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Original Article

Effects of Dietary Poppy Seed (Papaver somniferum) on Growth Metrics, Internal Organs, Gut Health, and Economic Efficiency in Japanese Quail (Coturnix coturnix japonica)

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Feed intake, feed conversion ratio, organ weight, poppy seed, quails.

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ABSTRACT

This study examined the impact of poppy seed (PS, *Papaver somniferum*) supplementation on the growth performance, organ weight, intestinal histomorphology, and economics of Japanese quail (*Coturnix coturnix japonica*) production. A total of 240-day-old unsexed Japanese quails obtained from a local market were divided into four groups: C, PS10, PS15, and PS20 in a completely randomized design (CRD). Each group was further divided into 6 replicates, with 10 quails per replicate. Group C was designated as the control group, while groups PS10, PS15, and PS20 were supplemented with PS at respectively 10, 15, and 20 g/kg in their feed for 35 days. The results showed significantly increased feed intake (449.4 g), weight gain (125.0 g), and better feed conversion ratio (3.50) in the PS20 diet group compared with the C. Similarly, significantly higher organ weight, villus height (0.990 mm) and ratio of villus height to crypt depth (VH: CD) (6.08), and the lowest crypt depth (0.164 mm) were observed in the PS20 diet group. Similarly, PS20 showed the highest gross return, net return, and cost-benefit ratio (CBR), and the lowest mortality rate as compared with all other groups. The results of this study suggest that adding PS to quails' feed can improve growth performance, reduce mortality, and enhance intestinal morphology, making it a promising approach to enhancing quail productivity.

INTRODUCTION

The most popular sources of animal protein in Pakistan are beef, milk, sheep, and poultry (Ali *et al.*, 2024; Business Recorder, 2024). As demand for animal-based protein continues to rise, scientists and researchers are actively working to enhance growth rate, feed efficiency, and meat production performance across various poultry species (Kleyn & Ciacciariello 2021). These efforts aim to maximize output while ensuring sustainability and food security. A common method is the use of various feed additives with medicinal properties (Elamin *et al.*, 2020; Hafeez *et al.*, 2020; Shuaib *et al.*, 2021; Adil *et al.*, 2023; Ullah *et al.*, 2024).

Poppy seed (PS) (*Papaver somniferum*), also known as opium poppy, postbeej, khaskhas, mohansaat, postdana, and khashkhashsafed, belongs to the Papaveraceae family. It is high in thiamin, iron, magnesium, calcium, manganese, phosphorus, potassium, sodium, zinc, vitamin C, and vitamin E (USDA, 2019). Although poppy seeds are obtained from the dry capsules (pods) of the opium poppy (*Papaver somniferum*), the seeds themselves do not naturally contain opium alkaloids; however, contamination with morphine or codeine may occur during harvesting and processing. (Knutsen *et al.*, 2018). The seeds are either white or black, and the oil content ranges from 40 to 60%

(Salunkhe & Deshpande 2012). PS contains varying levels of crude protein, crude fiber, and crude energy, as well as considerable amounts of essential minerals (Pushpangadan *et al.*, 2012). In India, PS is produced at 50-60 kg per hectare, and legal poppy cultivation is mainly practiced in the state of Uttar Pradesh (Mishra & Pathak, 2021).

The incorporation of alternative plant-based feed additives in poultry nutrition has gained considerable attention due to rising feed costs and the need for sustainable production systems (Adil *et al.*, 2023). PS is rich in essential fatty acids, proteins, dietary fiber, and minerals such as calcium, magnesium, and zinc, which may contribute to improved nutrient utilization and growth performance in poultry (Pushpangadan *et al.*, 2012; Muhammad *et al.*, 2021). Additionally, PS contain bioactive compounds and antioxidants that may enhance gut health and immune function (De, 2020; Nevara *et al.*, 2023). From an economic perspective, the use of locally available plant-derived feed ingredients such as PS could reduce dependence on conventional protein sources and improve production efficiency in poultry enterprises (Muhizi & Kim, 2021; Khan *et al.*, 2024a).

The literature shows that PS is a rich source of various nutrients, yet very little research has been conducted on its inclusion in diets and its impact on various aspects of quails. Therefore, the current study evaluated the effect of PS supplementation on growth performance, gut morphology, and economics of Japanese quail (*Coturnix coturnix japonica*) production.

