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Effect of soy hulls as alternative ingredient on growth performance, carcase quality, nutrients digestibility and intestinal histological features in broilers

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ABSTRACT

The objective of this study is to investigate the effects of increasing levels of soybean hulls in broiler chicken diets on growth performance, carcase composition, organ weights, nutrient digestibility, amino acid digestibility, and intestinal histomorphology to determine the optimal inclusion level for maximising poultry health and performance. A total of 680, 1-day-old male broiler chicks (Hubbard) were randomly assigned to five treatments with eight replicates, each consisting of seventeen birds, and housed in an environmentally controlled room with nipple drinkers and trough feeders. The experimental diets, containing 0%, 2%, 4%, 6%, and 8% dietary soybean hulls (SH), were fed to the broilers for 35 days. During the starter phase, the growth performance of chickens fed 2% SH was not significantly different from the control group, but differences emerged during the later stages. Chickens fed 2% SH showed significantly higher body weight and weight gain compared to higher SH levels. Carcase yield decreased with increasing SH content in the diet, while wing meat yield was highest in birds fed 0% and 2% SH. The relative weights of gizzard, jejunum, and ileum varied significantly among groups. Higher SH levels led to decreased nutrient digestibility but increased excreta nitrogen and ether extract content. Ileal amino acid digestibility varied among SH levels. Intestinal histomorphology revealed significant differences in villi height and crypt depth among groups. Overall, diets with 2% and 4% SH demonstrated superior nutrient utilisation and intestinal health compared to higher SH levels. These findings suggest an optimal inclusion level of SH in broiler diets to optimise performance and intestinal morphology.

HIGHLIGHTS

- Diets with 2% and 4% soybean hulls (SH) demonstrated superior nutrient utilisation and intestinal health.
- Chickens fed 2% SH showed significantly higher body weight and weight gain compared to higher SH levels, indicating the importance of optimal dietary composition.
- Carcase yield decreased with increasing SH content, while wing meat yield was highest in birds fed 0% and 2% SH, highlighting the impact of SH levels on meat quality.

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Introduction

The expenses associated with poultry feeds have long been a significant issue in local poultry farming (Nguyen et al. 2021; Hegazy et al. 2022). The costs of poultry production have consistently risen due to the fluctuating prices of premium raw materials such as soybean and corn (Jha et al. 2019; Rashid et al. 2022; Salman and Imran 2022). Efforts have been made to address this challenge by exploring more affordable and locally accessible alternatives to partially substitute protein and energy sources like soybean meal and corn in poultry feed formulations (Munezero and Kim 2022; Sampath et al. 2022; Quratulain et al. 2023). Despite various locally available and cost-effective feed ingredients being suggested, their acceptance in poultry farming has been limited, resulting in minimal incorporation into feed formulations (Zhang and Kim

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2013; Liu et al. 2019; Tejeda and Kim 2020; Abbas and Alkheraije 2023; Al-Hoshani et al. 2023; Hussain et al. 2023).

Based on how soluble or insoluble it is in water, dietary fibre is divided into two categories (Chakraborty et al. 2019). Poultry does not extensively ferment fibre polymers in the caecum and lacks the enzymes needed to break down fibre. A modest intake of insoluble dietary fibre, however, has been linked to improvements in nutrient utilisation, growth performance, gut health, and the gastrointestinal system (Sklan et al. 2003; Mateos et al. 2012; Kurul et al. 2020). According to González-Alvarado et al. (2010), broiler hulls such as oat, rice, sunflower, and soy (SH) are sources of insoluble fibre that may promote nutrient utilisation and improve live performance. According to other studies (González-Alvarado et al. 2010; Jiménez-Moreno et al. 2013, 2016), broilers given low-fibre diets can see improvements in live performance and nutrient utilisation when 3% of their diet is made up of oat hulls.

Rich in cell wall polysaccharides, soybean hulls make up 8–10% of the weight of the bean and have demonstrated great potential in improving nutrient utilisation (Mielenz et al. 2009; Flauzino-Neto et al. 2013). Even so, there is still a lack of knowledge regarding how modest soybean hull levels affect the growth performance of broilers, the quality of their carcases, the digestibility of amino acids, and the histology of their intestines. Thus, the purpose of this study was to look at how broiler growth performance and nutrient use were affected by feeding soybean hulls.

Materials and methods

Birds husbandry and experimental design

A total of 680, 1-day-old male broiler chicks (Hubbard) were utilised for the current study. The birds were accommodated in an electrically heated room equipped with nipple drinkers and trough feeders, all situated within an environmentally controlled environment. Upon arrival, the broiler chicks were randomly assigned to five treatments with eight replicates, each replicate consisting of seventeen birds, following a completely randomised design. The temperature was maintained at 35 °C throughout the first week and gradually decreased until reaching 25 °C by day 21. Initially, a lighting cycle of 23 h of light followed by 1 h of darkness was employed during the first week, which transitioned to a 16-hour light and 8-hour dark cycle for the duration of the experiment.

Experimental diets

The composition of the test diets and SH is presented in Table 1, and the same was used throughout the experiment. The dietary treatments comprised 0, 2, 4, and 6 and 8% dietary SH, and broilers were fed the experimental diets for 35 days. Soy hulls were obtained from local feed mill as byproduct of soybean processing. Soy hulls were ground to pass through a 2-mm screen using a hammer mill. Chromic oxide was included in the diets at a concentration of 5 g/kg (as-fed) as an exogenous indicator to aid in the determination of nutrient digestibility. The birds were provided ad libitum access to the diets in mash form and water.

Growth traits, sampling and calculations

Each morning, a predetermined quantity of experimental diet was provided to chicks freely, and any remaining feed in the feeding pan was recorded weekly. Body weight was measured on weekly basis. Feed Conversion Ratio (FCR) was assessed as the amount of

Table 1. Composition of experimental diets used in the experiment.

