Impact of Solid-State Fermented Wheat Offal Inclusion on Egg Production and Quality in ISA Brown Hens Under Semi-Arid Conditions

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Abstract

This experiment was conducted to determine the influence of solid-state fermented wheat offal (SSFWO) on the productive indices and egg quality traits of egg-type chickens using 180 ISA brown chickens aged 0 – 42 weeks. The chickens were divided into six (6) treatment units of thirty birds with three replications of ten birds each following a completely randomized design (CRD). For the chick (0 – 8 weeks); grower (9-16 weeks) and layer (30 - 42 weeks) stages, SSFWO was used to formulate six diets, which were included at 0, 5, 10, 15, 20 and 25% of the diets. The results of the study showed an increase ($P \leq 0.05$) in feed consumption, declining daily weight gain and final weight of the birds as the level of SSFWO increases at both chick and grower phases. Groups on the T_1 (0% SSFWO) had a lower cost per gain than the groups fed 5-25% SSFWO. Hens on 25% SSFWO diet had delayed onset of lay. Feed consumption and feed conversion ratio were highest ($P \leq 0.05$) in chickens on T_6 (25% SSFWO). The group also had lower ($P \leq 0.05$) hen-day egg production. Egg length, egg width, yolk height and width decreased while albumen weight and Haugh unit showed an increasing trend as the level of SSFWO advances. It was concluded that dietary SSFWO had no detrimental effect on productive performance and egg quality characteristics of egg-type chickens

Keywords: Growth traits, laying performance, egg quality, cost-benefit

Introduction

Poultry farming in semi-arid regions often faces unique challenges due to the limited availability of conventional feed ingredients and the high cost of imported alternatives (Eeswaran et al., 2022; Pius et al., 2021). Feed accounts for a significant portion of total production costs in poultry farming, particularly in these resource-scarce environments (Yu et al., 2024). To address these issues, there is growing interest in exploring locally available, cost-effective feed options that can sustain and even enhance poultry productivity (Bist et al., 2024). One such option is wheat offal—a by-product of the wheat milling process, which is commonly available but underutilized in poultry diets due to its lower digestibility and nutrient bioavailability in its raw form.

Solid-state fermentation (SSF) has emerged as a promising technique to enhance the nutritional profile of agricultural by-products, including wheat offal (Cano y Postigo et al., 2021; Javourez et al., 2022; Vandenberghe et al., 2021; Verduzco-Oliva & Gutierrez-Uribe, 2020). SSF involves the growth of beneficial microorganisms, such as fungi and bacteria, on a solid substrate, leading to an increase in bioavailable nutrients, improved digestibility, and the breakdown of anti-nutritional factors (Betchem et al., 2024; Feng et al., 2023; Vandenberghe et al., 2021; Wang et al., 2023). Fermentation processes also enrich the substrate with microbial proteins and bioactive compounds that can promote poultry health and potentially improve production outcomes (Ab et al., 2019; Sadh et al., 2018; Saeed et al., 2024).

The ISA Brown egg-type chicken, known for its high egg production and adaptability, provides an ideal model for testing alternative dietary strategies under the stressors common in semi-arid environments (Besbes et al., 2007; Simianer, 2000). Previous research has shown that ISA Brown chickens can adapt to a range of dietary changes (Franco et al., 2020; Nathaniel et al., 2022; Okedere et al., 2020); however, studies examining their response to SSF-treated feed additives in semi-arid climates remain limited. Given the environmental and nutritional stressors of these regions, the impact of such dietary modifications on production efficiency, egg quality, and general health in ISA Brown chickens warrants thorough investigation.

This study aims to assess the response of ISA Brown egg-type chickens to diets supplemented with solid-state fermented wheat offal, focusing on their growth performance, egg production, and health indicators in a semi-arid environment. By evaluating the effects of SSF wheat offal as a feed ingredient, the study seeks to contribute to sustainable feeding practices that may reduce costs and reliance on imported feed components in semi-arid poultry farming. The findings are expected to provide valuable insights into the potential of SSF wheat offal as a viable, locally sourced feed ingredient for enhancing the efficiency and sustainability of egg production in resource-limited settings.

Materials and Methods

Experimental site

The experiment was carried out at the poultry unit of the University of Maiduguri Teaching and Research Farm, Maiduguri, Nigeria.

Experimental birds and management

The study was carried out in two stages. The first stage was conducted using egg-type chickens at 0 – 16 weeks while the second stage involved layer chickens at 30 – 42 weeks. For both stages, 180 ISA brown chickens were used. The chickens were managed on a deep-litter floor from

0-16 weeks and thereafter transferred to battery cages. All necessary husbandry operations were duly observed during the study. The experiment was carried out by the Animal Welfare Act and does not infringe on animal rights. The chickens were vaccinated against common endemic diseases such as Gumboro, Newcastle Disease and Fowl pox.

