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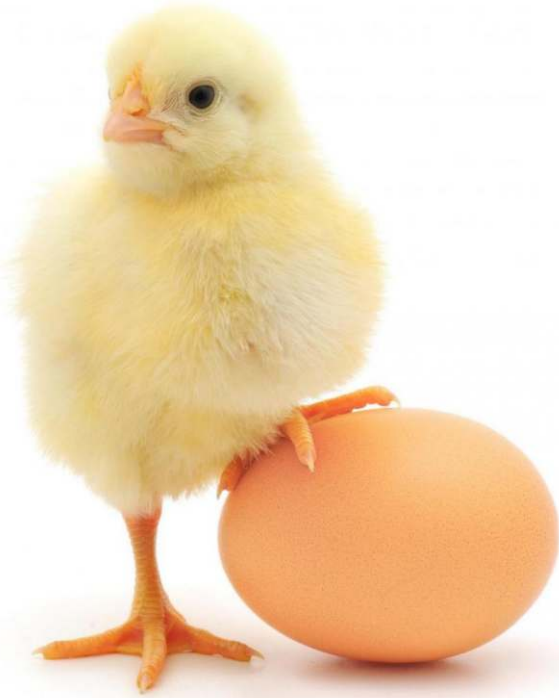

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Research Article
Growth Performance and Haematological and Serological Assessment of Broiler Chickens Fed Thermally Processed *Prosopis juliflora* Pod-based Diets

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Abstract
Objective: The aim of this study was to evaluate the effect of thermally processed *Prosopis juliflora* pods (PJP) on the growth performance of broiler chickens. **Methodology:** Two experiments were conducted. In experiment 1, the nutritive value of raw or thermally processed PJP was evaluated through an ileal digestibility assay. Apparent metabolizable energy (AME) and ileal digestibility of crude fibre in the formulated diet (corn, raw and thermally processed PJP) were determined. The second experiment (a growth study) was designed to test the effect of thermal processing on the nutritive value of PJP ($p<0.001$). Seven dietary treatments were evaluated in experiment 2, namely, the basal diet, three levels of inclusion of raw PJP-based diets (5, 10 and 15%) and three levels of inclusion of processed PJP-based diets (5, 10 and 15%). **Results:** The results of experiment 1 showed that the AME of processed PJP was higher (24%) than that of raw PJP. The raw PJP had significantly lower AME content (10.16 vs 13.41 and 15.26 MJ kg^{-1}) and lower apparent ileal digestibility coefficients of crude fibre (0.27 vs 0.46-0.65) compared to processed PJP and corn, respectively ($p<0.001$). The results of experiment 2, indicated that substitution of corn by 10% processed PJP significantly improved the crude fibre digestibility and AME ($p<0.001$) compared to the other dietary treatments. The weight gain of birds fed 10% processed PJP (55.13 g/bird/day) was similar to those of birds fed a basal diet (55.68 g/bird/day). **Conclusion:** Processed PJP can replace corn up to the level of 10% in broilers diets without affecting growth performance.

Key words: Ileal digestibility, Prosopis juliflora pods, performance, meat quality, broiler chicks

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Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

The acute shortage of fresh water in arid areas, such as Oman, is a major limiting factor to animal production in general and in particular, in poultry production, as it leads to the high costs of animal feed ingredients. Oman has natural rangeland plant species that have not yet been fully utilized as livestock feeds, such as *Prosopis juliflora* pods (PJP). Little work has been done to improve the nutritive value of PJP to include it in balanced poultry rations as an energy source to replace imported corn. The reduction in feed intake when diets contained large proportions of PJP can be attributed to the presence of tannins, which suppressed the appetite of the animals to the diet or may be due to the high fibre content in PJP that limits intakes[1]. Al-Marzooqi *et al.*[2] showed that there was no improvement in growth rate in chickens fed various levels of PJP diets supplemented with enzyme. It is well documented that birds do not possess the enzymatic capability to digest dietary fibre components[3] and there is always great difficulty in selecting potentially useful enzymes available in the market[4]. Marsman *et al.*[5] showed that thermal processing, such as toasting, improved the apparent ileal digestibility of non-starch polysaccharides. Periago *et al.*[6] indicated that thermal processing caused a redistribution of the NSP components in peas, increasing the solubility. Consequently, the overall starch digestibility was increased in processed peas. Heat processing of agricultural byproducts, such as PJP, as a feed ingredient for inclusion in poultry diets is not well documented. However, hypothetically, processing of PJP would enhance the apparent metabolizable energy content by increasing fibre digestibility in broiler chickens.

Therefore, the objective of experiment 1 (the ileal digestibility assay) was to assess the nutritive value of raw and processed PJP as a source of energy. Experiment 2 (a growth study) was designed to evaluate the performance of broiler chickens fed on a corn-soybean meal-based diet substituted with 5, 10 or 15% raw and processed PJP.

MATERIALS AND METHODS

Experiment 1 (Ileal digestibility assay)

Birds and housing: Seventy-five male and female newly hatched (Cobb 500) broiler chickens were housed in suspended grower cages. The cages were in an environmentally controlled room maintained at 35°C on day 1 and then reduced by 1°C/day until 22°C. Birds had free access to water and feed. The lighting was maintained with a photoperiod of 23 every 24 h. Birds were allocated to replicate cages on day 13 and live weights of the birds in the replicates differed by <10 g. Birds were fed a commercial broiler diet from day 1 to day 18. The birds were 19 day old at the commencement of the ileal digestibility assay.

Experimental diets and procedure: A corn, raw and thermally processed PJP was used as a sole source of dietary energy ingredient. Titanium oxide was used as an indigestible marker. The experimental ingredients and titanium oxide were thoroughly mixed before being cold-pelleted through a 3 mm die. Each of the 3 experimental diets was evaluated with five replicates of a cage with 5 birds each. Experimental diets were fed ad libitum for 4 days from days 19-23. On day 23, the birds were starved for 1 h and then fed for 2 h to ensure sufficient gut filling for digesta sample collection following the procedures as described by Al-Marzooqi and Wiseman[7].