	Dietary soybean hulls (SH) level				
Ingredients (g/100g)	A (0% SH)	B (2% SH)	C (4% SH)	D (6% SH)	E (8% SH)
Corn	58.0	56.0	56.0	55.0	54.0
Soybean meal	28.0	28.0	28.0	27.4	27.0
Fish meal	2.00	2.00	2.00	2.00	2.00
Canola meal	8.00	8.00	6.00	5.00	4.00
Soybean hulls[a]	0.00	2.00	4.00	6.00	8.00
Soybean oil	2.00	2.00	2.00	2.50	3.00
Dicalcium phosphate	1.00	1.00	1.00	1.00	1.00
L-Threonine	0.10	0.11	0.12	0.13	0.14
DL-Methionine	0.20	0.22	0.23	0.24	0.24
Lysine HCl	0.1	0.1	0.1	0.13	0.15
Vitamin-mineral premix[b]	0.40	0.40	0.40	0.40	0.40
Sodium Chloride	0.20	0.20	0.20	0.20	0.20
	100	100	100	100	100.13
	Calculated nutrient composition				
Dry matter (%)	90	90	90	90	90
ME (Kcal/kg)	3013	3000	3000	3000	3000
Protein (%)	21.0	21.0	21.0	21.0	21.0
Total crude fibre (%)	3.30	3.90	4.67	5.55	6.21
Calcium (%)	0.76	0.78	0.82	0.84	0.89
Dig. Phosphorus (%)	0.38	0.39	0.41	0.42	0.44
Dig. Met (%)	0.56	0.56	0.56	0.56	0.56
Dig. TSAA (%)	0.9	0.9	0.91	0.9	0.9
Dig. Lys (%)	1.20	1.20	1.20	1.20	1.20
Dig. Thr (%)	0.86	0.86	0.86	0.86	0.86

Abbreviations: ME: metabolisable energy; SH: soybean hulls.

[a] Composition of soybean hulls used in the ration: ME, 1203 kcal/kg; CP, 13.52%; Avg. TSSA, 0.31; Avg. lysine, 0.54%; Avg. Trp, 0.09%; Avg. Thr: 0.25; Av-Arg: 0.64, as recorded in experiment 1.

[b] Each kg of vitamin DSM premix (Parsippany, NJ) contained: Retinyl acetate (vit A), 4400 IU; Cholecalciferol (vit. D_3), 118 pg; DL-α-Tocopherol acetate (vit. E), 12 IU; Menadione sodium bisulphite (MSB, vit. K3), 2.40 mg; Thiamine (vit. B1), 2.5 mg; Riboflavin (vit. B2), 4.8 mg; Niacin (vit. B3), 30 mg; Pantothenic acid (vit. B5), 10 mg; Pyridoxine (vit. B6), 5 mg; Biotin (vit. B7), 130 μg; Folic acid, 2.5 mg; Cyanocobalamin (vit. B12), 19 μg; Iron, 80 mg; Manganese, 85 mg; Copper, 6 mg; Selenium, 130 μg; Iodine, 1 mg; Zinc, 75 mg.

feed consumed per unit weight gained, calculated as the ratio of feed consumed to weight gain. Dressing Percentage was evaluated by randomly selecting two birds from each replicate at the trial's end, weighing them, and then slaughtering them. The dressed body weight was measured after removing certain parts, including the head, feet, feathers, abdominal fat, skin, and visceral organs. Carcase, breast, leg and wing was determined as the percentage of boneless breast meat in relation to the eviscerated carcase. Abdominal fat percentage was determined by weighing the remaining fat in the abdominal cavity after processing and expressing it as a proportion of the carcase weight. Internal empty organs' percentage, including heart, gizzard, liver, duodenum, jejunum, and caeca was determined by separately weighing each organ and expressing it as a proportion of the carcase weight.

Digestibility of nutrients

On day 35, the pooled ileal digesta samples underwent drying in a forced-air oven at 55 °C for one week, while both the diets and dried ileal digesta samples were ground to pass through a 0.5 mm screen using an ultra-centrifugal mill. The dry matter (DM) content of the diets and ileal digesta samples was determined by drying them in a drying oven at 105 °C for 24 h, following the protocol outlined by AOAC International in 2006. Nitrogen content was measured using the Kjeldahl method, as described by AOAC International in 2006, with a nitrogen analyser. The ether extract (EE) concentration was determined using a Soxhlet apparatus. Subsequently, phosphorus and chromium concentrations were determined after digestion using nitric acid and perchloric acid and measured using UV spectrophotometry at wavelengths of 440 nm and 620 nm, respectively, in a plate reader.

The apparent metabolisable energy (AME) values were computed utilising a dedicated equation derived from the analysis results.

$$\text{AME (Kcal/Kg of diet)} = GE\ diet - \left[GE\ in\ digesta/excreta \times \left(\frac{Marker\ diet}{Marker\ excreta/digesta}\right)\right]$$

Where GE = gross energy
Marker = chromic oxide concentration.

$$\text{Apparent digestibility} = 100 - \left[100 \times \frac{\%\ nutrient\ in\ digesta \times \%\ Cr\ in\ diet}{\%\ nutrient\ in\ diet \times \%\ Cr\ in\ digesta}\right]$$

For determination of ileal amino acids digestibility, the following formula was used.

$$\text{Apparent ileal digestibility of amino acids} = \left[1 - \left(\frac{Cr\ in\ diet}{Cr\ in\ Digesta}\right) \times \left(\frac{Amino\ acid\ in\ digesta}{Amino\ acid\ in\ diet}\right)\right. \times 100$$

Intestinal morphology

The morphological characteristics of the duodenum, jejunum, and ileum were analysed following the protocols outlined by Feng et al. (2007). In summary, the duodenum, jejunum, and ileum were carefully washed and dissected, and representative tissue samples from each were preserved in ten percent formalin. A minimum of four cross-sectional samples from paraffin-embedded segments were prepared using a tissue microtome. Morphological features such as villus height and width, surface area, crypt depth, and the ratio of villus height to crypt depth were examined using a specialised imaging microscope (Leica Imaging System Ltd, United Kingdom).

