JWPR
Journal of World's Poultry Research

2026, Scienceline Publication
J. World Poult. Res. 16(1): 42-52, 2026
Research Paper
DOI: https://dx.doi.org/10.36380/jwpr.2026.5
PII: S2322455X2600005-16

ISSN: 2322-455X

Effects of *Opuntia Ficus-Indica* Fruit Cake and Seeds on Growth Performance and Carcass Yield of Broiler Chickens

Souheila Bouchra Benlaksira[1], Samia Djeffal[2,3]*, and Fairouz Djeghim[4]

[1]*Laboratory of Pharmacotoxicology, Institute of Veterinary Sciences, University of Frères Mentouri, Constantine1,25000, Algeria.*
[2]*GSPA Research Laboratory (Management of Animal Health and Productions), Institute of Veterinary Sciences, University of Frères Mentouri, Constantine1,25000, Algeria*
[3]*Department of Agronomy, University of Skikda, August 20, 1955, 21000, Algeria*
[4]*FNPAA team, Laboratory of Nutrition and Food Technology (L.N.T.A), Institute of Nutrition, Food and Agro-Food Technologies (INATAA), University of Frères Mentouri, Constantine1,25000, Algeria*

*Corresponding author's E-mail: s.djeffal@univ-skikda.dz

Received: December 16, 2025, Revised: January 20, 2026, Accepted: February 11, 2026, Published: March 05, 2026

ABSTRACT

In dry and semi-arid environments, prickly pears (*Opuntia ficus-indica*) are commonly used for their nutritional and commercial value. Cladodes are used for animal feed, and the fruits are consumed as a traditional food. The present study aimed to investigate the effects of incorporating *Opuntia ficus-indica* (*O. ficus-indica*) fruit seeds and cakes into broiler chickens' diets. A total of 100 one-day-old broiler chickens with an average body weight of 52 grams were reared for 49 days and allocated to four dietary treatments. The first group received diets supplemented with 5% *O. ficus-indica* fruit seed (S5), and the second group received diets supplemented with 10% *O. ficus-indica* (S10). The third group received either fruit seed cakes at 5% (C5), and the fourth group received fruit seed cakes at 10% (C10). Broiler growth performance and efficiency were assessed weekly. Mortality was recorded for all groups during each rearing phase, and seven carcass characteristics were documented for ten broiler chickens at the end of the trial. Finally, to evaluate the safety of the plant inclusion, a panel of blood biochemical parameters, including total protein, cholesterol, urea, creatinine, aspartate aminotransferase (AST), alanine aminotransferase (ALT), and triglycerides, was analyzed on day 49. Supplementing at 10% notably increased carcass weight and yield, and both 5% and 10% levels significantly enhanced feed efficiency across the groups. Group S5 had the lowest consumption index value (1.67), while the control group had the highest (2.60). Compared to the control group, which received only a basic feed (69.06%), Group S10 had the highest carcass yield (78.16%). The biochemical parameters of all groups were in agreement with reference values and lower than those recorded in the control group. The current findings emphasized the potential of *O. ficus-indica* as a valuable feed additive to improve broiler growth and carcass quality, without affecting biochemical parameters.

Keywords: Biochemical parameter, Broiler chicken, Growth performance, *Opuntia ficus-indica*

INTRODUCTION

In Algeria, the cost of raising animals depends on the importation of feed ingredients (Cherif et al., 2021). In poultry farming, soybean meal and corn are major raw materials, forming the foundation of many feed formulations. Although corn serves as a main energy source and soybean meal as a protein source, the extent of their dependence on imports differs across regions (Katu et al., 2025). Given fluctuations in the prices and supplies of key agricultural commodities, such as cereals and protein sources in international markets, exploring sustainable alternative feed ingredients has become essential to reduce production costs and enhance the productivity of livestock systems.

In dry and semi-arid areas, prickly pears (*Opuntia ficus-indica* L. Mill) are extensively grown for their nutritional and commercial value. The fruits of *Opuntia ficus-indica* (*O. ficus-indica*) are consumed locally, whereas the cladodes provide essential fodder for livestock. Furthermore, the bioactive components found within the plant possess potential applications in the culinary, pharmaceutical, and cosmetic industries (Inglese et al., 2018; Cherif et al., 2021). *Opuntia ficus-indica* is well adapted to water-scarce conditions and is part of the *Opuntia* genus, the largest and most widespread group within the *Cactaceae* family, comprising approximately 130 genera and 2,000 economically important species (Abouseadaa et al., 2020). *Opuntia ficus-indica* is cultivated in North Africa to fight desertification and prevent soil erosion (Belhadj Slimen et al., 2021). Besides its oil, which is one of the richest in vitamin E and essential fatty acids worldwide, the plant is also known for its many therapeutic benefits. *Opuntia* cultivation has advanced considerably in the Maghreb, functioning both as a diversification activity and as a supplement for herd feeding (Ayouz et al., 2012). Prickly pear plantations may be a viable approach to preserving Algerian steppes and marginal areas that have lost their agropastoral vocation (Neffar et al., 2011). From an ecological perspective, the cactus's morphological evolution, driven by climatic adaptation, underscores its additional importance (Taha et al., 2023).