Calculations: The titanium and crude fibre data were used to calculate the coefficient of the apparent crude fibre digestibility using the equation described by Al-Marzooqi and Wiseman[7]. Apparent metabolizable energy (AME) was calculated using the equation as described by Scott and Boldaji[8].

Experiment 2 (growth study)

Birds and housing: One hundred forty 1-d-old (Cobb 500) broiler chicks were used. On the day of arrival, the chicks were individually weighed and placed into narrow weight classes. Birds of relatively high or low body weight were excluded. Five birds were randomly assigned to each one of the 28 suspended wire cages (62×62×37 cm), so that all pens had a similar average initial weight. The cages were kept in an environmentally controlled shed. Light was provided for 23 h each day.

Preparation of processed PJP: The PJP samples were collected from different places and dried individually in an oven at 60°C until reaching a constant moisture content. After that, it was ground to pass a 1 mm screen and stored in containers at 1-3°C for further use. For autoclaving, a layer of air-dried ground PJP (approximately 5 cm in depth) was placed on stainless steel trays and put in an autoclave (Astell l autoclave front door 40 L) for 30 min at 105 kPa and 121°C.

Experimental diets: Birds were given ad libitum access to experimental diets and water. The compositions of the experimental diets are presented in Table 1. All diets were formulated according to Commercial Poultry Rations[9]. Seven

Table 1: Composition of the experimental diets (g kg^{-1} dry matter) used in the experiment 2 (growth study)

		Prosopis juliflora pod inclusion (%)					
		5	5	10	10	15	15
Dietary treatment stages	Basal	Raw	Thermally processed	Raw	Thermally processed	Raw	Thermally processed
Prosopis pods	0.0	5.00	5.00	10.00	10.00	15.00	15.0
Crushed corn	40.0	35.00	35.00	30.00	30.00	25.00	25.0
SBM46%	41.5	39.00	40.00	39.00	39.00	40.50	40.5
Wheat bran	7.0	5.25	5.00	6.00	6.50	3.75	3.0
Barley	2.3	5.50	5.50	6.00	6.60	1.50	4.2
Vegetable fat	0.5	0.00	0.00	0.10	0.10	1.50	1.3
Premix[1]	0.3	0.45	0.45	0.45	0.45	0.45	0.8
Salt	0.3	0.30	0.30	0.30	0.30	0.30	0.3
Limestone	3.0	3.00	2.60	3.00	2.00	3.00	1.6
Dicalcium phosphate	3.2	3.00	2.90	3.00	2.90	3.00	3.0
Binder	0.9	2.50	2.25	1.15	1.15	5.00	4.3
Titanium oxide	1.0	1.00	1.00	1.00	1.00	1.00	1.0
Calculated analysis							
Dry matter	89.60	89.85	88.26	89.28	89.22	86.92	86.56
ME (MJ kg^{-1})	13.87	13.64	13.59	13.49	13.61	13.44	13.52
Crude protein (%)	23.57	23.00	23.03	23.03	23.01	23.17	23.00
Fat (%)	2.62	2.09	2.00	2.04	2.05	3.09	2.88
Crude fibre (%)	2.97	3.90	3.74	4.61	4.69	4.99	5.04
Phosphorus (%)	1.03	0.98	0.94	0.95	0.94	0.91	0.91
Calcium (%)	1.98	1.94	1.94	1.95	1.92	1.97	1.98

[1] The vitamin and mineral premix provide the following quantities per kilogram of diet: Vitamin A: 10,300 IU, Vitamin D_3: 2,500 IU, Vitamin E: 40.00 mg, Vitamin k: 3.75 mg, Vitamin B1.00 mg, Vitamin B_2: 6.50 mg, Vitamin B_6: 6.00 mg, Vitamin B_{12}: 0.01 mg, Calcium pantothenate: 18.00 mg, Niacin: 30.00 mg, Folic acid: 2.00 mg, Biotin: 0.06 mg, Flavomycin: 50.00 mg, Ethoxyquin: 125.00 mg, Choline: 650.00 mg, Molybdenum: 2.00 mg, Manganese: 120.00 mg, Iron: 7.00 mg, Cobalt: 1.00 mg, Zinc: 90.00 mg, Iodine: 1.50 mg, Selenium: 0.15 mg

dietary treatments: Basal, three levels each of raw and thermally processed PJP (5, 10 and 15%) were prepared. Diets of 5% (raw or thermally processed), 10% (raw or thermally processed) and 15% (raw or thermally processed) PJP were formulated to partially substitute corn. There were four replicates for each of the dietary treatments with each replicate cage containing five birds. Treatments/replicate combinations were randomly allocated.

Growth and feed intake: The birds and feed of each cage were weighed at days 0, 7, 14, 21, 28, 35 and 42. The growth rate (GR), feed intake (FI) and feed conversion ratio (FCR) were recorded weekly. This allowed these parameters to be determined at these periods.

Collection of excreta: Total collection of excreta was carried out for the determination of AME over three collection periods (4-7, 21-24 and 32-35 days). Feed intake and excreta output were measured daily per cage over a 3 day period. Upon the completion of each excreta collection period, droppings collected over the 3 day period were pooled and a representative sub-sample was taken for each cage. The representative samples were then freeze dried, lyophilised to equilibrate with the atmospheric conditions and then ground through a 1 mm sieve grinder for laboratory analysis of the gross energy (GE), dry matter (DM) and crude fibre (CF). Samples of each diet were also ground for analysis of GE, DM and CF.

Weight of digestive organs: On day 42, four randomly selected birds from each treatment were selected and sacrificed. The weight of the live bird, carcass, total digestive tract, small intestine, proventriculus, gizzard, pancreas, heart, liver plus gall bladder and caecum were recorded.