Experimental diets and design

Fresh rumen content was collected from slaughtered cattle, it was manually squeezed through a mesh. The filtrate was collected and immediately used to inoculate wheat offal on a weight to weight basis. The inoculated wheat offal was compressed into plastic drums and allowed to ferment anaerobically for two weeks after which the content was emptied and allowed to sundry for three days. This was referred to as solid-state fermented wheat offal (SSFWO). Six diets were formulated for the chick, grower and layer stages with the inclusion level of SSFWO at 0, 5, 10, 15, 20 and 25%. These were designated as T_1 (0% SSFWO), T_2 (5% SSFWO), T_3 (10% SSFWO), T_4 (15% SSFWO), T_5 (20%) and T_6 (25% SSFWO), respectively. The birds were weighed and divided into six (6) groups. Each group consisted of thirty birds with three replications of ten birds each following a complete randomised design (CRD). Feed and water were administered ad libitum throughout the experimental period. The composition of the experimental chick, grower and layer diets are presented in Tables 1, 2 and 3.

Data collection

For the chick and grower stages, the following parameters were measured for each replicate as follows;

Feed intake (FI); This was determined by deducting leftovers from the initial feed given. Body weight gain (BWG); BWG was obtained by deducting the live weight of the previous week from the live weight of the present week. Feed conversion ratio (FCR); FCR was calculated by dividing FI by the BWG. Cost-per-gain analysis; The cost of feed per kg was obtained by collating the prices of individual feed items used in preparing the diets. Cost-per-gain was computed as a product of feed cost by FCR.

The following parameters were measured per replicate for the layer experiments according to Sekeroglu et al. (2014). Age at point of lay: this was determined at the time the pullets drop their first egg.

Hen day egg production (HDEP):

$$HDEP = \frac{Number\ of\ egg\ laid\ in\ a\ day}{Number\ of\ hens\ that\ are\ alive\ on\ the\ day} \times 100$$

Hen-housed egg production (HHEP):

$$HHE = \frac{number\ of\ laid\ eggs\ \ per\ day}{number\ of\ chickensat\ inception\ of\ experiment} \times 100$$

Egg mass = Total number of eggs produced × average weight of the egg

$$FCR = \frac{Quantity\ of\ feed\ consumed}{Quantity\ \ of\ egg\ produced}$$

Table 1. Composition of the experimental chick diets

Ingredients (%)	Level of rumen filtrate fermented wheat offal (SSFWO) inclusion (%)					
	T_1(0)	T_2(5)	T_3(10)	T_4(15)	T_5(20)	T_6(25)
Maize	45.00	45.00	45.00	45.00	45.00	45.00
Groundnut cake	27.00	26.00	25.00	24.00	23.00	19.50
SSFWO	00.00	05.00	10.00	15.00	20.00	25.00
Wheat offal	19.00	15.00	11.00	07.00	03.00	01.00
Fish meal	05.00	05.00	05.00	05.00	05.00	06.00
Bone meal	03.00	03.00	03.00	03.00	03.00	03.00
NaCl	00.30	00.30	00.30	00.30	00.30	00.30
*Premix	00.40	00.40	00.40	0.400	00.40	00.40
Lysine	00.10	00.10	00.10	00.10	00.10	00.10
Methionine	00.20	00.20	00.20	00.20	00.20	00.20
Total	100.0	100.0	100.0	100.0	100.0	100.0
Proximate composition						
Crude protein	20.86	20.70	20.10	20.09	19.50	18.93
Ether extract	6.13	5.91	5.65	5.34	5.46	5.46
Crude fiber	7.90	7.69	7.20	6.97	6.85	6.61
Ash	6.59	9.68	10.4	11.77	13.6	13.91
Energy	2884.06	2836.26	2866.86	2875.76	2850.39	2778.95

*Premix (Composition per kg diet): Vitamin. A (IU.) 2,800,000; Vitamin E (mg) 16,000; Vitamin. K (mg) 800; Vitamin. B_1 (mg) 1,200; Vitamin. B_2 (mg) 1,600; Vitamin. B_6 E.E4 (mg) 30; Folic Acid (mg) 0.4; Niacin (mg) 20,000; Panthotenic acid (mg) 4,400; Co (mg) 120; Cu (mg) 3,200; I (mg) 600; Se (mg) 48; Zn (mg) 24,000; Fe (mg) 16,000; Mn (mg) 40,000; Choline Cl (mg) 120,000; Antioxidant (mg) 48,000.

Table 2. Composition of the experimental grower diets

Ingredients (%)	Level of rumen filtrate fermented wheat offal (SSFWO) inclusion (%)					
	T_1(0)	T_2(5)	T_3(10)	T_4(15)	T_5(20)	T_6(25)
Maize	45.00	45.00	45.00	45.00	45.00	45.00
Groundnut cake	27.00	26.00	25.00	24.00	23.00	19.50
SSFWO	00.00	05.00	10.00	15.00	20.00	25.00
Wheat offal	19.00	15.00	11.00	07.00	03.00	01.00
Fish meal	05.00	05.00	05.00	05.00	05.00	06.00
Bone meal	03.00	03.00	03.00	03.00	03.00	03.00
NaCl	00.30	00.30	00.30	00.30	00.30	00.30
*Premix	00.40	00.40	00.40	0.400	00.40	00.40
Lysine	00.10	00.10	00.10	00.10	00.10	00.10
Methionine	00.20	00.20	00.20	00.20	00.20	00.20
Total	100.00	100.00	100.00	100.00	100.00	100.00
Proximate composition						
Crude protein	18.41	18.18	17.44	17.44	17.40	17.80
Ether extract	6.57	5.22	5.73	5.94	5.39	5.56
Crude fiber	5.93	8.39	7.39	8.23	8.13	7.88
Ash	9.03	8.79	8.85	8.92	9.52	9.26
Energy	2875.54	2723.78	2732.44	2721.68	2715.6	2737.98