Statistical analysis

The data were analysed using the GLM procedure of SAS (SAS Institute, 2006) based on a completely randomised design. Each pen was considered an experimental unit for all traits. The Kolmogorov-Smirnov test was used to verify the normal distribution of the data. Means were separated using Tukey's test, with significance determined at $p < 0.05$.

Results

Growth performance

Table 2 presents data on the growth performance of broiler chickens fed increasing levels of soybean hulls (SH). During the first two weeks, the inclusion of HS did not impact weight gain in broilers. Starting from day 21, the gradual inclusion of SH in the experimental feed led to notable differences in chick growth performance. Chickens consuming 2% SH exhibited significantly higher ($p < 0.05$) body weight (BW) and body weight gain (BWG) compared to groups C, D, and E, which had more than 2% SH. On days 21, 28, and 35, body weight was significantly ($p < 0.01$) lower in birds fed with 6% and 8% SH, followed by 4%, compared to the control. Body weight gain was significantly ($p < 0.05$) lower in group D and E, followed by group C and B on days 21, 28, and 35. No significant difference was found between group D and E during these intervals.

Table 2. Effect of increasing level of soybean hulls on body weight gain of broiler chickens.

Diet	A (0% SH)	B (2% SH)	C (4% SH)	D (6% SH)	E (8% SH)	SEM	*p*-value
Body weight, BW (g)							
1d	40.460	40.460	40.460	40.460	40.460	0.05	0.939
7 d	190.08	191.40	190.74	192.72	192.72	3.04	0.905
14 d	516.78	516.12	519.42	510.18	512.67	8.35	0.758
21 d	1053.2^{a}	1046.2^{b}	1016.7^{c}	905.00^{d}	901.88^{d}	12.4	0.008
28 d	1664.1^{a}	1652.9^{ab}	1606.4^{b}	1429.9^{d}	1424.9^{d}	34.2	<0.001
35 d	2242.8^{a}	2152.0^{b}	1989.1^{c}	1721.6^{d}	1647.6^{e}	37.8	0.006
Body weight gain, BWG (g)							
1–7 d	149.62	150.94	150.28	152.26	152.26	3.03	0.906
8–14 d	326.70	324.72	328.68	317.46	319.95	7.51	0.052
15–21 d	536.45^{a}	530.06^{a}	497.30^{b}	394.82^{c}	389.21^{c}	10.9	<0.001
1–21 d	1012.77^{a}	1005.72^{a}	976.26^{b}	864.54^{c}	861.42^{c}	12.4	0.007
22–28 d	610.87^{a}	606.78^{a}	589.70^{b}	524.90^{c}	523.09^{c}	21.8	0.026
29–35 d	578.70^{a}	499.04^{b}	382.70^{c}	291.70^{d}	222.65^{e}	35.4	<0.001
1–35 d	2202.3^{a}	2111.5^{b}	1948.7^{c}	1681.1^{d}	1607.2^{d}	37.8	<0.001

Mean values within each row showing the same superscript are not significantly different from each other at a *p*-level of 0.05. The values are the average of 136 birds per treatment.

Table 3. Effect of increasing level of soybean hulls on feed intake (FI) and feed conversion ratio (FCR) of broiler chickens.

	A (0% SH)	B (2% SH)	C (4% SH)	D (6% SH)	E (8% SH)	SEM	*p*-value
FI (g)							
1–7 d	142.48	146.64	144.50	147.00	148.50	3.83	0.861
8–14 d	399.30	401.22	406.08	411.48	406.08	9.90	0.059
15–21 d	688.20^{d}	711.75^{cd}	748.68^{c}	775.20^{b}	808.52^{a}	14.20	<0.001
1–21 d	1229.98^{e}	1259.61^{d}	1299.26^{c}	1333.68^{b}	1363.10^{a}	18.40	<0.001
22–28 d	985.60^{d}	1057.7^{c}	1200.4^{b}	1221.2^{a}	1224.4^{a}	21.34	<0.001
29–35 d	1232.6^{e}	1313.5^{d}	1412.0^{c}	1445.4^{b}	1510.9^{a}	39.90	<0.001
1–35 d	3448.2^{e}	3630.8^{d}	3911.7^{c}	4000.2^{b}	4098.4^{a}	47.50	<0.001
FCR							
7 d	0.95	0.97	0.96	0.97	0.98	0.01	0.127
14 d	1.22	1.24	1.24	1.30	1.27	0.03	0.371
21 d	1.28^{c}	1.34^{bc}	1.51^{b}	1.96^{ab}	2.08^{a}	0.03	<0.001
1-21 d	1.21^{c}	1.25^{c}	1.33^{b}	1.54^{a}	1.58^{a}	0.01	<0.001
28 d	1.61^{c}	1.74^{c}	2.04^{b}	2.33^{a}	2.34^{a}	0.070	<0.001
35 d	2.13^{e}	2.63^{d}	3.69^{c}	4.95^{b}	6.79^{a}	0.49	<0.001
1–35 d	1.57^{d}	1.72^{cd}	2.01^{c}	2.38^{b}	2.55^{a}	0.02	0.03

Mean values within each row showing the same superscript are not significantly different from each other at a *p*-level of 0.05; The values are the average of 136 birds per treatment.