MATERIALS AND METHODS

Ethical Approval of the Study

Approval for this study was obtained from the Ethical Committee of the Faculty of Animal Husbandry and Veterinary Sciences at the University of Agricultural Peshawar, Pakistan (No: 478/PS/UAP, dated March 04, 2023).

Study Location and Bird Husbandry

This experiment was conducted at the Poultry Complex, Department of Poultry Science, University of Agriculture, Peshawar, Pakistan. For the experiment, unsexed 240-day-old Japanese quails (*Coturnix coturnix japonica*), a strain primarily utilized for egg production, were obtained from a nearby market and reared on a deep litter system in metallic cages (80 × 60 × 45 cm), which were equipped with feeders and water drinkers for ease of access. Quails were supplied with *ad libitum* access to feed and clean water in wire cages, ensuring consistent management, sanitary conditions, and a stable environment. Incandescent bulbs were used for both heating and lighting. The house had a temperature of 35°C for the first five days, which gradually decreased.The temperature was maintained at 35°C for the first five days and was gradually decreased. Starting from day 10, an ambient temperature of 23 to 25 °C and a 17-hour light period were maintained until the end of the experiment (35 days). To protect the quails against viral infections, an appropriate vaccination regimen (Newcastle disease and infectious bursal disease) was administered on designated days during the study.

Experimental Diets and Layout

Layer feed was used for the experimental quails, as shown in Table 1. Poppy seeds (PS) were obtained from the local market and used as a feed supplement after the brooding period (first 7 days), from day 8 until the birds reached market weight on day 35. The nutritional value of raw PS is indicated in Table 2. In a completely randomized design (CRD), quails were divided into four groups (C, PS10, PS15, and PS20), and each was further divided into six replicates with 10 birds each. Group C was designated the control group, while the remaining groups were supplemented with PS at 10 g/kg, 15 g/kg, or 20 g/kg. Figure 1 shows the experimental design.

Table 1 – Composition of experimental diet.

Ingredients	(%)
Corn	54.10
Canola meal (34%)	4.150
Soybean meal (44%)	24.30
Poultry by-product meal Hi-fat	2.000
Poultry Oil	2.790
Salt	0.320
Sodium bicarbonate	0.100
Limestone/Chips	11.10
Dicalcium phosphate	0.770
DL-Methionine	0.080
Choline chloride (70 %)	0.100
Vitamin premix broiler*	0.070
Mineral premix*	0.060
Phytase	0.010
Enramycin	0.020
Ethoxyquin/Antioxidant	0.010
Non-starch polysaccharides	0.020
Total	100.0

One kg of diet provided: Retinyl acetate, 4400 IU; DL-α-tocopheryl acetate 12 IU; Cholecalciferol 118μg; Thiamine 2.5mg; Menadione sodium bisulfite 2.40 mg; Niacin 30mg; Vit.B_2 4.8 mg; D-pantothenic acid 10 mg; Vit. B_6 5mg; Vit. B_7 130 μg; Cyanocobalamine 19 μg; Vit.B_9 2.5 mg; Mn 85 mg; Zinc 75 mg; Fe 80 mg; Iodine 1 mg; Selenium 130 μg; Copper 6 mg.

Table 2 – Nutritional value of 100 g of raw poppy seed (USDA,2019).

Calories	425
Total fat	41.6 g
Fiber	19.5 g
Carbohydrate	41.6 g
Sodium (Na)	26 mg
Calcium (Ca)	1440 mg
Iron (Fe)	9.76 mg
Magnesium (Mg)	347 mg
Manganese (Mz)	6.71 mg
Phosphorus (P)	870 mg
Potassium (K)	719 mg
Zinc (Zn)	7.9 mg