*Premix contained per kg: vitamins: A 4000000 UI, D_3 800000 UI, E 2000 mg, K 800 mg, B_1 600 mg, B_2 2000 mg, niacin 3600 mg, B_6 1200 mg, B_{12} 4 mg, and choline chloride 80000 mg; minerals: Cu 8000 mg, Mn 64000 mg, Zn 40000 mg, Fe 32000 mg, and Se 160 mg

Table 3. Composition of the experimental layer diets

	Level of rumen filtrate fermented wheat offal (SSFWO) inclusion (%)					
Ingredients (%)	T_1(0)	T_2(5)	T_3(10)	T_4(15)	T_5(20)	T_6(25)
Maize	48.00	48.00	48.00	49.00	49.00	49.00
Groundnutt cake	22.00	21.00	19.00	18.00	16.00	15.00
SSFWO	00.00	05.00	10.00	16.00	20.00	25.00
Wheat offal	21.00	17.00	14.00	08.00	05.00	00.50
Fish meal	04.00	04.00	04.00	04.00	05.00	05.00
Bone meal	03.00	03.00	03.00	03.00	03.00	03.00
Nacl	00.30	00.30	00.30	00.30	00.30	00.30
Min- Vit premix	00.40	00.40	00.40	0.400	00.40	00.40
Lysine	00.10	00.10	00.10	00.10	00.10	00.10
Methionine	00.20	00.20	00.20	00.20	00.20	00.20
Palm oil	01.00	01.00	01.00	01.00	01.00	01.50
Total	100.00	100.00	100.00	100.00	100.00	100.00
Proximate composition						
Crude protein	18.07	18.39	18.58	18.8	18.85	19.07
Ether extract	6.16	6.16	6.25	6.3	6.25	6.22
Crude fiber	7.66	8.45	7.55	6.97	7.27	7.1
Ash	5.66	6.09	5.66	5.49	5.57	5.58
Energy	2876.7	2840.47	2884.4	2908.98	2895.93	2899.55

*Premix provided per 1 kg of diet: vitamin A, 10,000; vitamin D_3, 3,000 IU; vitamin E, 50 IU; vitamin K_3, 2 mg; vitamin B_1; vitamin B_2, 4 mg; vitamin B_6, 1.5; vitamin B12, 0.01 mg; Ca-pantothenate, 8 mg; niacin, 25 mg; folic acid, 0.5 mg; choline chloride, 250 mg; manganese, 100 mg; zinc, 50 mg; iron, 50 mg; copper, 8 mg; iodine, 0.8 mg; selenium, 0.2 mg; cobalt, 0.2 mg.

Parameters such as egg weight, albumen and yolk weight were determined with the aid of a sensitive electronic top weighing balance (Kerro- BLC 20001*0.1g). Egg, albumen, and yolk length, width and egg-shell thickness were measured using a digital Vernier caliper (Rider®). Egg shape index: - This was measured as the proportion of the width to length of the egg. Albumen index: was measured as the ratio of the height to the width of the albumen while the yolk index was calculated as the proportion of yolk height to width of the yolk.

Haugh unit (HU): - This was determined as:

$$HU = 100log\,[H + 7.57 - (1.7W0.37)]$$

Where;
H= albumen height
W= egg weight

Specific gravity: This was determined by serially immersing the eggs in eight (8) salt solutions of varying concentrations; the solution where the egg floats, was its specific gravity.

Statistical analysis

Record generated was analyzed using statistical analysis software (SAS, version 9.4). Significant differences were separated using the Duncans Multiple Range Test.

Results and discussion

Effect of solid-state fermented wheat offal on the productive performance of egg-type chickens (0-16 weeks)

The impact of solid-state fermented wheat offal (SSFWO) on the productive performance of egg-type chickens (0-16 weeks) is shown in Table 4. Daily feed intake, body weight gain and final weight were affected significantly ($p \leq 0.05$). No effects ($p > 0.05$) were, however, found in the feed conversion ratio at the chick phase.

At the chick stage, groups fed T_6 (25% SSFWO diet) recorded the highest ($p \leq 0.05$) feed consumption. The value recorded for the chickens given T5 (20% SSFWO) was comparable to the value noted for the birds fed T_2 (5% SSFWO). Additionally, the number was comparable to those observed among chickens fed T_1 and T_4 (0 and 15% SSFWO diets). The hens on T_3 10% SSFWO had the lowest ($p \leq 0.05$) daily feed intake.