The fruits of *O. ficus-indica* are rich in carbohydrates, dietary fiber, vitamins, and minerals, while the seeds and cladodes provide valuable lipids, proteins, and polyphenolic compounds (Giraldo Silva et al., 2023). These bioactive constituents confer antioxidant, anti-inflammatory, and hypoglycemic properties, making the plant a promising candidate to use as a functional food and a therapeutic agent (Ahmed et al., 2024). The plant is an important food source for different populations and contains natural antioxidants such as flavonoids, ascorbic acid, and carotenoids (Temagoult, 2017). Cladodes are known for their high nutritional value, particularly their abundance of minerals, proteins, dietary fiber, and phytochemicals, which contain bioactive compounds with proven health benefits (De Santiago et al., 2019; Silva et al., 2021). Traditional use of *O. ficus-indica* in food and medicine can explain the growing scientific interest in this plant. (Shoukat et al., 2023). The plant's seeds, which are used to extract oil, represent another profitable by-product besides that cladodes (Giuseppe and Foti, 2025). Oil cakes are the solid residues left after extracting oil from oleaginous seeds or fruits and are significant by-products of the oil-processing industry (Grahovac et al., 2025). Oil cakes are increasingly valued in animal nutrition as a cost-effective protein source (20-50%) and as a sustainable alternative in feed formulation. Their integration into poultry and livestock diets not only reduces feed costs but also enhances productivity and promotes the valorization of agro-industrial by-products (Pastorelli et al., 2022).

Extraction meals and expellers have the greatest economic significance. The extraction meals are especially valuable in traditional poultry management systems (Chitra, 2021). Several studies have indicated that *O. ficus-indica* by-products can be incorporated into animal feed without detrimental effects on the animal's performance (Moula et al., 2019; Tsega et al., 2020; Cherif et al., 2022; Benteboula et al., 2023). The application of such by-products has occasionally been linked to improved carcass quality and higher growth efficiency. Consequently, using locally sourced feed ingredients in poultry feed lowers production costs and reduces the risk of environmental pollution (Mutinda, 2023). The seeds and processing leftovers of *O. ficus-indica* are frequently neglected, despite being rich sources of nutrients such as fiber, lipids, and bioactive compounds. The present study aimed to assess the effects of *O. ficus-indica* fruit seeds and cakes added to broiler chickens' feed on their growth performance and carcass characteristics quality.

MATERIALS AND METHODS

Ethical approval

The present study was conducted in accordance with ethical guidelines approved by the scientific council of the Institute of Veterinary Sciences, Mentouri Brothers University, Constantine 1, Algeria, and with the guidelines for animal care and use in research.

Preparation of *Opuntia ficus-indica* fruit seed and cake

Opuntia ficus-indica fruits were collected in October 2019 from Constantine region (Northeast Algeria). Only ripe and healthy fruits were selected, thoroughly washed with running water, air-dried at 30°C, and manually peeled. After being extracted from the fruit, the seeds were cleaned of pulp using distilled water and allowed to dry for 72 hours at room temperature. The seeds were ground into a powder using an electric grinder (AOAC, 1990). Chemical analysis was conducted in accordance with AOAC protocols. Press cake of *O. ficus-indica* was mechanically produced at an agro-industrial facility in Souk Ahras, eastern Algeria. The solid residue resulting from the pressing process was converted into pelleted feed. Seed oil was extracted by cold pressing, and the resulting solid residue was then converted into granules.

Study design

The study was conducted in a poultry facility located in the Constantine region (Eastern Algeria) and involved 100 one-day-old broiler chickens (Cobb 500) with an average body weight of 52 g. Chickens were randomly allocated to five groups, with 20 broiler chickens per group. The chickens were reared on wood-shaving litter at a stocking density of 20 chickens per 1.5 m². Before chicken placement, the facility was thoroughly washed with detergent, then disinfected with sodium hypochlorite 5% and formalin 20%, and subjected to a 15-day sanitary downtime.