Carcass and meat quality assessment: Eight carcasses from each treatment group were randomly selected and four were used for each of the carcasses and meat quality characteristics following the procedure as described by Tabook *et al.*[10].

Blood sample collection: At the end of the experiment (day 42), blood samples were collected from 28 birds (4 birds/dietary treatment, were selected randomly) for the determination of the haematological and serum biochemical parameters following the procedure as described by Al-Marzooqi *et al.*[2].

Chemical analysis: Samples of the feed, ileal digesta and excreta used for laboratory analysis were ground to pass through a 1 mm mesh in a micro-Wiley mill. Samples of the feed, ileal digesta and excreta were freeze dried prior to grinding. Duplicate determinations of dry matter, crude protein, ether extract, crude fibre, gross energy, ash, calcium (Ca) and phosphorus (P) were made according to AOAC[11]. Neutral detergent fibre and acid detergent fibre was determined as described by Van Soest *et al.*[12]. Titanium (the indigestible marker) was analyzed using a modified version of the AOAC[11] method. Tannins was determined according to the methods of Waterman and Mole[13]. Total non-starch polysaccharide was determined according to the procedure of Englyst *et al.*[14]. Chemical analyses were performed in duplicate and repeated if the individual data differed by <5%.

Statistical analysis: Analysis of variance was carried out to test the effect of dietary treatments on experimental parameters using General Linear Models of the SAS statistical program package[15]. Data were subsequently analysed for the effect of level, process and their interaction. Significant differences between treatment means were assessed using the least significant difference procedure. Interaction between the treatments was excluded from the model when not significant (p>0.05).

RESULTS

Experiment 1-ileal digestibility assay: The chemical composition and anti-nutritional content of corn and processed PJP is summarized in Table 2. The gross energy content of corn, raw and processed PJP were 182, 185 and 188 MJ kg^{-1}, respectively. Crude protein was higher by 34.6 and 35.7% in raw and processed PJP, respectively, compared to corn. PJP contained 82% more crude fibre (17.3 vs. 3.11) than corn. Corn had a higher fat content than PJP. The ash content in corn was lower by 66% then PJP.

Lignin was 97.4% and 97.3% higher in raw and processed PJP (4.6 and 4.4 vs 0.13) than corn, respectively. The cellulose content in raw and processed PJP was higher by 69.7 and 69.3%, than corn (32.6 and 32.2 vs. 9.87), respectively. Corn had a lower hemicellulose content by 53.08% than the PJP (6.00 vs. 12.52). Both processed PJP and corn contained 69.1% and 70.1% less total non-starch polysaccharides than raw PJP (8.79- 8.48 vs. 28.4), respectively (Table 2).

Mean digestible coefficients of crude fibre and AME contents of PJP and corn are given in Table 3. The raw PJP had significantly lower digestibility coefficients of crude fibre (p<0.001) than the corn and processed PJP, (0.27 vs. 0.65 and 0.46), respectively. The AME value of raw PJP was significantly lower (p<0.001) by 33.4% and 24.2% than processed PJP and corn (10.16 vs 15.26 and 13.41), respectively.

Table 2: Chemical composition (%DM) and anti-nutritional contents in corn, raw and thermally processed *Prosopis juliflora* pods

		Prosopis juliflora pods	
Chemical composition (DM %)	Corn	Raw	Thermally processed
DM	89.10	90.20	90.10
GE(MJ kg^{-1})	18.20	18.50	18.80
CP	8.30	12.90	12.70
CF	3.11	17.30	17.60
EE	2.10	1.10	1.00
Ash	1.70	5.00	4.90
Lignin	0.12	4.60	4.40
Cellulose	9.87	32.60	32.20
Hemicellulose	6.00	12.52	13.20
Total non-starch polysaccharides	8.48	28.40	8.79
Anti-nutritional factors (g kg^{-1})			
Tannin	-	1.8	

DM: Dry matter GE: Gross energy, CP: Crude protein, EE: Ether extract, CF: Crude fibre

Table 3: Mean digestible coefficients of crude fibre and apparent metabolizable energy (AME) contents of corn, raw and thermally processed *Prosopis juliflora* pods

		Prosopis Juliflora pods			
Parameters	Corn	Raw	Thermally processed	SEM	Significance
Crude fibre	0.65^{a}	0.27^{c}	0.46^{b}	0.040	***
AME (MJ/kg)	15.26^{a}	10.16^{c}	13.41^{b}	0.275	***

SEM: Standard error of mean. ***p<0.001. Means with same row with different letters were significantly different (p<0.05)

Table 4: Effects of feeding basal, raw or thermally processed *Prosopis juliflora* pods diets on apparent metabolizable energy (AME) and fibre digestibility coefficient (FDC) in broilers

Dietary treatments process	Basal	*Prosopis Juliflora* pods inclusion (%) 5 Raw	5 Process	10 Raw	10 Process	15 Raw	15 Process	SEM	Significance DT[1]	Level	Process	Level *process
AME (day)												
(4-7)	14.08^{a}	14.09^{a}	14.03^{a}	13.18^{b}	14.03^{a}	11.95^{c}	13.20^{b}	0.056	***	***	***	***
(21-24)	14.28^{a}	14.20^{a}	14.10^{a}	13.40^{b}	14.25^{a}	11.75^{c}	13.35^{b}	0.046	***	***	***	***
(32-35)	14.46^{a}	14.45^{a}	14.46^{a}	13.62^{b}	14.47^{a}	11.81^{c}	13.60^{b}	0.168	***	***	***	***
Overall (0-42)	14.27^{a}	14.26^{a}	14.24^{a}	13.56^{b}	14.29^{a}	11.99^{c}	13.41^{b}	0.038	***	***	***	***
FDC (day)												
(4-7)	0.37^{a}	0.37^{a}	0.37^{a}	0.28^{b}	0.37^{a}	0.24^{b}	0.28^{b}	0.013	***	***	**	*
(21-24)	0.38^{a}	0.39^{a}	0.39^{a}	0.31^{b}	0.39^{a}	0.26^{c}	0.32^{b}	0.011	***	***	***	**
(32-35)	0.40^{a}	0.40^{a}	0.40^{a}	0.33^{b}	0.40^{a}	0.28^{c}	0.34^{b}	0.010	***	***	***	**
Overall (0-42)	0.38^{a}	0.39^{a}	0.39^{a}	0.31^{bc}	0.39^{a}	0.26^{c}	0.32^{b}	0.011	***	***	***	**