At the grower phase, groups on T_6 (25% SSFWO) also had the highest DFI. Values observed for chickens on T_1 and T_2 (0 and 5% SSFWO) were similar to the values found in the 25% SSFWO group. The lowest DFI (51.98g) was recorded in the group fed T_3 (10% SSFWO) diet. Groups on T_4 and T_5 (15 and 20% SSFWO) had similar values to the T_3 (10% SSFWO) group. Very high DFI in groups on T_6 (25% SSFWO) at both chick and grower stages could be a result of an adjustment to obtain the necessary energy required for optimum performance as chickens generally eat to satisfy their energy needs. The observation could also be related to the low energy value of the SSFWO which became more pronounced at the 25% inclusion level which is beyond the tolerable threshold. Observations made in this study align with the account of Efrem et al. (2016) who showed higher feed consumption in pullets fed graded levels of rumen content. Elmasry et al. (2017) and Lawal et al. (2012) also reported an increase in feed consumption as the level of fermented wheat offal and rice offal increases in broiler chickens. DFI values found at the chick (27.54 - 35.56 g) and grower (51.98 - 59.10 g) stages are lower than the 34.92 – 40. 25, 64.29 - 80.00g and 79.00 - 85.33g reported by Manshop, (2011) and Dim et al. [2022] in chickens on graded levels of palm kernel cake. The authors (Abdulazeez et al., 2023) also had similar observations in their experiment with SSFWO in broiler chickens at the starter phase. Lower feed intake observed in this study could be a result of the dark colouration of the test material which might have discouraged feeding, especially at the early stage of life. This might also be because the gastrointestinal tract is still developing and cannot fully degrade the increased concentration of SSFWO at the chick and grower stages of life. Daily weight gain (DWG) appeared to increase as the level of SSFWO increased. At the chick phase, chicks on the T_1 (control) diet had the highest DWG (10.12g). The values found in groups on T_2 (5% SSFWO) are comparable to the values observed in the control group. Chickens on 5% SSFWO also, had a gain that was similar to those

Table 4. Effect of solid-state fermented wheat offal (SSFWO) on productive performance of egg-type chickens (0- 16 weeks)

Parameters	Treatments/ Level of SSFWO inclusion (%)						SEM
	T_1 (control)	T_2 (5)	T_3 (10)	T_4 (15)	T_5 (20)	T_6 (25)	
Chick phase (0–8 weeks)							
Initial Weight (g)	29.77	29.68	29.85	29.94	29.57	29.68	0.25^{ns}
Daily feed intake(g/b)	31.14^{b}	30.05^{bc}	27.54^{d}	30.98^{bc}	29.22^{c}	35.56^{a}	0.18*
Daily weight gain (g/b)	10.12^{a}	9.87^{ab}	9.08^{bc}	9.55^{b}	8.93^{bc}	8.54^{c}	0.13*
Feed conversion ratio	3.08	3.05	3.04	3.25	3.30	4.17	0.06^{ns}
Final weight (g)	596.48^{a}	581.91^{a}	538.23^{ab}	564.56^{bc}	529.12^{bc}	507.18^{c}	7.06*
Grower phase (9-16 weeks)							
Daily feed intake (g)	54.35^{ab}	56.39^{ab}	51.98^{c}	54.58^{bc}	52.00^{c}	59.10^{a}	0.47*
Daily weight gain (g)	18.59^{a}	16.89^{a}	13.44^{b}	14.11^{b}	13.89^{b}	12.69^{b}	0.33*
Feed conversion ratio	2.91^{c}	3.34^{bc}	3.87^{ab}	3.86^{ab}	3.74^{ab}	4.65^{a}	0.08*
Final weight (kg)	1.63^{a}	1.54^{a}	1.26^{b}	1.32^{b}	1.28^{b}	1.21^{b}	28.06*

$^{a,b,\ c}$ Means on the same row having different superscripts are significantly different (P≤0.05); ns = not significantly different (p>0.05); SEM: Standard Error of Mean,

of T_3, T_4 and T_5 (10, 15 and 20% SSFWO)groups. The least DWG was observed in chickens on T_6 (25% SSFWO diet) which was comparable to the observation made in groups on T_3, T_4 and T_5 (10, 15 and 20% SSFWO) diets. This observation could indicate that the performance of the chicks fed up to 25% dietary SSFWO was comparable to that of the control and 5% SSFWO groups. For the grower stage, DWG in chickens fed T_3, T_4, T_5 and T_6 (10, 15, 20 and 25% SSFWO) was comparable and lesser than values (18.59 and 16.89g) observed in groups fed T_1 and T_2 (0 and 5% SSFWO) diets. Lower DWG in the groups on 10 – 25% SSFWO diets could be that the test material diluted the nutritional concentration of the diets such that the birds could not adequately meet their requirement. The results of this experiment are similar to those of Efrem et al. (2016) who also revealed a decrease in weight gain in pullets on varying levels of rumen content indicating the fibrous nature of the rumen content.

At the grower stage, the feed conversion ratio (FCR) significantly ($P \leq 0.05$) increased as the level of SSFWO increased. Groups fed T_6 (25% SSFWO) had the highest FCR that was comparable to what was observed in groups on T_3 – T_5 (10 – 20% SSFWO) diets. Chickens on T_1 (control) had the lowest FCR that was comparable to values recorded for groups on T_2, T_3 and T_4 (5, 10 and 15% SSFWO) diets. Increased FCR as SSFWO increases could be a result of high feed consumption and low DWG recorded for chickens on the SSFWO diet relative to the T_1 (0% SSFWO) groups. Similarly, the observation could indicate that pullets fed up to 20% SSFWO diet performed as well as those on 5% SSFWO and the control diet.