Similarly, in Table 3, significantly higher feed intake ($p < 0.05$) was observed in group E from day 15 onward until the end of the study (day 35) compared to the control. Feed intake was significantly ($p < 0.01$) higher in group E on days 21, 28, and 35, as well as for the overall period (1-35 days), followed by group D, except during days 22-28. Conversely, the feed conversion ratio (FCR) on a weekly basis during this period was also significantly higher ($p < 0.05$) in group E compared to the control. The FCR did not change in groups D and E on days 21 and 28 compared to group C and D. Similarly, no significant difference ($p < 0.01$) was found in FCR values on day 21 between groups C and D. The FCR also did not change significantly ($p < 0.05$) between groups A and B on days 21 and 28. It is also pertinent to note that the inclusion of HS in the broiler diet did not have any significant effect on feed intake and FCR during the first two weeks but did show effects during the growing period.

Carcase quality

Table 4 presents data on the carcase composition of broilers offered increasing levels of SH. Significant variations ($p < 0.05$) were observed in the relative carcase traits among the experimental groups. Carcase yield decreased ($p < 0.05$) with increasing fibre content in the diet. The control group exhibited the highest percent carcase yield (71.63%), followed by birds fed 2% and 4% SH in the diet (70.01% and 70.04%, respectively), while the lowest was observed in those fed 6% and 8% SH in the diet (68.56% and 68.73%, respectively). No significant difference ($p > 0.05$) was observed in carcase yield between group B and C. Similarly, group D and E did not differ significantly ($p > 0.05$).

Table 4. Effect of increasing level of soybean hulls on the carcase traits of broiler chickens.

Diet	A (0% SH)	B (2% SH)	C (4% SH)	D (6% SH)	E (8% SH)	SEM	*p*-value
Carcase yield (%)	71.63^{a}	70.01^{b}	70.04^{b}	68.56^{c}	68.73^{c}	0.94	0.036
Breast (%)	22.87	22.65	22.86	22.18	22.22	0.91	0.118
Leg (%)	22.17	22.60	22.42	22.01	22.42	0.74	0.066
Wing (%)	7.84^{a}	7.74^{a}	6.83^{b}	6.66^{b}	6.86^{b}	0.11	0.016

Mean values within each row showing the same superscript are not statistically different from each other at a *p*-level of 0.05. The values are the average of 136 birds per treatment.

Table 5. Effect of increasing level of soybean hulls on organ weights of broilers reared to 35 d of age.

Diet	A (0% SH)	B (2% SH)	C (4% SH)	D (6% SH)	E (8% SH)	SEM	*p*-value
Gizzard, g	39.02	41.75	38.59	40.15	35.19	0.88	0.1107
Gizzard, %	2.74^{c}	2.94^{b}	2.94^{b}	3.33^{a}	3.14^{ab}	0.09	$<$0.001
Pancreas, g	4.17	4.09	3.86	3.62	3.59	0.16	0.3586
Pancreas, %	0.186	0.19	0.194	0.21	0.218	0.02	0.6879
Liver, g	68.14^{a}	65.38^{ab}	60.43^{b}	50.62^{c}	50.05^{c}	1.29	$<$0.001
Liver, %	3.038	3.038	3.038	2.94	3.038	0.12	0.1793
Abdominal fat, g	9.42^{a}	7.10^{b}	4.97^{c}	3.44^{d}	3.62^{d}	0.21	0.0297
Abdominal fat (%)	0.42	0.33	0.25	0.2	0.22	0.03	0.082
Duodenum, g	32.97	33.74	29.24	26.99	27.45	0.54	0.2391
Duodenum, %	1.47	1.568	1.47	1.568	1.666	0.07	0.1381
Jejunum, g	76.93	78.03	70.18	70.86	72.66	1.47	0.2734
Jejunum, %	3.43^{c}	3.626^{c}	3.528^{c}	4.116^{b}	4.41^{a}	0.16	$<$0.001
Ileum, g	68.14	73.81	66.24	65.77	64.59	1.48	0.2097
Ileum, %	3.038^{c}	3.43^{b}	3.332^{b}	3.822^{a}	3.92^{a}	0.12	$<$0.001
Caeca, g	14.80	14.76	14.32	14.46	14.56	0.59	0.1332
Caeca, %	0.66	0.686	0.72	0.84	0.884	0.07	0.1538

Mean values within each row showing the same superscript are not statistically different from each other at a *p*-level of 0.05; The values are the average of 136 birds per treatment.

Significantly higher and equivalent wing meat yield was recorded in birds fed 0% and 2% SH in the diet (7.84% and 7.74%, respectively), while the lowest and equivalent yields were observed in those fed more than 2% SH in the diet. Wing weight did not vary significantly ($p > 0.05$) between the control and group B. Similarly, wing weight did not differ significantly ($p > 0.05$) between groups C, D, and E. There were no significant variations in the breast meat and leg meat of birds in different experimental groups.

Table 5 presents data on the relative organ weights of broilers fed increasing levels of SH. The results showed significant variation ($p < 0.05$) in the relative weights of the gizzard, jejunum, and ileum. Gizzard weight did not differ between group B, C and E. Similarly, gizzard weight did not differ between group D and E. While the liver and abdominal weights also exhibited significant variations, their relative weights among the groups were not significantly different. Liver weight was significantly ($p < 0.05$) lower in group D and E compared to the control. Similarly, liver weight did not vary between group B and C. Chicks fed higher levels of SH, ranging from 6% to 8%, demonstrated differences in the relative weight of the gizzard compared to those fed 2% to 4% SH, with the lowest weights observed in those fed a commercial broiler diet without any SH inclusion. The abdominal fat weight decreased significantly ($p < 0.05$) in groups D and E, followed by groups C and B compared to the control. However, there was no significant difference in abdominal fat weight between groups D and E. Similar patterns were observed for the relative weights of the jejunum and ileum. The jejunal percentage increased significantly ($p < 0.05$) in group E, followed by groups D, C, and B, with no significant difference found between groups B and C. The ileum percentage was significantly ($p < 0.05$) higher in groups D and E compared to the control. No significant difference was found between groups B and C, and similarly, no significant difference was observed between groups D and E in ileum percentage.