Breeding conditions and dietary treatments

All groups were raised under established management conditions for Cobb 500 broiler chickens, according to the latest updated catalog. The ambient temperature was 32°C for the first three days, then dropped to 22-24°C at one month of age and to 18°C during the finishing period.

Static ventilation was provided by windows (1 m × 0.6 m) positioned 2.8 m above the floor. The lighting program consisted of continuous illumination (24 hours) during the first three days, reduced progressively to 14 hours between days 16 and 21, and then increased by 2 hours per week to reach 22 hours of light.

All groups received the same preventive treatment, including vaccinations against infectious bronchitis and Newcastle disease (Cevac Vitabron, French laboratory) at day one by nebulization, followed by infectious bursal disease (Cevac IBDL, French laboratory) at day 14 by the oral route. Newcastle (Nobilis Ma5 plus Clone30, MSD USA laboratory) and infectious bronchitis (PHY.LMV.42 plus Massachusetts H120) vaccines were administered orally on day 21.

All groups were given a standard commercial feed. The diet mainly included corn, soybean meal, and wheat bran, serving as key sources of energy and protein. This nutritional foundation provided the essential calories and amino acids needed throughout the trial period (Table 1).

To assess the nutritional impact of cactus, the broiler chickens were divided into five experimental groups. The control group received only the standard feed. The first treatment group received the basal diet supplemented with 5% of *O. ficus-indica* seed (S5), and the second group received 10% of *O. ficus-indica* seed (S10). The third treatment group fed the basal diet supplemented with 5% of *O. ficus-indica* oilseed meal (C5), and the fourth group received 10% of *O. ficus-indica* oilseed meal (C10). Throughout the experiment, feed intake was rigorously weighed before distribution, and water was provided *ad libitum*.

Table 1. Food composition of the commercial diet during the study

Ingredient (%)	**Starter (Days 1-14)**	**Grower (Days 15-35)**	**Finisher (Days 36-49)**
Soybean meal	32.60	29.00	24.00
Corn	54.50	56.90	64.00
Wheat bran	9	10	7.50
Vitamin-mineral premix*	0.80	0.80	0.90
Enzymes and yeasts	0.10	0.10	0.10
Anticoccidials	0.10	0.10	-
Mycotoxin binder	0.10	0.10	0.10
Soybean oil	0.60	1.00	1.30
Dicalcium phosphate	1.15	1.00	1.00
Calcium carbonate	1.05	1.00	1.10
Calculated composition (%)			
Humidity level	11.43	11.57	11.53
Total dry matter	88.57	88.43	88.47
Total atolled matter crude protein	22.70	20.10	20.00
Fat content	2.65	3.95	4.35
Raw ashes	4.94	5.80	4.61

*Vitamin-mineral premix (additives per kg of product): Retinol: 666,000 IU, Cholecalciferol: 299,700 IU, Tocopherol: 1665 IU, Menadione: 100 mg, Riboflavin: 266 mg, Calcium pantothenate: 549 mg, Niacin: 1319 mg, Pyridoxine Hydrochloride: 133 mg, Cyanocobalamin: 0.8 mg, Biotin: 10 mg, Folic acid: 37 mg, Choline chloride: 19,999 mg, Folic acid: 37 mg, Thiamine: 83 mg. Minerals: Copper (Cu): 666 mg, Zinc (Zn): 3996mg, Manganese (Mn): 4995mg, Iron (Fe): 2331 mg, Iodine (I): 100 mg, Selenium (Se): 17 mg, Amino acids: DL-methionine, 120,000 mg, L-Lysine Monohydrochloride: 200,000 mg, L-Threonine: 53,330 mg.

Data collection and zootechnical parameters

Feed intake (FI) and feed conversion ratio (FCR) were calculated by weighing the amounts of feed supplied and any refusals every day. Three diets were administered according to the rearing phases, including starter (days 1-14), grower (days 15-35), and finisher (days 36-49), with transitions between phases implemented gradually over three days. The drinking water was adjusted at each distribution throughout the rearing period as well as the feed which contained two supplements (5% and 10% of fruit cake and seeds), the proportion of which was recorded on the first day, then every week (days 7, 14, 21, 28, 35, 42 and 49), always before the distribution of the feed using an electronic balance with a capacity of 5 kg and a precision of 1 g within the rearing facility. Mortality cases were recorded in the breeding technical sheet.

Zootechnical parameters, including FI, total weight gain (TWG), FCR, and mortality rate (MR), were calculated based on the collected data.