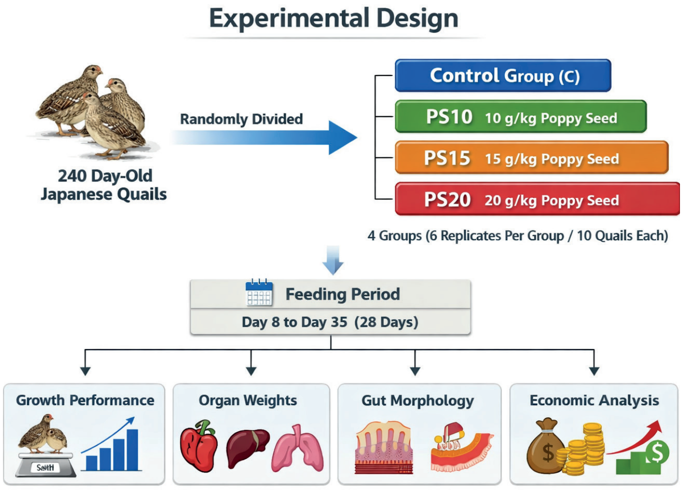

Figure 1 – Experimental design.

Production Performance Metrics

Production performance metrics, such as feed intake (FI), weight gain (WG), and feed conversion ratio (FCR), were calculated weekly from days 8 to 35. The amount of FI was determined by subtracting the amount of feed rejected from the total feed supplied each day. The WG was calculated by subtracting the initial weight from the final weight. The FCR was determined by dividing FI by the WG (Shahzad *et al.*, 2024).

Feed intake = Feed offer- feed rejected

Weight gain = Final weight-initial weight

Feed conversion ratio = Feed intake/weight gain

Mortality was recorded throughout the experiment, and *post-mortem* examinations were conducted on the deceased birds to determine the cause of death.

Organ Weights and Carcass Traits

At the end of the trial, a sample of three quail was randomly selected from each replicate to determine their live body weight. The quails were humanely euthanized, and their feathers removed. Their carcasses were eviscerated. The dressed carcasses were allowed to air-dry for one hour to remove any residual moisture before being weighed. Subsequently, the carcasses were divided into individual cuts, including the breast, thigh, wings, and neck, and weighed again to determine the weight of each segment. To measure the effect of PS, lymphoid organs were weighed and quantified after collection. The following formulas were used to calculate the ratios of the thymus, bursa, and spleen (Meher *et al.*, 2021):

Thymus, bursa, and spleen weight ratio = Relative organ weight (g)/Live body weight (g) ×100

Gut Morphology

At the end of the trial, two quails per replicate were selected randomly and subjected to terminal sampling to evaluate gut morphology (Mushtaq *et al.*, 2024). The harvested jejunum samples were fixed in 10% formalin. Using the embedding technique in the microtome (Model: SRM 200 CW, Accu-Cut, SRM 200, Netherlands), four cross-sections were prepared for each sample. The histological sections were stained using hematoxylin and eosin. The height and width of the villi were measured using a Nikon Eclipse 50 microscope (Nikon Corporation, Japan), with two villi randomly selected from each slide within a single microscopic field. The measurements were taken using a graded eyepiece with a 10X objective lens, and two fields were used to quantify the villus widths (VW), villus height (VH), and crypt depth (CD) under the microscope. The VH was calculated as the distance from its tip to the point of intersection with the crypt. At the same time, the VW was defined as the distance between the outer edges of the epithelial layer, measured horizontally from a line bisecting the villus's vertical midline.

Economics Parameters

Economic calculations were based on the combination of feed costs and the cost of supplementing ingredients (Ullah *et al.*, 2024). Total expenses, including feed, chicks, labor, electricity, and medicine incurred per chick during the experiment were used in the calculations. The gross return was determined using the market price of quails. The following equations were used to calculate the economic parameters.

Total cost = Feed cost, chick cost, electricity, and medicine costs

Gross return = Number of quails × Price per quail

Net return/Profit = Gross return-Total expenses

Cost-benefit ratio = Gross return ÷ Total expenses

Statistical Analysis

A completely randomized design (CRD) was used to analyze the experimental data. Analysis of variance (ANOVA) was performed using the software SPSS 2.0 (IBM Corp., USA). GraphPad Prism 8 (San Diego, CA, USA) was used to create histograms. The LSD test was used to compare the means at a 5% significance level ($p<0.05$).