The final body weight decreased with an increase in dietary SSFWO. At the chick phase, chickens on the T_1 (0 % SSFWO) had the heaviest final body weight. The value was, however, comparable to the values observed in groups on T_2 and T_4 (5 and 15% SSFWO) diets. Groups on T_6 (25% SSFWO) had the least final weight, the value was also comparable to the observed in groups fed 10 and 20% SSFWOdiets. This could infer that the chicks tolerated 15% SSFWO without a negative effect on final weight.

For the grower phase, pullets fed diets containing 10– 25% SSFWO diets had values that were lower than values found in pullets on 0 and 5% SSFWO. This mirrors the pattern of daily feed intake and weight gain. Observations of this study concur with the report of Efrem et al. (2016) and Manshop, (2011) that showed decreasing final weight in pullets fed graded levels of rumen content and palm kernel cake in diets. Low final weight in groups fed increased SSFWO levels might be related to the low BWG recorded in the groups. Lighter weight at this stage in layers is an advantage because of the negative effect of excessive weight on egg production.

Cost-per-gain analysis of egg-type chickens fed dietary solid-state fermented wheat offal (SSFWO)

Results of the cost-per-gain analysis of egg-type chickens fed diets containing SSFWO are shown in Table 5. The daily feed intake and total feed intake (TFI) trailed similar patterns. For both chick and grower stages, the highest TFI was noted in chickens fed the T_5 (25% SSFWO) diet while the lowest intake was observed in the group on the 10% SSFWO diet. For the grower stage, the control group had a value that was comparable to values observed in groups given T_2 - T_4 (5 to 20% SSFWO) diets.

Feed cost at the chick stage was lowest in groups fed 15% SSFWO diet followed by those on 25% SSFWO. At the grower phase, feed cost was lower in the groups on T_6 (25% SSFWO) compared to the control, indicating that dietary SSFWO reduced feed cost in egg-type chicken.

At both chick and grower stages, total feeding cost (TFC) was higher in chickens on T_6 (25% SSFWO diet). Hens fed T_3 and T_5 (10 and 20% SSFWO) diets had the lowest TFC value. Total weight-gain TWG followed a similar pattern with daily weight gain. It showed a decreasing trend with an increase in the SSFWO inclusion level. At both chick and grower stages, the lowest TWG value was recorded in chickens on T6 (25% SSFWO) while the heaviest TWG was observed in chickens on the T_1 (control)

Table 5. Cost-per-gain analysis of egg-type chickens fed diets containing solid-state fermented wheat offal (SSFWO)

Parameters	Treatments/ Level of SSFWO inclusion (%)						SEM
	T$_1$(Control)	T$_2$ (5)	T$_3$ (10)	T$_4$ (15)	T$_5$ (20)	T$_6$ (25)	
Chick phase							
Initial Weight (g)	29.77	29.68	29.85	29.49	29.57	29.68	0.25^{ns}
Total feed intake (kg)	1.74^{b}	1.68^{bc}	1.54^{d}	1.73^{b}	1.63^{c}	1.99^{a}	10.04
Total weight gain (g)	566.53^{a}	552.56^{ab}	508.48^{abc}	534.80^{abc}	499.89^{bc}	478.05^{c}	7.23^{*}
Feed cost/kg (₦)	244.35	244.40	244.45	237.70	244.55	243.65	------
Total Feeding cost (₦)	426.56	411.53	376.93	412.57	400.83	485.43	-------
Cost per gain (₦/kg)	754.66	744.18	741.46	771.58	807.66	1014.66	------
Grower phase							
Total feed intake (kg)	3.04^{bc}	3.16^{ab}	2.91^{c}	3.06^{ab}	2.91^{c}	3.31^{a}	26.85^{*}
Total weight gain (g)	1040.92^{a}	945.76^{a}	752.46^{b}	790.11^{b}	778.04^{b}	710.79^{b}	18.07^{*}
Feed cost/kg (₦)	274.83	276.75	274.25	276.85	274.35	269.38	------
Total Feeding cost (₦)	835.48	874.53	797.34	847.16	798.36	890.39	------
Cost per gain (₦/kg)	800.25	921.84	1061.35	1051.55	1065.35	1256.61	------

$^{a,b,\ c}$ Means on the same row having different superscripts are significantly different ($p \leq 0.05$); SEM: Standard Error of Mean, ns = not significantly different ($p > 0.05$), --- not statistically analyzed

diet. Earlier experiments with broiler chickens by Abdulazeez et al. (2023) revealed lower TWG in chickens on T$_5$ and T$_6$ (20 and 25% SSFWO) diets. Lower TWG in the groups on increased SSFWO diets is desirable in pullets to avoid excess adipose tissue deposition which is detrimental to future laying performance.

Cost-per-gain (CPG) followed a similar trend with FCR. It increased as the level of SSFWO increased. For both chick and grower stages, CPG values in chicks fed 10% and 0% SSFWO diets were the lowest, while the highest CPG was noted for chickens in the 25% SSFWO diet group. The result of this investigation concurs with Alade, (2018) who showed higher CPC in broiler chickens treated with 50% untreated sawdust. Observation made by Augustine et al. (2019) also showed higher CPG in chickens fed Senna obtusifolia seed meal-based diets and related it to poor nutrient utilization resulting in a slow growth rate and more expenditure on feeding. Earlier experiments with broiler chickens by Abdulazeez et al. (2023) revealed higher CPG for chickens on increased levels (15 - 25%) of SSFWO diets at the starter phase. Increased CPG as SSFWO level increased could be related to increased FCR noted for the chickens on the SSFWO groups and similarity in feed cost with the control group.