[1]DT: Dietary treatments, SEM: Standard error of mean, ***p<0.001, NS: Not significant, Means with same row with different letters were significantly different (p<0.05)

Experiment 2-growth study: The AME of the basal diets and test diets with different levels of raw and processed PJP was estimated between days 4-7, 21-24, 32-35 and the overall periods 0-42 are presented in Table 4. In general, diets containing various levels of processed PJP had significantly higher AME content compared with those that were unprocessed. Throughout the experimental period (0-42 days), there was no significant difference (p>0.05) between the basal diet, 5% (raw or processed) PJP diet and the 10% processed PJP diet. Increasing the level of PJP in the test diet resulted in a significant (p<0.001) linear decrease in AME during these periods (Table 4). The AME value of the 15% PJP diet was the lowest in comparison to the other dietary treatments throughout the experimental period (0-42 days). The AME values increased with the age of the birds.

Increasing the unprocessed PJP content of the test diet resulted in a significant (p<0.001) linear decrease in dietary fibre digestion coefficients (Table 4). A non-significant depression in fibre digestibility was observed when the PJP increased from 0-5% (raw or processed) and 10% processed diets, whereas inclusion of 15% PJP resulted in significant depression in fibre digestibility compared with the other dietary treatments. In general, processing significantly improved the fibre digestibility at the 10 and 15% levels of PJP in the diets (p<0.0001). Although, there was an improvement in fibre digestibility as the birds grew older, the improvement was not statistically significant.

The daily gain, feed intake and feed conversion ratio on a weekly basis and in the overall period (0-42 days) are presented in Table 5. The inclusion level of PJP had significant effects on feed intake in weeks 1, 2, 3, 4, 5 and 6. Birds on 10 and 15% unprocessed diets consumed less than the other processed diets. Daily weight gain was also significantly affected by the inclusion level of PJP in weeks 1, 2, 3, 4, 5 and 6. Birds on 10 and 15% raw diets gained less than the other processed groups. The feed conversion ratio was significantly affected by the inclusion level of PJP in week 2, 3, 4, 5 and 6. Birds on a 10% raw diet had 0.1, 0.11, 0.3, 0.37 and 0.15 (g FI g^{-1} gain) more FCR than the other groups given the basal and the processed diets. Birds on the 15% raw diet had 0.34, 0.38, 0.49, 0.62 and 0.61 (g FI g^{-1} gain) more FCR than the other groups given the basal and processed diets.

Overall the 0-42-day experimental period included processed PJP at the 10% level, which did not significantly affect feed intake, daily gain and feed conversion ratio. However, when the inclusion level of the PJP was increased to 10% raw, 15% raw or processed, the body weight gain was significantly depressed by 18.9, 36.8 and 22.2%, respectively. This was accompanied by significantly lower feed intakes (p<0.0001). The corresponding feed intake was significantly reduced by 8.6% (92.60 vs. 84.60), 17.8% (92.60 vs. 76.10) and 10.1% (92.60 vs. 83.28), when 10 and 15% raw processed PJP was substituted into the basal diet. In addition, during this period, the feed conversion ratio was also poor. The corresponding feed conversion ratios were significantly reduced by 11.9% (1.67 vs. 1.87), 29.9% (1.67 vs. 2.17) and 15.6% (1.67 vs. 1.93), when 1, 15% raw or processed PJP was included into the basal diet. The inclusion of processed PJP in the diets at the 10% level did not affect the feed intake, daily gain and feed conversion ratio (Table 5).

The weight of the total digestive tract, small intestine, proventriculus, gizzard, liver, heart and caeca per unit body weight (g kg^{-1} body weight) are presented in Table 6. The weight of the total digestive tract and the small intestine significantly increased (p<0.01) with increasing PJP levels up to 15% in the diet. Whereas the weight of the pancreas and

Table 5: Effect of feeding basal, raw or thermally processed *Prosopis juliflora pods* diets on daily gain (DG, g/bird/day), feed intake (FI, g/bird/day) and feed conversion ratio (FCR, g feed/g gain) in broilers