Nutrients digestibility

Table 6 displays data on the nutrient digestibility of broilers offered varying levels of SH in their diets. Significantly higher dry matter (DM) digestibility was observed in birds fed 0% SH (73.20%), followed by those fed 6% SH (63.81%), with the lowest digestibility recorded in those fed 8% SH (61.74%). The DM

Table 6. Effect of increasing level of soybean hulls on nutrient digestibility of broiler chicks.

Diet	A (0% SH)	B (2% SH)	C (4% SH)	D (6% SH)	E (8% SH)	SEM	*p*-value
Dry Matter, %	73.20^{a}	69.31^{ab}	70.60^{ab}	63.81^{b}	61.74^{c}	6.46	0.034
Energy, %	76.88	75.01	75.65	72.24	74.15	9.31	0.156
Crude Protein, %	49.91^{a}	45.26^{ab}	50.40^{a}	45.21^{ab}	43.15^{b}	6.56	0.006
EE, %	55.39^{c}	73.28^{b}	80.67^{a}	83.01^{a}	83.60^{a}	9.50	0.009
AME (MJ/Kg)	12.91^{a}	13.08^{a}	12.93^{a}	11.76^{b}	11.06^{b}	1.78	0.020

Mean values within each row showing the same superscript are not significantly different from each other at a *p*-level of 0.05. The values are the average of 12 birds per treatment.
EE: ether extract

Table 7. Effect of increasing level of soybean hulls on standardised ileal amino acid digestibility of broiler chicks.

Nutrient	A (0% SH)	B (2% SH)	C (4% SH)	D (6% SH)	E (8% SH)	SEM	*p*-value
Met, %	91.08	91.47	91.79	91.18	91.76	0.3	0.301
Lys, %	86.23	87.20	85.75	86.62	85.75	0.4	0.156
Thr, %	75.27^{b}	75.34^{b}	74.78^{c}	75.08^{b}	77.41^{a}	0.6	0.001
Val, %	77.41^{ab}	78.38^{a}	77.12^{ab}	77.50^{ab}	76.34^{b}	0.6	<0.001
Ile, %	80.03	80.80	79.54	80.32	79.25	0.5	0.071
Leu, %	81.58^{ab}	82.26^{a}	80.80^{b}	81.96^{ab}	81.09^{b}	0.5	0.0028
Tyr, %	80.12^{ab}	81.38^{a}	79.83^{ab}	80.80^{ab}	78.47^{b}	0.5	0.0036
Phe, %	81.38^{b}	82.55^{a}	80.89^{b}	82.16^{a}	81.38^{b}	0.6	<0.001
His, %	84.00^{b}	86.04^{a}	83.42^{c}	84.48^{b}	83.61^{c}	0.7	0.0421
Arg, %	87.01^{b}	88.37^{a}	86.91^{b}	87.97^{a}	86.59^{b}	0.5	0.0073
Trp, %	87.88	87.53	87.20	88.07	88.06	1.03	0.3759
Sum EAA	82.91	83.76	82.55	83.29	82.70	–	–
Cys, %	68.58^{b}	71.68^{a}	67.90^{b}	67.99^{b}	67.12^{b}	1.1	0.0055
Asp, %	77.98^{bc}	79.25^{a}	77.69^{c}	78.28^{b}	77.60^{c}	0.6	0.001
Ser, %	79.15	80.61	78.76	79.15	78.67	0.6	0.175
Glu, %	84.49	85.26	84.19	84.87	84.09	0.4	0.78
Pro, %	78.96	80.12	78.47	79.05	78.08	0.5	0.05
Gly, %	75.95	77.02	75.95	75.76	73.82	0.6	0.084
Ala, %	80.22	81.19	79.54	80.51	79.54	0.6	0.083
Sum NEAA	80.65	81.89	80.24	80.86	79.99	–	–
EAA:NEAA	1.03	1.02	1.03	1.03	1.03	–	–

Mean values within each row showing the same superscript are not significantly different from each other at a *p*-level of 0.05. The values are the average of 12 birds per treatment.
NEAA: Non essential amino acids

percentage did not vary significantly ($p < 0.05$) between group B, C and D. The digestibility of birds fed 2% SH (69.31%) and 4% SH (70.60%) did not significantly differ from that of groups A and D ($p = 0.034$). The crude protein percentage was significantly lower in group E compared to groups A and C ($p < 0.01$). No significant difference was found between groups B and D. Ether extract was significantly higher in groups C, D, and E compared to groups A and B ($p < 0.05$). The apparent metabolisable energy (AME) concentration was significantly higher in groups A, B, and C compared to groups D and E ($p < 0.05$), with no significant difference observed within groups D and E. Additionally, there was no significant difference in AME between groups A, B, and C.