RESULTS

Production Performance Metrics

The results of the impact of poppy seed (PS) supplementation on production performance metrics in quail are presented in Table 3. The data showed that adding PS to the diet significantly affected feed intake (FI) throughout the trial. Groups PS20 and PS15 showed significantly higher FI than the control (C). The data showed that adding PS to the PS20 diet resulted in higher weight gain (WG) ($p<0.05$) in comparison to the C, PS10, and PS15 groups during the third and fourth weeks. Overall, the highest WG values were observed in the PS20 group, while the C group had the lowest. There were no significant differences among the C, PS10, and PS15 groups. The data indicate that PS had a significant effect on the total and weekly feed conversion ratio (FCR), except for the second week. The PS20 group exhibited a significantly better FCR ($p<0.05$) than the PS10 and the control. Figure 2 shows the relationship between PS supplementation and quail mortality rate. The results indicate that the control group experienced the highest mortality rate at a rate greater than 5%. Group PS10 exhibited a mortality rate of approximately 4%, which was not statistically distinct from that of the PS15 group. In contrast, the PS20 group, with the highest level of PS supplementation, had the lowest mortality throughout the trial.

Table 3 – Effect of poppy seed supplementation on production metrics in quails.

Diets*	Feed intake (g)	Weight gain (g)	FCR
Week2			
C	59.5^{b}	27.5	2.16
PS10	66.8^{a}	29.5	2.25
PS15	64.0^{ab}	26.1	2.44
PS20	65.8^{a}	29.7	2.21
SEM	2.54	2.13	0.22
p-value	0.047	0.016	0.108
Week3			
C	99.4^{a}	24.1^{c}	4.11^{a}
PS10	97.7^{a}	26.5^{b}	3.67^{b}
PS15	90.9^{b}	26.0^{b}	3.48^{b}
PS20	91.4^{b}	30.1^{a}	4.06^{a}
SEM	1.88	1.65	0.25
p-value	0.003	0.012	0.014
Week4			
C	124.9^{b}	28.1^{b}	4.43^{a}
PS10	124.2^{b}	28.25^{b}	4.39^{a}
PS15	128.1^{a}	29.4^{b}	4.35^{ab}
PS20	126.3^{ab}	31.0^{a}	4.06^{b}
SEM	1.11	1.72	0.24
p-value	0.015	0.003	0.010
Week5			
C	154.0^{b}	32.2	4.77^{b}
PS10	156.2^{b}	32.2	4.84^{b}
PS15	165.6^{a}	32.2	5.13^{a}
PS20	165.8^{a}	34.0	4.86^{b}
SEM	1.42	1.65	0.25
p-value	0.000	0.007	0.006
Overall			
C1	437.8^{b}	112.0^{b}	4.00^{a}
PS10	444.9^{ab}	116.6^{ab}	3.90^{a}
PS15	448.9^{a}	113.9^{b}	3.81^{ab}
PS20	449.4^{a}	125.0^{a}	3.50^{b}
SEM	3.02	5.08	0.39
p-value	0.003	0.000	0.011

Data are presented as mean and pooled standard deviation (SD). Data are presented as mean and pooled standard deviation (SD).Means within the same column followed by different superscripts differ significantly ($p<0.05$). *C = Control with standard diet, PS10 = Basal diet with 10 g/kg PS supplementation, PS15 = Basal diet with 15 g/kg PS supplementation, and PS20 = Basal diet with 20 g/kg PS supplementation.

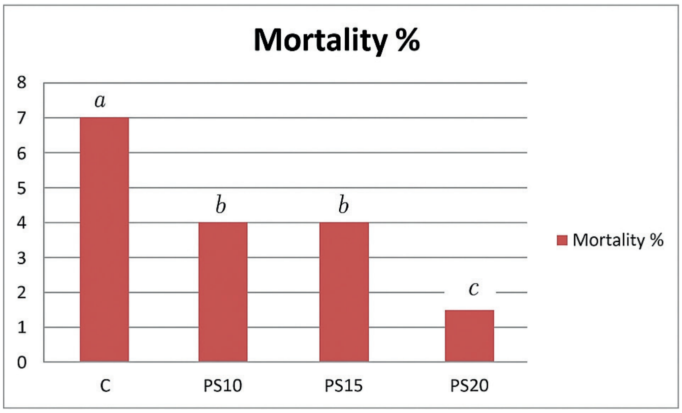

Figure 2 – Effect of poppy seed supplementation on quail mortality. The different superscript on bars shows a significant difference ($p<0.05$). C = Control group with standard diet, PS10 = Basal diet with 10 g/kg PS supplementation, PS15 = Basal diet with 15 g/kg PS supplementation, and PS20 = Basal diet with 20 g/kg PS supplementation.