Biochemical parameters and carcass yield

On day 49, blood samples were collected from 10 randomly selected chickens of each group for biochemical analysis using colorimetric methods on an automated biochemistry analyzer (ARCHITECT C1 8200, USA). These parameters included cholesterol, triglycerides, total proteins, aspartate aminotransferase (AST), alanine aminotransferase (ALT), urea, and creatinine.

At the end of the experiment (day 49), broiler chickens were slaughtered by bleeding, followed by thermal scalding to facilitate feather removal. A random sample of 10 chickens was taken from each experimental group to evaluate slaughter performance. After removal of the extremities, head, and feet and evisceration, successive weighings were used to calculate carcass yields (CY). The internal organs of the liver, and gizzard were isolated and weighed individually. The CY was calculated as the carcass weight divided by live weight at slaughter (Formula 1).

CY = carcass weight (g) / live weight at slaughter (g) × 100.
(Formula 1)

Statistical analysis

Current data were analyzed using one-way analysis of variance (ANOVA), followed by Fisher's least significant difference (LSD) post-hoc test for pairwise comparisons when significant differences were detected. Differences were considered statistically significant at p-values less than 5% ($p < 0.05$). Statistical analyses were performed using Statgraphics 2009 (StatPoint Technologies, Inc.), and graphs were created using XLSTAT 2009. Zootechnical parameters were presented as the mean ± standard deviation (SD).

RESULTS

Physico-chemical parameters

The physicochemical values of O. *ficus-indica* flour revealed a specific nutritional profile, characterized by a moderate protein content of 8.74% and a low lipid content of 3.13%. The mineral composition was marked by high concentrations of calcium (1.17%) and phosphorus (0.16%), resulting in a total ash content of 1.55%. The *O. ficus-indica* flour exhibited a low moisture content of 6.11% and a high cellulose content of 38.83%.

Growth performance

Live weights

Significant differences in live weight among the groups were observed from day 35 of the rearing period onwards ($p < 0.05$). During the finisher phase (day 49), the chickens in the experimental groups grew more than the control group (2,499.30 g). Group S10 recorded the highest average weight at 3,305.80 g (Table 2). The current results revealed a significant difference in growth performance between S5 and S10 and the control group ($p < 0.05$).

Feed intake and feed conversion ratio

The quantity of food intake varied across the groups (Table 3). Consumption was highest in the control group (6364.2 g), a difference that was especially pronounced during the growth-finishing phase. In terms of FCR, all four experimental diets showed a tendency to improve compared with the control group. Groups S5 and S10 achieved FCR values of 1.67 and 1.88, respectively, compared to 2.60 in the control group.

Carcass weight, yield, and offal

Analysis of carcass weights post-evisceration exhibited significant differences between the experimental groups and the control group ($p < 0.05$). The present results indicated that S10 had the highest CY, at 78.16%. Carcass yields were significantly higher in C10 (75.84%) and C5 (75.24%) compared to the control group (69.06%). For organ weights, the largest gizzard was found in S10, while S5 exhibited the highest liver mass at 66.20 g (Table 3).

Mortality rate

During the present study, overall mortality remained low, particularly in the groups supplemented with *O. ficus-indica* seeds and meal. In the starter phase, mortality was limited to 1 case (5%) across groups, except for group C10, which recorded no mortality. Clear disparities emerged during the growth phase, with the highest mortality observed in the control group (25%) and in C10 (10%), while S10 and C5 maintained a low rate of 5%. By the finishing phase (Day 49), mortality decreased significantly to 5% in S10 and C5 ($p < 0.05$) and was eliminated in the other experimental groups. Notably, the control group's high mortality of 25% occurred despite the absence of specific macroscopic lesions at necropsy (Table 4). The present results indicated that dietary supplementation improved chicken viability, with S10 and C5 showing the most favorable effects.

Blood biochemical parameters

The blood biochemical profile was not modified by the incorporation of *O. ficus-indica* fruit seeds and cakes at 5% (S5, S5) and 10% (S10, C10) into broiler diets. All measured parameters (ALT, AST, total proteins, urea, and creatinine) fell within the normal physiological range specified by COBB-VANTRESS performance guides. Cholesterol and triglyceride levels were lower in the treatment groups than in the control group ($p < 0.05$; Table 5).