Table 7 presents data on the ileal amino acid digestibility of broilers fed increasing levels of SH. The results indicate significant variations in the ileal digestibility of some essential and non-essential amino acids. Ileal digestibility of Val, Leu, Tyr, His, Cys, and Asp was significantly higher ($p < 0.05$) for birds fed 2% SH in their diets, followed by those fed 4-8% SH. Threonine showed highly significant digestibility ($p < 0.01$) in birds of group E (consuming 8% SH), while the digestibility of Phe and Arg was significantly higher ($p < 0.05$) and the same for birds in groups B and D (consuming 2% and 6% SH in the diet, respectively). The concentration of threonine showed no significant variation among groups A, B, and D. Valine concentration exhibited a significant increase ($p < 0.05$) in group A compared to group E. However, no significant differences were observed in valine digestibility between groups A, C, D, and E. Leucine concentration significantly decreased ($p < 0.05$) in groups C and E compared to group B. Nevertheless, there were no significant differences in leucine concentration between groups A, C, D, and E. Similarly, the concentrations of tyrosine, phenylalanine, histamine, and arginine significantly decreased ($p < 0.05$) in group E compared to group B. However, there were no

Table 8. Effect of increasing level of soybean hulls on intestinal morphometrics of broiler chicks reared to 35 d of age.

Diet	A (0% SH)	B (2% SH)	C (4% SH)	D (6% SH)	E (8% SH)	SEM	*p*-value
Duodenum							
Villi height, µm	2150.12^{b}	2076.62^{c}	2034.48^{d}	2008.02^{d}	2268.7^{a}	29.4	0.0010
Crypt, µm	256.76	243.04	244.02	263.62	279.3	11.76	0.0646
Villi: Crypt	8.82	8.82	8.624	8.134	8.428	0.294	0.1411
Jejunum							
Villi height, µm	1293.6^{a}	1285.76^{a}	1136.8^{b}	1094.66^{c}	1097.56^{c}	21.56	<0.001
Crypt, µm	184.24^{a}	185.42^{a}	182.08^{a}	169.54^{b}	168.36^{b}	4.9	0.0078
Villi: Crypt	7.15	6.93	6.24	6.46	6.58	0.196	0.0696
Ileum							
Villi height, µm	628.18^{bc}	608.58^{c}	753.62^{a}	665.42^{b}	618.38^{bc}	14.7	0.001
Crypt, µm	155.82^{b}	143.08^{c}	176.4^{a}	143.08^{c}	158.76^{b}	4.9	0.004
Villi: Crypt	4.116^{b}	4.41^{ab}	4.41^{ab}	4.9^{a}	3.92^{b}	0.156	0.008

Mean values within each row showing the same superscript are not significantly different from each other at a *p*-level of 0.05. The values are the average of 12 birds per treatment.

significant differences in the concentration of these amino acids between groups C and E.

Intestinal histomorphology

Table 8 presents data on the intestinal histomorphology of broilers fed increasing levels of SH. The results indicate significant variation ($p < 0.05$) in villi height, crypt depth, and their ratio. In the duodenum, significantly longer villi were observed in birds consuming 8% SH in their diet, while the shortest duodenal villi were found in birds of groups C (4% SH) and D (6% SH). However, no significant variation was recorded for duodenal crypt depth among the experimental groups ($p = 0.0646$). No significant difference was found between group C and D in term of villus height. The jejunal villi height of birds in groups A (0% SH) and B (2% SH) was the highest compared to the rest of the treatments ($p < 0.01$). Birds consuming 8% SH exhibited significantly higher jejunal villi compared to those in group D (6% SH). Additionally, significantly higher crypt depth was recorded in the jejunum of birds in group C (4% SH) compared to other experimental groups ($p < 0.01$). No significant difference was found in villus height between group D and E. No significant difference was found in villus height and crypt depth between group D and E. In the ileum, birds consuming 4% SH in the diet showed significantly superior villi height and crypt depth (753.62 mm and 176.4 mm, respectively) compared to other experimental groups ($p < 0.01$). The ileal crypt depth was significantly higher in birds consuming 0% and 8% SH, respectively, compared to those consuming 2% and 6% SH, respectively. The ratios of duodenal and jejunal villi to their crypt among the groups were not significantly different ($p > 0.05$). However, the ileal villi to crypt ratio was significantly higher in birds of group D while lowest ($p = 0.008$) in groups A (0% SH) and E (8% SH). There were no significant differences in villus height between groups D and E ($p < 0.05$). Likewise, crypt depth did not significantly change between groups B and D ($p < 0.01$). Furthermore, the ratio of villus height to crypt depth did not show significant variations among groups A, B, C, and E ($p < 0.05$).

Discussion

Birds fed 0% and 2% SH showed higher growth performance, likely because higher fibre levels in diets with more than 2% SH may have negatively impacted nutrient absorption and gut efficiency, leading to reduced growth in those groups. Despite all treatment diets having the same protein and energy content, significant differences were observed in the growth performance parameters of birds receiving different levels of SH from day 21 onwards. Birds consuming 0% and 2% SH in the diet exhibited significantly higher ($p < 0.05$) growth performance compared to those in groups C, D, and E, which received more than 2% SH in the diet. Our findings suggest that SH can be included at a 2% level in broiler diets without any negative effects on growth performance. During the starter phase, broilers fed 2% SH did not exhibit significant differences in body weight or feed conversion ratio (FCR) compared to the control group. This aligns with previous studies, which have shown that dietary fibres can be included at a minimum of 3% in broiler feed to reduce feed costs without compromising growth performance (Jiménez-Moreno et al. 2009; Tejeda and Kim 2020). In Kurul et al. (2020) study, broilers fed diets containing increasing levels of dietary SH (20, 40, and 60 mg/kg) did not show significant differences in feed intake, body weight gain, or feed efficiency at 21 days of age. Conversely, González-Alvarado et al. (2007) reported that including 30 g/kg of SH in the diet increased body weight gain and improved the FCR of broilers without affecting feed intake. However, the addition of higher levels of soluble fibre (6 to 8%) significantly decreased the growth rate and FCR of broiler chickens at all measured stages. These findings align with previous studies by Tejeda and Kim (2020) and González-Alvarado et al. (2007), who suggested that including 3 to 4% crude fibre (CF) in the diet is acceptable for broilers. The performance of the birds likely depends on the quantity and type of dietary fibre provided at specific stages of growth. Excessive inclusion of soluble dietary fibres, exceeding 4% in poultry feed, negatively impacts growth performance by hindering nutrient absorption and resulting in poorer bird performance (Cao et al. 2003).