The similarity between the T_1 (control) and the groups fed T_2 – T_5 (5 - 20% SSFWO) diets in terms of feed cost, total feeding cost and cost-per-gain (chick phase) suggests that the control diet had no superiority to the SSFWO diet groups and that SSFWO could be included up-to 20% level in the diet with no detrimental influence on the performance of ISA brown chickens at the chick and grower phases.

Effect of solid-state fermented wheat offal (SSFWO) on productive performance of laying chickens (30 – 42 weeks)

The effect of SSFWO on the productive performance of layer chickens is shown in Table 6. Age at first lay, feed intake, feed conversion ratio and hen-day egg production were significantly affected ($P \leq 0.05$) while the weight of the egg, egg mass and hen-housed egg production (HHEP) were not significantly ($P > 0.05$) affected.

Chickens on T_1, T_2, T_3 and T_5 (control, 5, 10 and 20% SSFWO) diets had similar and earlier onset of lay than chickens on T_6 (25% SSFWO). Chickens on the T_4 (15% SSFWO) diet came into lay in about 143.67 days which was comparable to the period recorded for T_1 (control) and chickens fed T_2 - T_6 (5 – 25% SSFWO). Results from this trial are similar to the report of Jesuyon (2017)] who observed that layers that consumed less feed to the first egg recorded shorter days, while those that consumed more feed took longer days to onset of lay. Increased feed intake was observed in chickens on increased SSFWO levels and they recorded a later onset of lay. Delay in the onset of lay and increased feed intake might also be a result of the nutrient density of the diets. It was earlier observed that the grower diet containing 25% SSFWO had lower CP and ME values compared to the control diet. Thus, groups with increased SSFWO levels consumed more feed to meet their nutritional requirement. Therefore, 25% SSFWO could be used to delay the onset of lay in precocious pullets.

Daily feed intake (DFI) showed an increasing trend with increasing levels of dietary SSFWO. Groups on the T_6 (25% SSFWO) diet had the highest ($P \leq 0.05$) DFI which was comparable to values recorded in groups on the T_2 and T_5 (5 and 20% SSFWO). The values observed for the later groups were also similar to values recorded for chickens on the control diets. The increase in feed intake in chickens on the SSFWO diets could be a result of the fibrous nature of the test material which could dilute the energy level of the diet.

Higher ($p \leq 0.05$) FCR was observed for chickens on T_3, T_5 and T_6 (15, 20 and 25% SSFWO) diet. Values recorded for chickens on T_2 and T_5 (5 and 20% SSFWO

Table 6. Productive performance and cost-benefit analysis of laying hens fed solid-state fermented wheat offal (SSFWO)

Treatments	Level of SSFWO inclusion (%)						SEM
	T$_1$ (0)	T$_2$ (5)	T$_3$ (10)	T$_4$ (15)	T$_5$ (20)	T$_6$ (25)	
Productive parameters							
Onset of lay (days)	139.67^{b}	140.33^{b}	140.67^{b}	143.67^{ab}	140.33^{b}	146.33^{a}	1.53*
Daily feed intake	117.34^{b}	129.65^{ab}	139.16^{a}	142.75^{a}	136.03^{ab}	144.70^{a}	2.48*
Egg weight (g)	53.83	52.31	52.37	53.43	54.11	53.69	0.46^{ns}
FCR	2.19^{b}	2.48^{ab}	2.76^{a}	2.67^{a}	2.56^{ab}	2.80^{a}	0.05*
Egg mass (g)	43.28	47.39	49.58	48.24	47.49	49.20	0.91^{ns}
HDEP (%)	69.90^{a}	67.41^{ab}	63.62^{ab}	66.52^{ab}	61.09^{b}	61.89^{b}	0.87*
HHEP (%)	61.68	57.37	58.03	63.48	57.12	59.43	0.83^{ns}
Cost-per-gain analysis							
Feed cost (N/kg)	280.47	279.98	280.27	285.08	288.28	290.78	
Total fee intake (kg)	10.27	11.31	12.11	12.41	11.84	12.57	
Total feeding cost (N)	2888.53	3177.95	3318.91	3539.47	3410.30	3649.65	
Cost per gain (N/kg)	616.02	712.77	750.69	777.79	733.26	818.59	

$^{a, b, c}$ Means on the same row having different superscripts are significantly different ($p \leq 0.05$) SEM: Standard Error of Mean, Hen housed egg production (HHEP), Hen day egg production (HDEP); FCR; Feed conversion ratio

diets were, however, comparable ($p \leq 0.05$). Chickens on T$_1$ (0% SSFWO) had the lowest FCR, although the value was comparable to the values observed for groups fed T$_2$ and T$_5$ (5 and 20% SSFWO) diets. This study's observations concur with observations made by Efrem et al. (2016) who showed increased FCR as the level of dietary rumen content advanced in layers. Increased FCR was also reported in laying hens fed processed *Senna oblusifolia* seed meal-based (Augustine et al. 2019). Increased FCR with an increase in SSFWO inclusion might be a result of increased feed intake and similar egg weight noted in the SSFWO groups compared to the control.