Table 2. Live weight of broiler chickens in different groups during 49 days of the study

Groups/day	CON (g)	S5 (g)	S10 (g)	C5 (g)	C10 (g)	P-value
D_7	101.4 ± 12.98^b	104.6 ± 10.41^b	118.7 ± 23.01^a	100.5 ± 12.57^b	100.8 ± 7.66^b	0.03
D_{14}	351 ± 51.95^a	360.6 ± 206.99^a	373 ± 87.98^a	341.8 ± 82.31^a	360 ± 78.14^a	0.98
D_{21}	756.1 ± 171.13^a	793.2 ± 182.59^a	833.8 ± 97.84^a	781.5 ± 173.41^a	787 ± 79.91^a	0.70
D_{28}	1,165.3 ± 267.54^a	1,212.5 ± 326.32^a	1,266.6 ± 157.51^a	1,177.5 ± 165.90^a	1,201 ± 111.60^a	0.90
D_{35}	1,616.2 ± 415.18^b	1,917.9 ± 294.81^{ab}	2,082.2 ± 383.02^a	1,253 ± 220.25^c	1,994.9 ± 360.77^a	< 0.0001
D_{42}	2,127.8 ± 909.76^a	2,495.6 ± 751.65^a	2,565 ± 617.18^a	2,551 ± 545.01^a	2,663 ± 346.51^a	0.46
D_{49}	2,499.3 ± 621.90^c	3,122.80 ± 432.18^{ab}	3,305.80 ± 407.46^a	2,562.8 ± 623.98^c	2,825.8 ± 288.98^{bc}	0.002

$^{a, b, \text{ and } c}$ Means with different superscript letters in the same row differ significantly ($p < 0.05$). Data was presented as mean ± standard deviation. CON: Control group, S5: Group supplemented with 5% *Opuntia ficus-indica* seeds, S10: Group supplemented with 10% *Opuntia ficus-indica* seeds, C5: Group supplemented with 5% *Opuntia ficus-indica fruit* cakes, C10: Group supplemented with 10% *Opuntia ficus-indica* fruit cakes.

Table 3. Dietary supplementation of 5% and 10% *Opuntia* (seeds and cake) on feed intake, growth performance, carcass yield, and carcass yield in broiler chickens

Variables	CON	S5	S10	C5	C10	P-value
Feed intake (g)	6364.2	5113.06	6121.82	5957.14	6121.82	-
Feed conversion ratio	2.60	1.67	1.88	2.37	2.21	-
Final weight (g)	2,499.3 ± 621.90^c	3,122.8 ± 432.18^{ab}	3,305.8 ± 407.46^a	2,562.8 ± 623.98^c	2,825.8 ± 288.98^{bc}	0.002
Pre-evisceration weight (g)	2,204.1 ± 523.40^b	2,726 ± 397.83^a	2,771 ± 480.23^a	2,230 ± 545.10^b	2,463.2 ± 245.57^{ab}	0.0147
Post-evisceration weight (g)	1,707.2 ± 607.10^c	2,349.80 ± 363.36^{ab}	2,506.30 ± 446.89^a	1,938.4 ± 514.12^{bc}	2,144.50 ± 248.86^{ab}	0.0022
Carcass yield (g)	69.06 ± 9.44^b	74.34 ± 2.47^a	78.16 ± 2.33^a	75.24 ± 2.44^a	75.84 ± 3.42^a	0.0026
Liver weight (g)	57.3 ± 16.33^a	66.20 ± 22.16^a	63.80 ± 14.80^a	54.00 ± 11.66^a	58.00 ± 13.43^a	0.4349
Gizzard (g)	31.80 ± 6.35^b	42.00 ± 13.63^{ab}	48.10 ± 10.11^a	37.20 ± 8.12^{ab}	37.60 ± 10.65^{ab}	0.0117

$^{a, b, \text{ and } c}$ Means with different superscript letters in the same row differ significantly ($p < 0.05$). Data is presented as mean ± standard deviation. CON: Control group, S5: Group supplemented with 5% *Opuntia ficus-indica* seeds, S10: Group supplemented with 10% *Opuntia ficus-indica* seeds, C5: Group supplemented with 5% *Opuntia ficus-indica fruit* cakes, C10: Group supplemented with 10% *Opuntia ficus-indica* fruit cakes.