In our current trial, no differences were observed in the body weight and FCR of birds fed 2% soluble fibre during the starter phase. This indicates that lower levels of insoluble fibres typically remain inert in the gastrointestinal tract (Hetland et al. 2004). However, introducing higher levels of crude fibre (above 4% in our trial) can hinder nutrient absorption, resulting in poorer bird performance. The performance of young chicks given insoluble fibre varies depending on the variety of ingredients in the diet, but the effect is more pronounced when fibre inclusion levels are low (Mateos et al. 2012, 2013).

In this study, the carcase yield notably decreased as the amount of soluble fibre (SH) in the feed increased. Birds fed 0% and 2% SH in their diet exhibited significantly higher or similar wing meat yield compared to those fed higher levels of SH, where the yield decreased. There is limited literature available on the effect of SH on the carcase traits of broiler chickens. However, the findings of this study align with those of Shahin and Abd Elazeem (2005), who observed reduced carcase weight in birds fed a high-fibre diet compared to those on a control diet. Similarly, in line with the results of our trial, Sittiya et al. (2020) reported a decrease in wing meat yield in birds fed a diet containing 2.5% SH, contrasting with those on a control diet. The decrease in carcase yield with increased levels of SH in the diet is likely due to high fibre content impairing nutrient absorption and digestion efficiency, leading to less effective feed utilisation and growth. Birds fed 0% and 2% SH maintained higher or similar wing meat yields because their diets had less fibre, which allowed for better nutrient uptake and conversion into muscle mass.

The results of this trial showed no significant variations in gross organ weights except for the liver, jejunum, ileum, and abdominal fat. Birds on a 0% SH diet had significantly higher liver weight compared to those on a 4% SH diet, while the lowest liver weight was observed in birds consuming 6% and 8% SH. The liver weight of birds on a 2% SH diet was not significantly different from those on 0% and 4% SH diets, respectively. Similarly, significantly higher abdominal fat weight was recorded in birds on a control diet (0% SH), followed by a linear decline with increasing SH in their feed. The body weight of birds varies with organ size and genetic makeup (Kokoszyński et al. 2020). Therefore, it’s logical to attribute the higher body weight of birds on a control diet to their higher liver weights, although relative liver weights decreased over time (Tejeda and Kim 2020). Noteworthy disparities were found in relative organ weights among different treatment groups in this investigation, consistent with findings by Tejeda and Kim (2020), who observed similar variations in relative organ weights with increasing SH intake. However, González-Alvarado et al. (2007) found no deviations in organ weights of birds on a 3% SH diet compared to a control diet. The linear decline in liver weight with increasing SH, especially at 6% and 8%, likely reflects the adverse effects of high fibre on nutrient absorption and liver metabolism. The observed reduction in abdominal fat with increasing SH suggests that higher fibre levels improve lipid metabolism, reducing fat deposition in birds.

Additionally, Sadeghi et al. (2015) documented significant enhancement in organ weight and intestinal morphology in birds given different fibre sources. In this trial, SH provision significantly improved relative gizzard and small intestine weights. Relative gizzard weight was better in birds offered higher SH (6-8%) followed by those on 2-4% SH, while it was lowest in birds on a commercial broiler diet without SH. Similar results were observed for the percent weights of jejunum and ileum. Soybean hulls consist of a combination of insoluble and soluble carbohydrates, affecting the gastrointestinal tract (GIT) and digestive organs differently from simple fibres like refined cellulose (Tejeda and Kim 2020). Various studies have reported increases in gizzard weight in birds offered dietary fibres such as sugar beet pulp or oat hulls (Chiou et al. 1996; Jiménez-Moreno et al. 2013). Internal organs like the gizzard and intestine increase in size to compensate for higher fibre consumption, leading to higher maintenance requirements and net protein availability but potentially diverting nutrients from muscle growth and performance (Nyachoti et al. 2004). Additionally, high-performing birds can consume more feed to compensate for the poor nutrient composition of diets with added dietary fibre, possibly explaining the higher feed intake observed in birds consuming higher SH levels (6 to 8%) in this trial.

The study revealed statistically significant differences in nutrient digestibility among the groups, with birds fed 0% SH showing the highest dry matter (DM) digestibility, followed by those fed 6% SH. The lowest digestibility was observed in birds on an 8% SH diet, suggesting that higher levels of soluble fibre (SH) negatively impact nutrient absorption. It has been documented that the highly viscous soluble fibre in SH adversely affects the apparent DM digestibility coefficient (Tejeda and Kim 2020). Similar findings were reported by Silva et al. (2013), who observed lower DM digestibility in broilers with increasing levels of pectin in the feed. Birds consuming grains rich in soluble viscous non-starch polysaccharides (NSPs) also had reduced apparent DM digestibility (Shakouri et al. 2009).