Organ Weights and Carcass Traits

The results of the effect of PS supplementation on organ weight (OW) are presented in Table 4. PS supplementation significantly affected all organ weight parameters, including live body weight (LBW), breast weight (BW), thigh weight (TW), wing weight (WW), and neck weight (NW). Among these parameters, the highest values were observed for LBW, BW, TW, WW, and NW in the PS20 group as compared to the control. The data show that PS supplementation significantly increased thymus, spleen, and bursa weight, with the PS20 group exhibiting the highest values. The thymus, spleen, and bursa weights of PS20 were significantly higher than those of the control (p<0.05).

Table 4 – Effect of poppy seed supplementation on organ weight in quails.

Groups*	Organs' weight (g)							
	LBW2	BW	TW	WW	NW	TW	SW	BW
C	149.6^{c}	36.83^{c}	23.50^{b}	8.13^{b}	7.53^{b}	0.123^{c}	0.273^{b}	0.133^{b}
PS10	159.0^{b}	39.53^{ab}	25.06^{a}	8.53^{b}	7.60^{b}	0.128^{b}	0.320^{b}	0.132^{b}
PS15	155.0^{b}	39.00^{b}	22.40^{b}	7.96^{b}	7.60^{b}	0.132^{a}	0.306^{b}	0.139^{a}
PS20	173.0^{a}	41.00^{a}	25.53^{a}	9.46^{a}	8.36^{a}	0.136^{a}	0.390^{a}	0.141^{a}
SEM	2.57	0.80	0.23	0.30	0.19	2.06	0.02	1.94
p-value	0.001	0.007	0.001	0.001	0.003	0.004	0.021	0.006

Data are presented as mean and pooled standard deviation (SD). Means within the same column followed by different superscripts differ significantly (p<0.05). The organ's weight was measured in grams (g). *C = Control with standard diet, PS10 = basal diet with 10 g/kg PS supplementation, PS15 = basal diet with 15 g/kg PS supplementation, and PS20 = basal diet with 20 g/kg PS supplementation. [2]LBW, Live body weight; BW, Breast weight; TW, Thigh weight; WW, Wings weight; NW, Neck weight; TW, Thymus weight; SW, spleen weight; BW, Bursa weight.

Gut Morphology

Table 5 shows the impact of supplementing quail's feed with PS on intestinal morphology. The results indicate a substantial effect on the height of the villi and the ratio of villi height to crypt depth in the quail's intestine. Among the groups, the greatest villus height (VH) was recorded in the PS20 group (p<0.05) compared with the rest. However, the control group (C) and the PS10 groups did not differ significantly.

Table 5 – Effect of poppy seed supplementation on intestinal histomorphology in quails.

Groups	Intestinal histomorphology parameters			
	VH (mm)	VW (mm)	CD (mm)	VH: CD
C	0.550b	0.250	0.313a	1.826b
PS10	0.566b	0.204	0.275a	2.076b
PS15	0.550b	0.242	0.309a	1.843b
PS20	0.990a	0.186	0.164b	6.081a
SEM	0.05	0.02	0.03	0.54
p-value	0.001	0.080	0.008	0.002

Data are presented as mean and pooled standard deviation (SD). Means within the same column followed by different superscripts differ significantly (p<0.05). *C = Control with standard diet, PS10 = basal diet with 10 g/kg PS supplementation, PS15 = basal diet with 15 g/kg PS supplementation, and PS20 = basal diet with 20 g/kg PS supplementation. Abbreviations: millimeter (mm); Villus height (VH); Villus width (VW); Crypt depth (CD).

Crypt depth (CD) was significantly lower in PS20 compared with the other treatments (p<0.05). The highest VH/CD ratio was observed in the PS20 group, which was significantly higher than in all the other treatments (p<0.05).