Hen day egg production (HDEP) also showed a decreasing tendency as the level of SSFWO increased. Chickens on T$_1$ (0% SSFWO) had the highest HDEP although the value was comparable to the values recorded in groups fed 5–15% SSFWO levels. Groups fed T$_5$ and T$_6$ (20 and 25% SSFWO) diets had similar but lower HDEP (61.09, 61.89%) than the groups fed the T_1 (0% SSFWO) diet. This finding concurs with the work of Efrem et al. (2016) who showed lower HDEP in chickens fed graded levels of rumen content. Similarly, Dairo and Fasuyi (2008) reported decreased HDEP in laying chickens fed fermented palm-kernel meal (PKM) and copra-meal (CM) compared to the control. The reports of Iyayi and Aderolu, (2004). also showed that layer chickens treated with fermented palm-kernel meal had depressed HDEP. Values recorded in this study (61.09 - 69.90%) are higher than the 50.06 to 53.99% reported by Manshop, (2011) in layers fed PKM, 54.10 - 58.79 reported by Dim et al (2022) in laying chickens fed brewers spent grain (BSG) and 57.47% reported by Bello et al. (2021) for three strains of layers reared in a semi-arid environment. The values are, however, within the range of 52.42-69.87% reported by Augustine et al (2019) for ISA brown layers fed *Senna obtusfolia* seed meal. Lower HDEP in layers on the SSFWO groups could be related to the fact that dietary fibre dilutes nutrient (especially energy and protein) concentration of the diet thus, affecting their availability for efficient egg production. Better egg production parameters recorded for the control group may be due to the better nutrient balance of the diet.

Cost-per-gain analysis of laying hens fed dietary SSFWO

Cost-per-gain analysis of layer chickens fed dietary SSFWO is presented in Table 6. Groups fed T_6 (25% SSFWO) had the highest feed cost, this was followed by groups on T_5 and T_4 (20 and 15% SSFWO) diets. Groups on T_1 and T_3 (0 and 10% SSFWO) diets had similar values. The lowest feed cost was found in the T_2 (5% SSFWO) group. Increased feed cost in groups with high SSFWO inclusion could be a result of an increase in the cost of palm oil which was included to increase the dietary energy concentration. Groups fed T_3, T_4, and T_6 (10, 15 and 25% SSFWO) diets had total feed intake (TFI) values that were higher than the values recorded for groups fed T_2 and T_5 (5 and 20% SSFWO) diets while those on T_1 (0% SSFWO) had the least TFI. The increase in TFI in chickens on the SSFWO diets could be related to the high fibre content of the diets which might have reduced the caloric density and thus, the need for more feed consumption to satisfy the birds' energy requirement.

Total feeding cost (TFC) also increased as the level of SSFWO increased. Chickens in the T1 (control) group had the lowest TFC comparable to values obtained for the group T_2 (5% SSFWO) diet. Chickens on T_3 – T_6 (10 – 25% SSFWO) diets had higher values compared to the control group. The increase in TFC in the groups on the SSFWO diets could be related to higher feed intake and cost of feed. This study's findings follow the results of Augustine et al. (2019) who noted higher TFC in pullets fed *S. obtusifolia* seed meal-based diets.

Cost-per-gain (CPG) increased as the level of SSFWO advances. Chickens on the T_6 (25% SSFWO) diet had the highest

CPG while the control group had the lowest value. The findings of this study agree with the report of Augustinev et al (2019) who showed increased CPG in laying hens fed processed *S. oblusifolia* seed meal-based diets. The observation of this study might be connected to the high FCR and feed cost.

Egg quality characteristics of layer chickens (30 – 42 weeks) fed rumen filtrate fermented wheat offal (SSFWO)

The effect of SSFWO on egg quality characteristics of laying chickens is presented in Table 7. Egg length, egg width, albumen weight, Haugh unit, yolk height and yolk width were significantly ($p \leq 0.05$) affected by dietary treatments. No effects ($p > 0.05$) were observed for egg weight, specific gravity, egg-shape index, shell thickness, albumen height, albumen width, albumen index, yolk weight and yolk index.

There were significant ($P \leq 0.05$) differences observed among the treatment groups for egg length. Chickens on the T_1 (control) diet had the longest length which is distinctively different from groups fed T_3 and T_6 (10 and 25% SSFWO) diets that had the shortest egg length. Values observed in the later groups were similar to those observed for groups fed T_2, T_4 and T_5 (5, 15 and 20% SSFWO) diets. The values obtained in this study (52.08 -55.02mm) are similar to the 53.96 - 55.12 mm reported by Aruwayo et al. (2022) in layers-fed maize milling waste. Egg length of 51.3 – 56.0 mm has been reported in ISA brown layers by Adeoye et al (2022) and Abdullahi et al. (2019). Egg width was highest ($P \leq 0.05$)in groups fed T_1(0% SSFWO) than in other groups that had values that were similar and lower. Values observed in this study (40.98-44.11mm) are similar to the 25.0 – 45.0 mm reported by Aruwayo et al and Adeoye et al (2022) in ISA brown layers. Albumen weight was heaviest $P \leq 0.05$)in groups fed T_5 (20% SSFWO). The control group had the lightest weight. Groups on T_2, T_3, T_4 and T_6 (5, 10, 15 and 25% SSFWO) diets had values that were comparable to the values found in T_1 and T_6 (0 and 25% SSFWO) groups. Albumen weight values (29.17 - 30.45g) are within the range of 27.40 - 51.00g reported for ISA Brown layers by Aruwayo et al. (2022) in semi-arid regions.