		Prosopis Juliflora pods inclusion (%)							Significance			
Dietary treatments process	Basal	5 Raw	5 Process	10 Raw	10 Process	15 Raw	15 Process	SEM	DT[1]	Level	Process	Level *process
Week 1												
FI	16.63^{ab}	16.98^{a}	16.48^{ab}	15.47^{ab}	16.91^{a}	13.41^{b}	15.72^{ab}	0.695	**	**	NS	NS
DG	14.71^{ab}	15.27^{a}	13.67^{abc}	12.99^{c}	14.88^{ab}	11.12^{d}	13.32^{bc}	0.394	***	***	**	***
FCR	1.13^{a}	1.11^{a}	1.21^{a}	1.2^{a}	1.14^{a}	1.21^{a}	1.18^{a}	0.048	NS	NS	NS	NS
Week 2												
FI	45.32^{a}	45.00^{ab}	45.60^{a}	39.89^{bc}	45.21^{a}	34.12^{d}	38.79^{cd}	1.156		***	***	NS
DG	38.18^{a}	37.56^{a}	37.38^{a}	30.93^{b}	37.24^{a}	22.45^{c}	30.66^{b}	1.264	***	***	***	**
FCR	1.20^{b}	1.20^{b}	1.22^{b}	1.30^{b}	1.22^{b}	1.54^{a}	1.27^{b}	0.046	***	**	**	*
Week 3												
FI	77.04^{a}	76.47^{ab}	77.54^{a}	67.83^{bc}	77.34^{a}	58.00^{d}	65.98^{cd}	1.980	***	***	**	NS
DG	57.23^{a}	56.33^{a}	56.13^{a}	46.31^{b}	55.77^{a}	33.65^{c}	46.00^{b}	1.889		***	***	**
FCR	1.36^{b}	1.36^{b}	1.38^{b}	1.47^{b}	1.39^{b}	1.74^{a}	1.44^{b}	0.053	***	**	*	*
Week 4												
FI	115.56^{a}	114.74^{ab}	116.28^{a}	101.71^{bc}	115.61^{a}	87.06^{d}	98.95^{cd}	2.983	***	***	**	NS
DG	69.48^{a}	68.38^{a}	69.28^{a}	52.45^{b}	69.08^{a}	40.73^{c}	50.80^{b}	1.202	***	***	***	***
FCR	1.65^{b}	1.68^{b}	1.68^{b}	1.95^{ab}	1.68^{b}	2.14^{a}	1.95^{ab}	0.080		***	*	NS
Week 5												
FI	145.00^{a}	144.85^{a}	144.85^{a}	135.58^{b}	144.38^{a}	126.98^{b}	134.45^{b}	1.947	***	***	**	*
DG	74.51^{a}	74.17^{a}	73.86^{a}	58.67^{b}	73.91^{a}	49.86^{c}	53.82^{bc}	1.880	***	***	***	**
FCR	1.95^{b}	1.95^{b}	1.96^{b}	2.32^{a}	1.96^{b}	2.57^{a}	2.51^{a}	0.078	***	***	*	*
Week 6												
FI	156.28^{a}	155.63^{a}	156.18^{a}	146.93^{b}	155.58^{a}	136.90^{c}	145.73^{b}	1.680		***	***	*
DG	80.01^{a}	80.92^{ab}	81.55^{a}	69.73^{bc}	79.93^{ab}	53.47^{d}	65.19^{c}	2.577	***	***	**	*
FCR	1.96^{b}	1.93^{b}	1.93^{b}	2.11^{b}	1.95^{b}	2.57^{a}	2.26^{ab}	0.083	***	***	*	NS
Overall (0-42)												
FI	92.60^{a}	92.30^{a}	92.80^{a}	84.60^{b}	92.50^{a}	76.10^{c}	83.28^{b}	1.250	***	***	***	*
DG	55.68^{a}	55.43^{a}	55.31^{a}	45.18^{b}	55.13^{a}	35.21^{c}	43.30^{b}	0.771	***	***	***	***
FCR	1.67^{c}	1.67^{c}	1.68^{c}	1.87^{b}	1.68^{c}	2.17^{a}	1.93^{b}	0.032	***	***	***	**

[1]DT: Dietary treatments, SEM: Standard error of mean, *p<0.05, ***p<0.001, NS: Not significant, Means with same row with different letters were significantly different (p<0.05)

Table 6: Effect of feeding basal, raw or thermally processed *Prosopis juliflora pods* diets on mean weight of digestive organs per unit body weight (g/kg body weight) in broilers

		Prosopis Juliflora pods inclusion (%)							Significance			
Dietary treatments process	Basal	5 Raw	5 Process	10 Raw	10 Process	15 Raw	15 Process	SEM	DT[1]	Level	Process	Level *process
Total digestive tract	14.76^{c}	16.29^{bc}	16.22^{bc}	18.82^{abc}	16.35^{bc}	22.17^{a}	21.49^{ab}	1.330	**	**	NS	NS
Small intestine	3.76^{b}	3.76^{b}	3.75^{b}	5.08^{ab}	3.85^{b}	6.15^{a}	6.16^{a}	0.398	***	***	NS	NS
Proventriculus	0.72^{a}	0.66^{a}	0.70^{a}	0.78^{a}	0.65^{a}	0.78^{a}	0.76^{a}	0.069	NS	NS	NS	NS
Gizzard	2.29^{a}	2.30^{a}	2.36^{a}	2.72^{a}	2.45^{a}	2.65^{a}	2.54^{a}	0.148	NS	NS	NS	NS
Heart	0.53^{a}	0.49^{a}	0.54^{a}	0.51^{a}	0.47^{a}	0.49^{a}	0.51^{a}	0.035	NS	NS	NS	NS
Liver	2.21^{a}	2.41^{a}	2.05^{a}	2.30^{a}	2.10^{a}	2.28^{a}	2.19^{a}	0.152	NS	NS	NS	NS
Pancreas	1.66^{b}	1.65^{b}	1.66^{b}	1.94^{ab}	1.66^{b}	2.14^{a}	2.28^{a}	0.086	***	***	NS	NS
Caeca	4.60^{b}	4.65^{b}	4.63^{b}	6.46^{ab}	4.61^{b}	7.00^{a}	6.63^{ab}	0.416	**	***	NS	NS

[1]DT: Dietary treatments, SEM: Standard error of mean, **p<0.01, ***p<0.001, NS: Not significant, Means with same row with different letters were significantly different (p<0.05)

caeca significantly increased (p<0.001) with increasing PJP level by 15%. Birds fed processed PJP diets has no significant differences (p>0.01) in the weight of digestive organs.