Table 4. Mortality rate of broiler chickens during the study

Group	Starter	Grower	Finisher	Mortality rate (%)
CON	1	3	1	25
S5	1	1	0	10
S10	1	0	0	5
C5	1	0	0	5
C10	0	2	0	10

CON: Control group, S5: Group supplemented with 5% *Opuntia ficus-indica* seeds, S10: Group supplemented with 10% *Opuntia ficus-indica* seeds, C5: Group supplemented with 5% *Opuntia ficus-indica fruit* cakes, C10: Group supplemented with 10% *Opuntia ficus-indica* fruit cakes

Table 5. Blood biochemical parameters of broiler chickens recorded on day 49 following the addition of 5% and 10% *Opuntia* (seeds and cake) to the diet

Biochemical parameters	CON	S5	S10	C5	C10	P-value
Urea (g/L)	0.06 ± 0.10[a]	0.036 ± 0.01[a]	0.035 ± 0.01[a]	0.03 ± 0.01[a]	0.036 ± 0.01[a]	0.43
Creatine (mg/L)	2.39 ± 0.10[a]	2.78 ± 0.19[ab]	2.95 ± 1.09[b]	2.92 ± 0.30[b]	2.76 ± 0.30[ab]	0.15
AST (IU/L)	293.4 ± 135.46[a]	264.6 ± 109.14[a]	244.2 ± 117.31[a]	294.5 ± 122.26 [a]	283.6 ± 113.79[a]	0.86
ALT (IU/L)	4.6 ± 0.70[b]	4 ± 0.47[ab]	4.4 ±1.35 [b]	3.5±0.53 [a]	3.6 ± 0.97[a]	0.02
Cholesterol (g/L)	1.00 ± 0.34[b]	0.765 ± 0.20[a]	0.843 ±0.13[ab]	0.958 ± 0.15[b]	0.819 ± 0.14[ab]	0.07
Triglycerides (g/L)	0.80 ± 0.48[b]	0.518 ± 0.14[a]	0.609 ± 0.17[ab]	0.57 ± 0.16[ab]	0.658 ± 0.21[ab]	0.16
Total protein(g/L)	22.6 ± 2.99[a]	26.3 ± 5.31[ab]	29.1 ± 4.33[b]	28.3 ± 7.65[b]	25.4 ± 3.13[ab]	0.04

[a, b, and c] Means with different superscript letters in the same row differ significantly ($p < 0.05$). Data is presented as mean ± standard deviation. CON: Control group, S5: Group supplemented with 5% *Opuntia ficus-indica* seeds, S10: Group supplemented with 10% *Opuntia ficus-indica* seeds, C5: Group supplemented with 5% *Opuntia ficus-indica fruit* cakes, C10: Group supplemented with 10% *Opuntia ficus-indica* fruit cakes.

DISCUSSION

Broiler chicken feed accounts for 60-70% of total production costs (Aziz et al., 2021). A complete poultry diet should be balanced in energy, protein, minerals, and vitamins (Ahiwe et al., 2018). Phytobiotics (or phytogenics) are plant-derived compounds, such as natural or nature-identical plant extracts, that are increasingly being evaluated in scientific studies (Bello et al., 2023). Because they improve feed characteristics and animal performance, these supplements constitute a new class of growth-promoting feed additives that enhance production (Obianwuna et al., 2024).

The present study highlighted the use of *Opuntia* cakes and seeds as supplements to conventional feed ingredients in poultry. The protein content of *O. ficus-indica* powder was 8.74%, slightly higher than that reported by Moula et al. (2019) in Algeria (6.40%). The protein content of the *O. ficus-indica* powder investigated as a broiler feed additive in the current study was 9.8%, consistent with Bentboula et al. (2023) but lower than the 12.87% reported for cladode flour by Juárez et al. (2024). The observed differences in protein content may primarily be due to cladode flour generally having higher protein than seed powder. Additionally, factors such as geographical origin, cultivation conditions, genetic variation, and specific prickly pear cultivars contributed to variability in nutritional composition (De Wit et al., 2018). Physicochemical analysis of *O. ficus-indica* flour revealed favorable preservation properties (6.11% moisture) and high mineral density (1.55% ash), both of which supported the growth. However, an exceptionally high cellulose content (38.83%) represented a limiting factor for digestibility. Therefore, an incorporation rate of 5% was selected to optimize nutritional benefits while maintaining digestive efficiency.

Phytochemical studies of *O. ficus-indica* have demonstrated the presence of secondary metabolites. Indeed, the seeds are an important source of phenolic compounds and flavonoids, which are potent antioxidants. Furthermore, total polyphenols, flavonoids, and tannins are often more concentrated in the solid residue after oil extraction or in aqueous/methanolic extracts of the whole seed (Ali et al., 2022; Bouaouich et al., 2023).