Haugh unit (Hu) increased as the level of SSFWO increased. It followed a similar trend with albumen weight. Chickens on the T_1 (control) diet had the lowest Hu (93.77). The value was, however, similar ($p \leq 0.05$) to the 96.15 and 97.98 recorded for chickens fed T_2 and T_3 (5 and 10% SSFWO) diets. Values obtained for layers on T_3, T_4 and T_5 (10, 15 and 20% SSFWO) diets were also similar. The highest Hu was recorded for layers on the T_6 (25% SSFWO) diet although the values compared with the value found in groups on T_3 – T_5 (10 – 20% SSFWO) diets. Hu signifies egg quality, especially freshness and keeping quality. Values observed in this study are higher than the 92.44 – 92.66 reported by Abdullahi et al. (2019) and 94.82 - 96.04 reported by Abdullahi et al (2021). They are also higher than the 91.37 - 92.79 reported by Gebremedhn et al (2019) for layers-fed brewers spent grain. (BSG). This revelation implies that the SSFWO had

Table 7. Egg quality characteristics of layer hens fed dietary solid-state fermented wheat offal (SSFWO).

Parameters	Treatment/ Level of RUFWO inclusion (%)						SEM
	T_1 (0)	T_2 (5)	T_3 (10)	T_4 (15)	T_5 (20)	T_6 (25)	
Egg weight (g)	52.12	52.14	52.32	52.80	52.91	52.17	0.25^{ns}
Specific gravity	1.08	1.09	1.09	1.24	1.09	1.09	0.06^{ns}
Egg length (mm)	55.02^{a}	53.64^{ab}	52.08^{b}	53.04^{ab}	53.28^{ab}	52.25^{b}	0.29^{*}
Egg width (mm)	44.11^{a}	41.79^{b}	41.07^{b}	41.47^{b}	41.05^{b}	40.98^{b}	0.25^{*}
Egg shape index	79.68	78.16	79.24	77.84	77.04	78.72	1.04^{ns}
Shell thickness (mm)	0.45	0.45	0.46	0.44	0.43	0.48	6.23^{ns}
Albumen weight (g)	28.00^{b}	29.17^{ab}	29.39^{ab}	29.33^{ab}	30.45^{a}	29.58^{ab}	0.26^{*}
Albumen height (mm)	8.30	8.80	9.18	9.63	9.65	10.09	1.71^{ns}
Albumen width (mm)	60.96	59.37	58.37	60.03	59.27	100.84	7.27^{ns}
Albumen index	13.93	15.55	15.80	16.17	16.31	10.07	8.19^{ns}
Haugh unit	93.77^{c}	96.15^{bc}	97.98^{abc}	99.80^{ab}	99.73^{ab}	101.98^{a}	1.42^{*}
Yolk weight (g)	13.95	13.74	13.99	13.52	13.61	13.15	1.78^{ns}
Yolk height (mm)	20.59^{b}	17.51^{a}	16.55^{a}	16.36^{a}	16.69^{a}	16.95^{a}	0.21^{*}
Yolk width (mm)	39.93^{a}	37.18^{b}	35.64^{b}	36.15^{b}	35.74^{b}	35.86^{b}	0.26^{*}
Yolk index	50.16	46.93	40.02	45.27	46.69	47.27	2.98^{ns}

$^{a,\ b,\ c}$ Means on the same row having different superscripts are significantly different ($p \leq 0.05$) SEM: Standard Error of Mean, * = significantly different ($p \leq 0.05$); ns =not significantly different ($p > 0.05$)

no negative impact on keeping the quality of the eggs and also showed a definite trend of improvements in Hu as the level of SSFWO increased. This is an advantage, especially in tropical environments where temperatures are high and eggs are mostly stored at room temperature.

Yolk height and width were highest ($P \leq 0.05$) in the T_1 (0% SSFWO). Other groups were statistically similar and recorded values that were lower than those of the control group. Efrem et al. (2016) and Gebremedhn et al (2019) reported that inclusions of BSG and rumen content in layers ratio did not affect yolk height. The values recorded for yolk width in this study are similar to the 34.0 – 45.0 mm reported by Abdullahi et al (2021) for ISA brown layers. Yolk height and width are used to measure yolk index which provides an indication on the freshness of the egg. Since dietary SSWO had no negative effect on the yolk index this infers that the test material did not have adverse effect on the parameters.

Conclusion

It was concluded from this work that SSFWO incorporated at up to 25% in the diet of egg-type chickens had no negative influence on the productive performance and egg-quality characteristics. However, supplementing SSFWO beyond 10% is not encouraged due to the high cost per gain.

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Conflict of interest

No conflict of interest was declared by the authors.

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