw et al. (2016), who indicated that thermal processing methods significantly affect the nutritional quality and ANFs; roasting reduces TI content, yet residual TI levels remain higher than those in commercial SBM. Additionally, a recent large-scale analysis by Schulz et al. (2024), which evaluated 434 soybean meal samples globally, reported substantially higher TI levels in full-fat SBM (17.1 mg/g) compared to expeller (10.8 mg/g) and solvent-extracted SBM (5.1 mg/g), suggesting that incomplete TI inactivation during FFSB processing may impair nutrient utilization.

The inclusion of 10-25% roasted FFSB had no significant effect on egg production rate, consistent with the findings of Senkoylu et al. (2005), who observed that increasing FFSB inclusion up to 22% in layer diets did not adversely affect egg production between 33 and 42 weeks of age. However, hens fed the 10% FFSB diet produced a higher egg mass than those receiving 15% and 25% inclusion levels, which may be attributed to the increased presence of anti-nutritional factors (ANFs) at higher FFSB levels. Although hens fed diets containing 10-25% FFSB exhibited a lower body weight change than the control group, they maintained their initial body weight throughout the study, with no evidence of weight loss even at the highest inclusion level (25%).

In the present study, the control group exhibited a significantly lower FCR, attributed to its superior egg production performance. This finding aligns with findings by Ruiz et al. (2004), who also reported that feed conversion was more efficient in the SBM treatment than FFSB. In the current study, a numerical increase in FCR was observed with increasingly higher FFSB inclusion levels, although these differences were not statistically significant. This trend agrees with the findings of Karimi et al. (2022), who reported that replacing soybean meal with 25-100% roasted FFSB increased the FCR of Bovans White laying hens. Similarly, Senkoylu et al. (2005) observed better FCR performance at a lower inclusion level (10% FFSB) compared to higher levels (22% FFSB), suggesting that excessive FFSB inclusion may reduce feed efficiency.

The internal and external qualities of eggs are important measures in the poultry industry because of food safety and economic implications. Full-fat soybean inclusion in layer diet at levels ranging from 10% to 25% demonstrated minimal impact on overall egg quality, with no significant alterations observed in key parameters such as albumen height, haugh units, or shell thickness. However, eggshell weight was highest in hens fed the 10% FFSB diet, attributed to their relatively greater egg weight and thicker eggshells. Senkoylu et al. (2005) also reported that increasing the level of dietary FFSB inclusion up to 22% did not alter the external egg quality.

This study used blood tests to check the overall health of the hens. While both hematological and blood chemistry values were in normal range across the different diets, WBC counts exceeded the reference ranges of 12-30 $\times 10^3/\mu L$ (Bounous and Stedman, 2000). This elevation likely reflects the hen's exposure to tropical heat stress and may represent a compensatory response to counteract pathogen invasion, which is exacerbated by heat-induced compromised immunity (Hassan et al., 2023).

Feed costs per hen were lowest in the highest FFSB inclusion level (25%) and highest in the control group (20% SBM), reflecting that FFSB is a cheaper alternative ingredient in the layer diet. However, higher egg production in the control group resulted in the greatest total return ($6.53) and net return($3.00), indicating that savings in feed cost in 15-25%FFSB inclusion levels did not compensate for reduced productivity. Overall, these results highlight that while feed cost reduction is possible, maintaining optimal nutrient density is critical for maximizing egg production and economic profitability.

CONCLUSION

The inclusion of roasted full-fat soybean (FFSB) in layer diets influenced productivity and efficiency, but its benefits were limited at higher inclusion levels. Although egg weight and quality parameters remained largely unaffected, increasing levels of FFSB led to a reduction in hen-day egg production and feed efficiency compared to the control diet. These outcomes likely stem from the presence of residual anti-nutritional factors, particularly trypsin inhibitors that persist despite thermal processing and may impair nutrient utilization. Hens fed diets containing up to 25% roasted FFSB maintained stable body weight and normal hematological and biochemical profiles, indicating no adverse health effects. Economically, although feed costs decreased with increasing FFSB inclusion, the reduction in egg production offset these savings, resulting in lower overall net returns. Consequently, even though FFSB may appear fairly similar to SBM as a layer feed ingredient, its full substitution for SBM proved financially unprofitable, highlighting SBM's continued dominance in cost-efficient formulation. It is suggested that future studies investigate alternative locally applicable processing methods, such as cooking or fermentation, to more effectively deactivate ANFs in FFSB and thereby minimize its performance gap compared to soybean meal.

DECLARATIONS

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Authors' contributions

All authors contributed to the study conception and design. Yemsrach Yimer conducted material preparation, data collection, and analysis, and drafted the initial manuscript. Firew Tegegne and Solomon Demeke collaborated on the critical review and editing. All authors read and approved the final manuscript.

Competing interests

The authors declare that they have no competing interests.

Availability of data and materials

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

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Ethical considerations

All authors have ensured compliance with ethical standards, including checks for plagiarism, publication consent, research misconduct, data fabrication or falsification, duplicate publication or submission, and redundancy. The authors confirmed they have not assisted the AI in conducting the present study and preparing the present article.

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