Intake and feed conversion ratio

Throughout the three rearing phases, feed intake did not differ significantly among the treatment groups. The control group had a higher cumulative FCR across all phases, whereas the groups receiving 5% and 10% fruit seed supplementation had FCR below2. The present results demonstrated that the addition of fruit seeds and oilcake was clearly beneficial. Under heat-stress conditions, the use of natural plants as feed additives has been shown to significantly improve broiler performance, notably increasing weight gain and improving FCR (Saeed et al., 2020; Attia et al., 2023). Mahmood et al. (2009) demonstrated greater FCR improvement by using crushed garlic at 5g/kg of feed. According to Abdel-Wahab (2019), dietary supplementation with marjoram leaf powder significantly improved FI and FCR in broiler chickens, with the supplemented groups achieving the lowest FCR values.

Additionally, Adil et al. (2015) found that adding fenugreek at concentrations of 0.5% to 1.5% improved feed efficiency and zootechnical performance. The reduction in FCR likely results from the antibacterial properties of the plant extracts, which reduce colonic microflora and thus reduce competition for nutrients (Kroismayr et al., 2008; Steiner et al., 2010; Abudabos et al., 2021).

Carcass yield live weight, and offal

The current findings aligned with those of Benteboula et al. (2023), who reported improved outcomes in Arbor Acres broiler chickens fed a diet supplemented with prickly pear seeds (2,271 g), and with Boudour et al. (2024), who observed the highest slaughter weight in a group receiving 2% prickly pear cladode powder. Numerous studies have demonstrated that *O. ficus-indica* and its phytobiotic derivatives can positively influence the digestive physiology of broiler chickens by modulating gut health and metabolic status. Incorporating the plant into the diet in the form of fruit peel, seed meal, husks, or cladode powder has been linked to greater FCR, improved carcass characteristics, and increased body weight gain, indicating improved nutrient utilization (Belghiti et al., 2021; Cherif et al., 2022; Benteboula et al., 2023). The performance benefits are frequently attributed to the fiber and mineral content, as well as the high polyphenolic and antioxidant profile, of *O. ficus-indica*. The performance benefits are largely explained by the fiber, minerals, and high polyphenolic-antioxidant content of *O. ficus-indica*. These factors may promote positive changes in the gut microbiota, reduce oxidative stress in the intestinal mucosa, and improve nutrient absorption (Boudour et al., 2024). The present results are consistent with those of Juárez et al. (2024), who demonstrated that hens fed cactus flour gained considerably more weight (49.7 g) by the end of the trial than those in the control group. Numerous studies confirmed the nutritional and performance benefits of cactus-based feed (Nefzaoui and Ben Salem, 2001; Ben Salem and Abidi, 2009).

Opuntia ficus-indica fruit has a nutritional value similar to many common fresh fruits. Due to its high moisture content, *O. ficus-indica* provides around 50 kcal/100 g, comparable to apricots, oranges, and pears (Feugang et al., 2006). Protein content is lower than that recorded in legumes but comparable to that of cereals (Andriamanamisata et al., 2022). The fruit of *Opuntia* provides protein, with values typically ranging from 4% to 10% (Feugang et al., 2006). The addition of *Opuntia* seeds and cakes increased gizzard weight across all treatment groups, suggesting improved digestive efficiency (Cherif et al., 2021). Jiménez-Moreno et al. (2010) and Novotný et al. (2023) noted that a well-developed, functional gizzard reflects a diet that suitably meets the poultry nutritional needs, thereby facilitating the action of digestive enzymes and intestinal nutrient absorption (Cherif et al., 2021). The current findings are consistent with the study conducted by Benteboula et al. (2023), who demonstrated that adding *opuntia* cakes to the broiler chickens' feed increased the weight of the gizzards. The health and performance of broiler chickens are notably influenced by dietary particle size, which promotes gizzard development, enhances gut motility, and improves nutrient utilization (Novotný et al., 2023). In contrast, fine particles may impair gizzard development, reduce foregut motility, and ultimately decrease digestive efficiency (Novotný et al., 2023).

The current results for liver yield indicated that the highest weight was recorded in the group supplemented with 5% *O. ficus-indica* seed. These results were consistent with those of Moula et al. (2019) and Benteboula et al. (2023), who reported an increase in liver weight when *O. ficus-indica* seed meal was included in the diet. As suggested by Bouaouich et al. (2023), the secondary chemicals in the cactus may have facilitated the substantial breakdown of the seed cake during digestion, leading to heavier carcass and viscera yields.