An increasing trend in excreta nitrogen and ether extract content with higher SH levels indicates poorer nutrient utilisation as SH content rises. Diets with 2% to 4% SH resulted in better excreta nutrient utilisation and higher AME and AMEn compared to those with 6% and 8% SH, suggesting optimal SH levels for nutrient efficiency lie between 2% and 4%. These results are consistent with the findings of Kimiaeitalab et al. (2017), who observed a similar improvement in AMEn in broilers fed 3% sunflower hulls in the diet. Additionally, broilers consuming 2.5% oat hulls (OH) showed a 2.1% increase in the energy content of the diet, while 3.0% OH resulted in a 4.4% increase (González-Alvarado et al. 2010; Jiménez-Moreno et al. 2013). Moreover, ether extract digestibility was enhanced with the provision of 20% sunflower meal in a broiler diet (Kalmendal et al. 2011). However, the provision of 8 to 9% sunflower meal-based crude fibre reduced the digestible crude protein, fat, and gross energy in turkeys (Sklan et al. 2003), and adding 10% OH reduced AMEn in broilers (Hetland and Svihus 2001). Conversely, Tejeda and Kim (2020) found no significant differences in the apparent digestibility of crude protein and ME in birds fed various levels of soluble and insoluble fibres. These contradictory observations may be attributed to variations in the type and quantity of fibre as well as differences among the species used in the experiments.

The inclusion of SH in broiler diets had profound impacts on intestinal histomorphology and organ development, potentially associated with improvements in amino acid digestibility (Tejeda and Kim 2020). However, this enhanced digestibility appears to be linked with greater maintenance requirements of high-fibre compensating organs like the gizzard, jejunum, and ileum. This results in higher maintenance requirements, coupled with increased tissue formation and net protein availability, directing a higher flow of nutrients towards these tissues for maintenance rather than muscle growth and performance (Nyachoti et al. 2000). Tejeda and Kim (2020) reported higher amino acid digestibility and higher relative gizzard, jejunum, and ileum weights, but poorer body weight and feed conversion ratio in birds consuming 8% SH compared to those fed 4% SH in the diet, suggesting a higher allocation of nutrients towards organ maintenance compensating for fibre. This distribution of nutrients varies with the amount of fibre included in the diet. Sadeghi et al. (2015) observed changes in the intestinal architecture of broilers when consuming a diet supplemented with 30 g/kg sugar beet pulp, indicating a potential adaptive response to highly viscous fibre constituents. Additionally, laying hens fed a diet containing 10% cellulose exhibited decreased nitrogen digestibility and absorption, suggesting impaired utilisation of dietary nitrogen in these birds (Cao et al. 2003). Water-soluble fibres can produce propionic acid, acetic acid, and butyric acid through bacterial degradation, serving as energy sources, antimicrobials, and immune modulators (Liu et al. 2019), which can enhance the gastrointestinal tract and improve amino acid digestibility (Kaczmarek et al. 2016).

Birds consuming 8% SH in their diet exhibited significantly larger villi in the duodenum, while the shortest duodenal villi were observed in birds fed 4% and 6% SH. Increased intestinal reflux in the upper intestinal tract due to high fibre content has been linked to enhanced villus height (Sacranie et al. 2012; Tejeda and Kim 2020). In this trial, birds in the 0% and 2% SH groups had longer jejunal villi compared to the other treatments, consistent with the findings of Tejeda and Kim (2020) and Praes et al. (2011). Praes et al. (2011) found higher duodenal and jejunal villus height in laying hens fed 7.5% SH but observed no significant variation in bird performance. Significantly higher ileal villi height and crypt depth were recorded in birds consuming 4% SH compared to other treated birds. Dietary fibre, including SH, is known to alter intestinal morphometry (Sklan et al. 2003; González-Alvarado et al. 2007; Sadeghi et al. 2015; Rezaei et al. 2018; Tejeda and Kim 2020). SH contains various fibre types such as hemicellulose, pectin, and cellulose, which influence intestinal morphology (Stein et al. 2008). Birds fed diets with 4%, 6%, and 8% SH exhibited a reduction in ileum and jejunum villi, indicating that higher levels of fibre negatively affect intestinal health and villus development. This suggests that 2% crude fibre from SH is optimal for promoting healthy intestinal villus development in juvenile birds, ensuring adequate nutrient absorption and overall gut health. Jiménez-Moreno et al. (2011) observed increased mucosal surface abrasion, shortened villi, and increased mucus output in broilers fed 7.5% pea hulls or sugar beet pulp. Similarly, Sadeghi et al. (2015) found shortened jejunal and ileal villi in broilers fed 3% sugar beet pulp, which predominantly consisted of soluble carbohydrates, compared to those fed control and rice hull-based diets. Higher amounts of such water-soluble carbohydrates can reduce jejunal and ileal villi and may be associated with inefficient abrasive stimulus typically seen in insoluble fibres (Rezaei et al. 2018).

Conclusion

Body weight gain from 1–21 days was similar between control and 2% SH diets, but significantly declined with higher SH levels at 35 days. Relative weights of breast, leg, and wing meat remained unchanged up to 2% SH inclusion but decreased beyond this level, while carcase yield was negatively affected by all SH levels. Nutrient digestibility remained unaffected up to 4% SH inclusion but declined significantly beyond this level. The study reveals that varying levels of dietary SH significantly influence intestinal histomorphology in broilers, with notable differences observed in villi height, crypt depth, and their ratios across different segments of the intestine. In summary, including 2% SH in the diet was safe and did not negatively affect overall growth performance, carcase yield, or nutrient digestibility in broilers. However, bird performance significantly declined when the SH inclusion level exceeded 2%.

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Ethical approval

The study was approved by the ethical committee of the Faculty of Animal husbandry & Veterinary Sciences, The University of Agriculture, Peshawar, Pakistan (Approval No. 12/FAH&VS/2023).

Consent to participate

All authors are agreed to submit the article to this journal

Consent to publish

All authors are agreed to publish in this journal

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The relevant data is provided in the paper. However, any other relevant data/information regarding the research would be provided. The data of the current experiment can be obtained from corresponding author when needed.

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