The carcass chemical composition of the broilers fed different experimental diets is presented in Table 7. Replacing 5, 10 or 15% of corn ingredient with PJP without or with processing had no significant (p>0.05) effect on the broiler

Table 7: Effects of feeding basal, raw or thermally processed *Prosopis juliflora pods* diets on broiler carcass chemical composition meat quality characteristics of broiler breast *(M. pectoralis)*

Dietary treatments process	Basal	*Prosopis Juliflora* pods inclusion (%) 5 Raw	5 Process	10 Raw	10 Process	15 Raw	15 Process	SEM	Significance DT[1]	Level	Process	Level *process
Chemical composition												
Dry matter	74.93	72.87	73.24	69.26	70.35	70.46	70.91	1.840	NS	NS	NS	NS
Protein	79.90	77.76	76.59	73.08	75.86	80.37	78.90	3.020	NS	NS	NS	NS
Fat	6.86	6.51	5.76	6.36	6.89	5.86	5.25	0.956	NS	NS	NS	NS
Ash	4.48	4.60	5.08	4.42	4.39	5.72	4.78	0.436	NS	NS	NS	NS
Meat quality characteristics												
PH	5.59	5.61	5.78	5.71	5.62	5.81	5.66	0.076	NS	NS	NS	NS
Express juice	29.80	24.57	25.87	27.10	28.15	28.21	29.59	1.690	NS	NS	NS	NS
Cooking lose	20.64	21.39	21.44	21.29	21.80	21.89	21.59	0.155	NS	NS	NS	NS
Tenderness	2.18	2.10	2.33	2.19	2.17	2.01	2.06	0.071	NS	NS	NS	NS
SL (μm)	1.77	1.83	1.84	1.80	1.78	1.78	1.80	0.046	NS	NS	NS	NS
Lightness (L*)	47.00	44.63	45.64	46.41	48.48	41.25	46.75	2.370	NS	NS	NS	NS
Redness (a*)	6.59	5.31	7.13	5.29	5.21	4.66	4.76	0.730	NS	NS	NS	NS
Yellowness (b*)	3.84	3.33	3.87	3.23	3.88	3.29	3.73	0.389	NS	NS	NS	NS

[1]DT: Dietary treatments, SEM: Standard error of mean, *p<0.05. NS: Not Significant, Means with same row with different letters were significantly different (p<0.05) SL: Sarcomere length (μm)

Table 8: Effect of feeding basal, raw or thermally processed *Prosopis juliflora pods* diets on haematological and serum parameters of broiler chicken

Dietary treatments process	Basal	*Prosopis Juliflora* pods inclusion (%) 5 Raw	5 Process	10 Raw	10 Process	15 Raw	15 Process	SEM	Significance DT[1]	Level	Process	Level *process
Haematological parameters												
RBC ($mm^3 \times 10^6$)	2.78	2.81	2.79	2.69	2.55	2.82	2.40	0.142	NS	NS	NS	NS
HGB ($g\ dL^{-1}$)	12.50	13.05	12.58	12.53	11.71	13.18	11.14	0.748	NS	NS	NS	NS
PCV (%)	30.50	32.25	30.75	31.00	28.75	31.50	31.75	1.404	NS	NS	NS	NS
MCV (Fl)	114.06	113.80	112.94	114.71	111.71	111.82	111.64	0.858	NS	NS	NS	NS
MCH (pg)	43.31	44.69	45.20	46.63	44.73	46.71	46.35	1.436	NS	NS	NS	NS
MCHC (%)	41.00	40.49	40.90	40.44	40.67	41.79	41.55	1.355	NS	NS	NS	NS
Serum electrolyte parameters												
Sodium ($mmol\ L^{-1}$)	148.90	147.52	148.77	153.30	145.90	153.58	152.66	4.450	NS	NS	NS	NS
Potassium ($mmol\ L^{-1}$)	5.38	5.18	4.70	5.07	5.64	5.13	6.65	0.484	NS	NS	NS	NS
Chloride ($mmol\ L^{-1}$)	119.45	118.27	121.73	125.28	118.53	127.43	132.00	5.26	NS	NS	NS	NS
Calcium ($mg\ dL^{-1}$)	8.60	9.18	10.33	10.08	11.33	10.03	12.38	0.848	NS	NS	NS	NS
Serum chemistry parameters												
Total protein ($g\ dL^{-1}$)	3.70	3.78	4.75	4.60	4.88	4.48	4.65	0.435	NS	NS	NS	NS
ALT ($IU\ L^{-1}$)	12.75	10.25	11.00	10.75	10.50	11.00	13.75	1.049	NS	NS	NS	NS

[1]DT: Dietary treatments, SEM: Standard error of mean, NS: Not significant, ALT: Alanine amino-transferase

carcass chemical composition. There was no effect (p>0.05) on the level of PJP nor processing on the broiler meat quality characteristics (colour, pH, expressed juice, Warner-Bratzler shear values and cooking loss %).

The haematological, serum electrolytes and serum chemistry values of broiler chicken fed various levels of raw and processed PJP diets are presented in Table 8. Replacing 5, 10 or 15% of corn ingredient with PJP without or with processing had no significant (p>0.05) effects on broiler haematological and serum biochemical components.

The economic feasibility of inclusion of processed PJP in broiler diets is an attempt for evaluating the economic feasibility of inclusion of PJP in broiler feed. Table 9 summarizes the feed cost, revenue and the gross margin per bird according to the growth study length period of 4, 5 or 6 weeks. The maximum growth margin was achieved for 10% processed PJP and a growth duration of 4 weeks (Fig. 1). The maximum gross margin fulfilled was $1.79 per bird for 10% processed PJP versus $ 1.65 per bird for basal diets, with a difference of $ 0.14 per bird. The gain in the gross margin was 8.5% compared to the basal diet. In addition, this will represent the lesser use of corn and the use of available sources, which otherwise will be lost for the same quality poultry product.