Economics Parameters

Table 6 shows the influence of PS supplementation on economic parameters per quail. The PS20 group had the highest (p< 0.05) total cost (TC), gross return (GR), net return (NR), and cost-benefit ratio (CBR) among all groups (PS15, PS10, and C). Group C resulted in the lowest value for these parameters.

Table 6 – Effect of poppy seed supplementation on economic parameters in quails.

Groups*	Economics' parameters (PKR)			
	TC1	GR	NR	CBR
C	106.9^{c}	128.9^{c}	22.15^{c}	1.20^{c}
PS10	109.0^{b}	131.0^{b}	22.19^{c}	1.20^{c}
PS15	108.3^{b}	133.0^{b}	24.94^{b}	1.22^{b}
PS20	115.4^{a}	154.6^{a}	27.12^{a}	1.33^{a}
SEM	0.63	4.16	0.18	0.33
p-value	0.001	0.030	0.001	0.021

Data are presented as mean and pooled standard deviation (SD). Means within the same column followed by different superscripts differ significantly (p<0.05). Economic parameters are calculated in Pakistani rupees (PKR). *C = Control with standard diet, PS10 = Basal diet with 10 g/kg PS supplementation, PS15 = Basal diet with 15 g/kg PS supplementation, and PS20= Basal diet with 20 g/kg PS supplementation. [1]TC= total cost; GR= Gross return; NR= Net return; CBR= Cost benefit ratio.

DISCUSSION

In recent decades, poppy seeds (PS) have been increasingly used as feed additives in animal nutrition, attracting growing attention. The use of feed additives often improves animals' overall development, health, and well-being (Shuaib *et al.*, 2022; Khan *et al.*, 2024a; Ul Saqib *et al.*, 2025). In this study, the PS20 group exhibited the highest growth performance metrics. Enhanced feed consumption was observed in the PS20 group, while this parameter was the lowest in the control group. The increased FI in the PS20 group might be attributed to the high levels of essential fatty acids (omega-3 and 6) in PS, which increased appetite and stimulated digestive enzymes (Simopoulos, 2016). Enhanced FI in the PS20 group may be due to improved diet quality. Similar results have been obtained in laying hens (Küçükersan, 2009). The findings of this study are also in line with those of Bayram *et al.* (2006), who concluded that supplementation of 25% poppy seed meal (PSM) in broiler diets significantly increased FI. Similarly, a significantly higher FI was observed in broilers fed a diet supplemented with 20% PSM compared with the control group (Khan *et al.*, 2024b).

The addition of PS significantly influenced the weight gain (WG) of quails. Overall, maximum body WG was recorded for the PS20 group, while the lowest WG was recorded for the control group. The improved WG in this group may be due to the higher FI and the essential nutrients in PS (Bayram *et al.*, 2006). Our outcomes agree with the findings that pigs fed PS showed a significant increase in body weight gain throughout the trial (Muhammad *et al.*, 2021). Additionally, broilers showed a significant increase in WG when fed a diet supplemented with 20% PSM compared with the control group (Khan *et al.*, 2024b). Similarly, in another study, PS was found to have a positive effect on WG compared with the control group in broilers (Bayram *et al.*, 2006). PS is rich in essential fatty acids (omega-3 and omega-6), high-quality proteins, and minerals such as calcium, magnesium, zinc, and phosphorus, making it a nutrient-dense feed ingredient (USDA, 2023). These nutrients play important roles in metabolic processes, enzyme activation, and protein synthesis, which may enhance nutrient utilization and growth performance in poultry (Alagawany *et al.*, 2019). Additionally, the presence of dietary fiber and bioactive compounds may promote digestive efficiency, modulate gut microflora, and improve nutrient absorption (Jha & Mishra, 2021).

An overall better feed conversion ratio (FCR) was recorded in the PS20 group, which is consistent with the work of Muhammad *et al.* (2021), who found that supplementation of PSM in the quail diet had a significant effect on FCR compared with the control group. Similarly, a significantly improved feed efficiency was reported in broilers fed a diet with 20% PSM compared with the control group (Khan *et al.*, 2024). The present study reveals the significant effect of PS incorporation in the quail diet, which is similar to the report of a significant impact of PS on the quail FCR (Bayram *et al.*, 2008).