Mortality

Throughout the study period, overall mortality remained low (≤5%) in groups supplemented with *O. ficus-indica* fruit seeds and oilcake. Benteboula et al. (2023) reported a comparable mortality rate of 9.6% in broiler chickens. Moula et al. (2019) observed a 10% mortality rate in chickens receiving a 10% inclusion of *O. ficus-indica* cladodes. Necropsy, along with macroscopic examination of cadavers and organs, revealed no lesions, indicating the plant's harmlessness. The addition of *O. ficus-indica* processing by-products, such as husks, oilcakes, and peels, at 15% has been indicated to have no adverse effects on mortality in rabbits and chickens (Bakr et al., 2017; Badr et al., 2019). The low mortality rate can be explained by the plant's minimal toxicity, supported by an acute toxicity study in mice (Boukeloua et al., 2012), and its noted bioactive properties, including antibacterial (Aragona et al., 2018), anti-inflammatory (El-Mostafa et al., 2014), and antioxidant effects (Andreu et al., 2017; Cano et al., 2017; Nabil et al., 2020).

Biochemical parameters

The blood biochemical profile was slightly modified by the incorporation of *O. ficus-indica*, which contradicted the results of Moula et al. (2019), who noted that the biochemical parameters (triglycerides, glucose, uremia, and cholesterol) were influenced by diet. The biochemical results remained within the physiological ranges established by the Cobb-Vantress performance guides (Hochleithner, 2013; Arzour et al., 2019). Cholesterol and triglyceride levels were reduced in the treatment groups compared to the control group, consistent with several studies reporting a hypolipidemic effect of the fruit (Saenz, 2000; Kaur et al., 2012). Different studies have proven that the richness of seed oil in phytosterols, particularly in β-sitosterol, causes a regression of blood cholesterol levels, a consequence of a decrease in the solubility of cholesterol and its absorption across the intestinal barrier (Ramadan and Mörsel, 2003; Barkas et al., 2023; Cicero et al., 2023). Administering the *O. ficus-indica* seed (33%) could considerably decrease triglyceride and total lipid levels in the liver (Ennouri et al., 2007). Total plasma protein values consistently fell within the published range of 25-45 g/L (Thrall et al., 2012). These levels were lower than the reference interval of 33-55 g/L established by Hochleithner (2013). The blood biochemical results (ALT, AST, total protein, urea, and creatinine) remained within the physiological ranges reported in multiple studies, indicating healthy liver and kidney function (Ennouri et al., 2007; Moula et al., 2019). Liver function, assessed by measuring ALT and AST, revealed values within the reference range described by Hochleithner (2013), not exceeding 6 IU/L for ALT, and less than 230 IU/L for AST.

Plasma urea and creatinine concentrations were within the species' normal physiological ranges, remaining below 3.00 mg/dL and 0.001-0.004 g/L, respectively (Hochleithner, 2013). The current finding was consistent with the study by Halmi et al. (2013), who reported no notable changes in renal parameters in rabbits administered aqueous *O. ficus-indica* extract.

CONCLUSION

The current study highlighted that supplementing the basal diet with 5% and 10% of *O. ficus-indica* could positively affect weight, consumption index, and carcass yield. Despite these performance benefits, the practical application of *Opuntia* seeds remains constrained by their limited supply. In semi-arid regions, cacti and legumes can be locally grown, reducing reliance on imported grain and enhancing food security. The bioactive components present in different parts of *O. ficus-indica* indicated substantial potential as a nutritional resource. However, further investigation is necessary to fully elucidate the plant's functional properties. Such inquiries should include optimizing inclusion levels, comparing the effects of different plant fractions, and assessing the impact of processing methods on bioavailability. Furthermore, clarifying the mechanisms underlying gut health and metabolic benefits can facilitate the development of functional foods and feed products that maximize the efficacy of *Opuntia* derivatives.

DECLARATIONS

Acknowledgments

The authors wished to express their gratitude to all staff members of the Nopaltec unit (Souk Ahras, Algeria) for their cooperation during the collection and processing of the *Opuntia* fruit, and to Chikh Abir Achouak for their technical assistance in sampling.

Authors' contributions

Benlaksira Souheila Bouchra contributed to the conceptualization of the study, was responsible for the execution of the experiment and the collection of experimental data, interpreted and drafted the paper, and revised it. Samia Djeffal performed the formal data analysis and interpretation, contributed to the draft paper, and provided the critical review and editing of the manuscript. Djeghim Fairouze performed the formal data analysis and statistical evaluations. All authors have read and approved the final edition of the manuscript before publication in the present journal.

Availability of data and materials

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

Ethical considerations

All the authors read and approved the original article. This study has never been under consideration for publication elsewhere and used original data. The article was checked for plagiarism before submission to the journal. The authors did not use AI tools to write the whole text of this article.

Funding

The present study was not supported by any external funding sources.

Competing interests

The authors have declared that no competing interest exists.

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