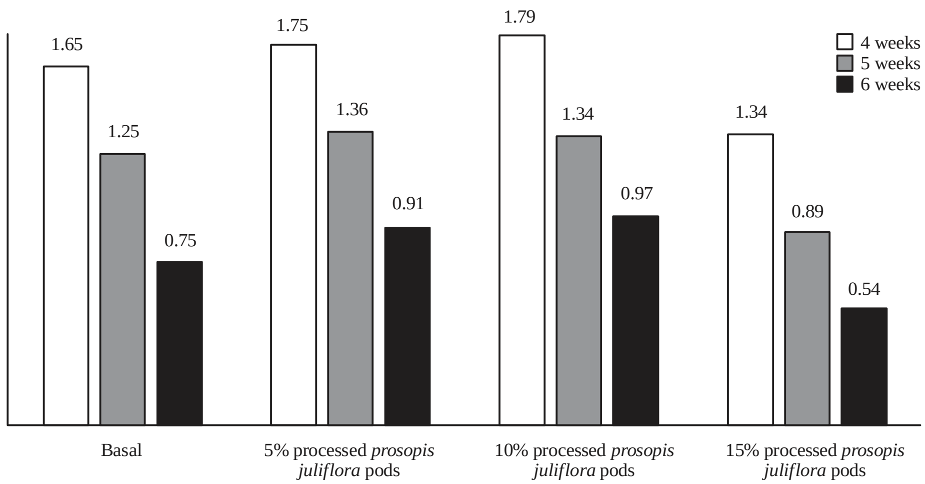

Fig. 1: Gross margin $/bird as a function of diet and age in weeks

Table 9: Feed intake, feed cost, revenue and gross margin in US$ per bird and age

		Processed *Prosopis juliflora* pods inclusion (%)		
	Basal	5	10	15
Feed intake in kg/bird (week 4)	1.782	1.791	1.785	1.536
Feed intake in g/bird (week 5)	2.797	2.805	2.796	2.477
Feed intake in g/bird (week 6)	3.891	3.899	3.885	3.497
Feed cost US$ per bird (week 4)	0.780	0.690	0.690	0.650
Feed cost US$ per bird (week 5)	1.230	1.090	1.090	1.050
Feed cost US$ per bird (week 6)	1.710	1.510	1.510	1.480
Average weight kg/bird (week 4)	0.781	0.783	0.796	0.639
Average weight kg/bird (week 5)	0.795	0.783	0.776	0.622
Average weight kg/bird (week 6)	0.789	0.776	0.793	0.649
Average revenue US$/bird (week 4)	2.440	2.440	2.480	1.990
Average revenue US$/bird (week 5)	2.480	2.440	2.420	1.940
Average revenue US$/bird (week 6)	2.460	2.420	2.470	2.020
Gross margin US$/bird (week 4)	1.650	1.750	1.790	1.340
Gross margin US$/bird (week 5)	1.250	1.360	1.340	0.890
Gross margin US$/bird (week 6)	0.750	0.910	0.970	0.540
Gross margin US$/bird/week (week 4)	0.410	0.440	0.450	0.340
Gross margin US$/bird/week (week 5)	0.250	0.270	0.270	0.180
Gross margin US$/bird/week (week 6)	0.120	0.150	0.160	0.090

DISCUSSION

Experiment 1-ileal digestibility assay: The effect of processing on the chemical composition of the thermally processed (autoclaved) PJP and the content of its nutrient digestibility were not determined before. The present study showed that corn had a higher digestibility coefficient of dry crude fibre and AME than raw/processed PJP. Generally, the nutrients contained in corn are considered highly digestible[16]. Moritz *et al.*[16] showed that the gain to feed ratio and AME in the starter phase did not differ between broilers fed diets containing processed corn and the control that exclusively contained unprocessed corn.

In the current study, the unprocessed PJP had a lower digestibility coefficient of dry crude fibre and AME than corn and this is most likely due to the high fibre content of PJP. The decreased AME value of PJP indicated that it has a high fibre content and had a significant effect on the digestibility. Similar observations were reported by other studies which showed that some wheat varieties have very low AME values when fed to broiler chickens and that the poor AME values were due to increased levels of non-starch polysaccharides (NSP) in wheats[17,18]. NSPs are present in several feed ingredients, ranging from cereal grains to legume seeds[19,20]. However, the chemical nature of NSP differs from one ingredient to the other[21]. It's well documented that most NSPs generally increase the digesta viscosity, which interferes with nutrient intake and body growth[19].

In the present study, the processed PJP had 24.2% higher AME than raw PJP and this probably is due to its lower content of total NSP (8.79 vs. 28.40). Many researchers have reported that the nutritive value of NSP rich feedstuffs was enhanced by heat processing[22,23]. The heating disrupts the structure of the cell, releasing the starch from the protein matrix and may increase the solubility of the dietary fibre[24]. In general, the results of this preliminary study indicate that processed PJP has the potential to at least partially replace corn as a source of energy through improving its nutrition value by other means, such as thermal processing.

Experiment 2-growth study: Because of the lack of information on the AME of processed PJP, the results of the present study will be discussed in light of outcomes with other non-conventional ingredients used in poultry diet. Feed processing provides an opportunity to improve broiler performance[25]. Therefore, an important area for research in poultry nutrition is the preparation of feeds prior to ingestion to increase the value of the feed. In the current study, a moderate thermal treatment (autoclaving) was used in an attempt to improve the nutritive value of PJP as a broiler feed. Many advantages are cited in favour of feed processing, including increased availability of the protein and energy and destruction of anti-nutritive factors[26].

Hypothetically, the addition of processed PJP to poultry diets to partially replace corn would improve the energy availability for growth and decrease the anti-nutritional effects of NSP. This study showed that by autoclaving, the level of inclusion of PJP can be increased in broiler diets up to 10%. Modification in the chemical structure and physicochemical properties of NSP caused by processing is strongly dependent on processing conditions and the type of NSP[27].