PS supplementation in quail feeds significantly affected their mortality rate. The control group experienced the highest mortality rate, exceeding 5%, while the PS20 group had the lowest mortality throughout the trial. PS supplementation may cause this effect by providing a source of essential fatty acids and antioxidants. These nutrients possess anti-inflammatory and immune-boosting properties (De, 2020), which may help protect the birds from diseases and enhance their overall health. Additionally, the high levels of protein and fiber in PS may aid in digestion and nutrient absorption, further promoting the overall health and well-being of the birds (Nevara *et al.*, 2023). The higher mortality rate observed in the control group had no specific identified cause. However, it is suggested that environmental factors or the absence of PS supplementation may have contributed to this outcome, and further studies are required to confirm this hypothesis.

The results of the present trial show a significant increase in live body weight, breast weight, thigh weight, wing weight, neck weight, thymus weight, spleen weight, and bursa weight in the PS20 group, whereas the control group recorded the minimum values. Similarly, significantly higher live BW was observed in broilers fed 20% PSM in the diet compared with other groups in the experiment (Khan *et al.*, 2024b). Increase in the live BW and organ weight in the present study might be attributed to the nutrient value of PS (zinc, lysine, fiber, calcium, iodine, magnesium, and copper), which promotes stronger immunity, improved metabolism, secretion of digestive enzymes, and a healthy gut by supporting intestinal health (Muhammad *et al.*, 2021; Khan *et al.*, 2024ab).

Intestinal morphometry of quails was significantly affected by PS supplementation, with the results showing significant increases in VH, CD, VW, and VH: CD in the PS20 group and the lowest values in the control group. This effect may be attributed to specific nutrients or chemicals in the PS that influence the growth and development of intestinal tissue (Muhammad *et al.*, 2021). Additionally, the second reason is improved digestion, which increases the surface area for nutrient absorption. The enhancement in intestinal morphology observed in the PS20 group may be associated with the presence of bioactive compounds, dietary fiber, and essential fatty acids in PS (USDA, 2023). These components may stimulate intestinal epithelial cell proliferation, improve gut microbial balance, and increase digestive enzyme activity, thereby enhancing nutrient absorption efficiency (Alagawany *et al.*, 2019; Jha & Mishra, 2021).

Economically, the PS20 group had the highest gross return and net return among all groups. Since PS contains phenolic compounds, adding them to the diet of quails may have increased the FCR and WG by raising the body's metabolic rate. On the other hand, PS are high in protein and energy, which help increase the weight of birds' bodies and organs (Muhizi & Kim, 2021). Greater economic value mainly depends on the market value of the feed, available ingredients, and the price of birds and meat at that specific time. The practical implications of our work for quail production include identifying ideal PS inclusion levels, balancing nutrient profiles for growth and carcass quality, assessing economic viability, and analyzing industry adoption.

CONCLUSION

Overall, supplementation with PS at 20 g/kg feed has significantly improved production performance metrics, intestinal histomorphology, and economic parameters, while also reducing mortality in quails. The results suggest that PS could be a viable alternative feed ingredient for poultry species. Further research is needed to determine the optimal dose of PS supplementation in other poultry species and to explore the potential health benefits of this plant for various food and medicinal applications.

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ETHICS STATEMENT

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AUTHOR CONTRIBUTIONS

Imran Stanikzai: Conceptualization, methodology, interpreted the study findings, writing-review & editing. Imran Ullah: Conceptualization, methodology, formal analysis, supervision, writing-review & editing. Muhammad Shuaib: Formal analysis, software, writing-original draft preparation, visualization. Sohaib Ul Hassan, Muhammad Mukhtiar, Kasim Sakran Abass, Muhammad Shahkar Uzair, Azizullah Khan, Muhammad Fazal Hameed, Wing-Fu Lai, Hani A. Ba-Awadhi, Alaa Bassuny Ismael and Ayman A. Swelum: Validation, data curation, writing-review & editing. All authors read and approved the final manuscript.

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DATA AVAILABILITY STATEMENT

Data are available from the corresponding author upon reasonable request.

CONFLICT OF INTEREST

The authors declared no conflicts of interest.

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