Increased fibre in poultry rations is known to hinder the protein and energy digestibility and depresses feed intake, as well as enzymatic activity that assists in carbohydrate, protein and fat digestion[28,29]. However, in the current study, the crude fibre content of the dietary treatment tends to increase as the level of PJP increased and for 10 and 15% inclusion, the crude fibre level was higher in comparison to the basal diet but still within the maximum limit 5% recommended level in the broiler ration[9].

The present study indicated an increase in fibre digestibility as the birds aged. This suggests that the low fibre digestibility at a younger age is also more likely to be associated with undeveloped intestinal absorption surface and/or low pancreas secretion[10,2]. Traditionally, in most research conducted on poultry feeding, dietary fibre has been considered a diluent of the diet[30], with negative implications in relation to voluntary feed intake and nutrient digestibility[31]. Therefore, commercial diets, especially those for young broilers, were formulated to contain less than 3% crude fibre.

The substitution of corn by 15% of PJP in the present study, resulted in a significant depression in broiler performance compared to the basal diet. The reduction in the performance of the birds at high level PJP inclusion can be attributed to the negative effects of the high NSP contents in the ground pods on the feed intake. High dietary fibre is often associated with a slower rate of passage and may inhibit optimal digestion through the gut filling effect, which may lead to a consequent reduction in feed consumption[32].

Birds fed diets containing various levels of processed PJP gained more weight compared with those fed unprocessed diets. The result of the current study agrees with Kianfar *et al.*[33] who reported the beneficial effects of feeding autoclaved wheat on the body weight, weight gain and feed conversion ratio in quails. This was attributed to improved nutrient digestibility and AME. Afsharmanesh *et al.*[34] also showed that heat treatment significantly improved the feed conversion ratio and AME and protein digestibility in wheat-based diets. Teitge *et al.*[35] reported that autoclaving of rye can gelatinize starch and increase the solubility of NSP, resulting in an increase in chick growth.

However, the lack of improvement in the performance of chickens fed 15% processed PJP diets may be due to the fractional changes in the digestibility of the fibre fraction due to processing. Detailed information on the composition of the NSP fraction and digestibility of its components will help to identify and understand modifications that occur during processing[36].

Feeding PJP to the birds caused an increase in the weight of the small intestine (above 10% PJP), pancreas and caecum (above 15% PJP) only. The increase in the weight of the pancreas and caecum at 15% inclusion of PJP would have also contributed to the increased weight of the digestive tract at this level. The increase in the small intestine weight may be due to the increase in the small intestine length or in its absorptive area. This is in agreements with the finding of Brenes *et al.*[37], who found that feeding diets based on viscous grains resulted in significant increases in the relative size of the digestive tract of broilers chickens. It is well known that the bird intestine responds to the stresses caused by the presence of fibrous substances in the diet in terms of length, weight, absorptive area and the rate of turnover of enterocytes[38].

The increase in the caeca weight may be due to the presence of fibrous PJP materials, which are passed to the bird's hindgut undigested and provide a suitable environment for microbial growth. This probably increased the fermentation processes that may lead to an increase in the length of the caeca. The length of the caeca (relative to body weight) was closely and positively correlated with dietary fibre levels[39]. The presence of fibrous materials from PJP may have also stimulated the pancreas to increase its production of luminal enzymes, which may consequently lead to the increase in the pancreas weight. Partridate and Wyatt[40] suggested that pancreatic weight, as a proportion of body weight, is increased in the presences of soluble fibres, implying that feedback mechanisms in the bird's gut stimulate hypertrophy of this organ.

Inclusion of raw or processed PJP had no significant effects on both the carcass composition and meat quality characteristics in the present study. Shear value is an indirect measurement of muscle tenderness. Lower shear values indicate more tender meat[41]. In the current study, a shear force value of 1.7-3.7 kg was considered tender[42]. Cooking loss or weight loss during cooking, is a measurement of the water-holding capacity of the muscle. There were no differences among any of the experimental treatments. The numerical distinctions among these means may simply reflect the variable nature of measuring small weight changes in individual muscle samples.

Blood parameters reflect the physiological responsiveness of the birds to it is internal and external environment, including the type of feed the bird consumed and the feeding practices[43]. Serum biochemical constituents are positively correlated with the quality of the diet[44]. In the current study, the values obtained for all haematological and serological parameters were almost uniform across the dietary treatments, were within the normal range and were comparable to those reported in the literature for broiler chickens[2,45]. Liver function tests for glutamic oxaloacetic transaminase (GOT) and glutamic pyruvic transaminase (GPT) produced similar results in control birds and experimental birds and are congruent with the similar reference values reported for chicks previously[46].

In the current study, the economic analysis indicates that birds should be slaughtered optimally at the end of week 4 and with a 10% processed PJP diet rather than basal. On average, the gross margin per bird and per week is the highest for 10% processed PJP and for a 4 week production cycle. The results are not sensitive to the cost of processing PJP, as a 100% increase in its cost will keep the same advantage for the 10% processed PJP. In fact, if we assume that 50% of the small and medium scale framers will substitute processed PJP with corn, the volume of corn that could be potentially saved is estimated at 3,000 t year^{-1} with a value of $780,000 per year.

CONCLUSION

This study is one of very few that thoroughly investigated the use of raw or processed PJP as an energy source to substitute corn in Oman. Processed PJP can be used successfully in poultry diets up to 10% without affecting the birds' growth performance, which will contribute to reduced feed cost for small and medium scale farmers.

SIGNIFICANCE STATEMENT

This study discovered the positive effect of the thermal processing of PJP, which can be beneficial for enhancement of the nutritive value of PJP for use as a feed ingredient for poultry. This study will help the researcher to uncover the critical areas of increasing the level of inclusion of PJP in broiler diets that many researchers were not able to explore. Thus, a new approach to utilize PJP in balanced poultry rations as a substitute for other energy sources, such as the conventionally used imported corn, may be identified.

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