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Ziziphus mauritiana Fruit as a Maize Substitute in the Diet of Osmanabadi Goat Kids: Effects on Growth, Biochemical Parameters and Oxidative Status

Praveen Kumar Gupta[1], Meenu Dubey[1], M.K. Gendley[1], Raina Doneria[1], Vivek Kumar[2], Ashutosh Tiwari[3], D. Suryam Dora[4], Pooja Ghritlahare[1], Sonali Prusty[1], Ramchandra Ramteke[1]

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ABSTRACT

Background: *Ziziphus mauritiana* (Ber), is a hardy, drought-tolerant shrub/tree species found abundantly across Chhattisgarh. Tribal and rural communities in Chhattisgarh have long used ber as a supplemental livestock feed, especially for goats and sheep. As a naturally available, low-cost resource, ber contributes significantly to sustainable and traditional animal husbandry in Chhattisgarh. Its use reduces dependence on commercial feed inputs, thereby lowering the cost of livestock production. India the research on the use of *Ziziphus mauritiana* (Ber) in animal feed is very scarce with this in view the present study was conducted.

Methods: An *in vivo* experiment was conducted on 24 Osmanabadi goat kids (4-5 months old), randomly divided into four groups (T0, T1, T2 and T3) with six animals each, to evaluate the effects of replacing maize with ground whole ber fruit (0%, 20%, 30% and 40%) in concentrate mixtures on growth performance, blood biochemistry and oxidative stress indices. All goats were dewormed, housed under intensive management and fed according to specifications, with uniform crude protein (18.5%) across diets. The 90-day trial involved feeding 200 g/day of respective concentrate mixtures (C0, C2, C3 and C4) along with green fodder (Berseem hay). Body weight, dry matter intake and feed conversion ratio were recorded fortnightly. Blood samples were collected for serum biochemical and oxidative stress markers using standard protocols and diagnostic kits.

Result: The results of the 90-day feeding trial demonstrated that partial replacement of maize with ground whole ber fruit in the concentrate mixture positively influenced growth performance, serum biochemistry and oxidative stress indices in Osmanabadi goat kids. Results revealed that dietary replacement of maize with ber fruit powder up to 40% had no significant effect on fortnightly body weight, average daily gain (ADG), dry matter intake (DMI) and feed conversion ratio (FCR). All animals exhibited normal growth patterns throughout the 90-day experimental period. Although numerically higher body weight gain and better FCR were observed in the 40% replacement group (T3), these differences were not statistically significant, indicating that ber fruit powder did not compromise growth performance. Biochemically, T3 exhibited significantly higher serum glucose and total protein levels ($P<0.05$), along with reduced blood urea nitrogen, cholesterol and triglyceride levels by day 90, suggesting improved energy metabolism, protein utilization and lipid profile. Importantly, oxidative stress indices revealed a significant increase in reduced glutathione (GSH) and a marked decrease in malondialdehyde (MDA) in T2 and T3, reflecting enhanced antioxidant status and reduced lipid peroxidation. Overall, these findings suggest that replacing maize with ground whole ber fruit up to 40% in the diet can be a beneficial strategy for improving growth, health and oxidative stability in growing goats.

Key words: Blood biochemical parameters, Growth performance, Maize substitute, Osmanabadi goat kids, Oxidative stress indices, *Ziziphus mauritiana*.

INTRODUCTION

Ziziphus mauritiana is known for its diverse medicinal properties, which are attributed to various parts of the plant, including its seeds, fruits, bark, leaves and flowers. Plants that contain essential bioactive compounds can provide a cost-effective way to enhance nutrient utilization efficiency and improve growth performance in animals (Chouhan *et al*., 2023). Scientific studies have identified a wide range of biologically active compounds within the plant, such as alkaloids, flavonoids, glycosides, saponins, terpenoids, tannins, fatty acids and phytosterols. These phytochemicals are thought to play a key role in the plant's therapeutic benefits, which include antioxidant, anticancer, antidiarrheal, antihyperglycemic, antimicrobial, anti-steroidogenic, wound-healing, immunomodulatory, anti-inflammatory and liver-protective activities (Butt *et al*., 2021; Ramar *et al*., 2022).

In addition to its health and nutritional benefits, *Ziziphus mauritiana* (commonly known as ber) is highly

[1]Department of Animal Nutrition, DSVCKV, Anjora, Durg-491 001, Chhattisgarh, India.
[2]Teaching Veterinary Clinical Complex, DSVCKV, Anjora, Durg-491 001, Chhattisgarh, India.
[3]Department of Physiology and Biochemistry, DSVCKV, Anjora, Durg-491 001, Chhattisgarh, India.
[4]Department of Livestock Production Management, DSVCKV, Anjora Campus, Durg- 491 001, Chhattisgarh, India.

Corresponding Author: Praveen Kumar Gupta, Department of Animal Nutrition, Dau Shri Vasudev Chandrakar Kamdhenu Vishwavidyalaya, Anjora, Durg-491 001, Chhattisgarh, India.
Email: praveen321gupta@gmail.com
ORCID: https://orcid.org/0000-0002-6096-8158

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appreciated for its unique and enjoyable flavour, which becomes more pronounced as the fruit ripens, making it popular in both its fresh and dried forms (Zozio *et al*., 2014). Known also as jujube, the fruit is rich in soluble sugars (ranging from 50% to 67%), positioning it as a promising natural supplement in silage production. Its high content of water-soluble carbohydrates promotes the proliferation of lactic acid bacteria (LAB), which play a vital role in effective fermentation processes (Abudureyimu *et al*., 2021).

Jujube fruit is distinguished by its comparatively high protein content on a dry matter basis, enhancing its appeal as a nutrient-rich component in animal feed. *Ziziphus mauritiana* has become increasingly favoured by farmers due to its low input requirements, high economic yield and resilience in challenging environments, including arid conditions and saline or alkaline soils. The ongoing escalation in the cost of conventional feed sources has prompted a search for more cost-effective and locally accessible alternatives, with growing interest in ber fruit as a promising non-traditional feed option. Incorporating ber into livestock rations not only helps address the scarcity of standard feed materials but also promotes the sustainable use of agricultural by-products, thereby aiding in waste reduction. Commercial production requires a shift in feeding practices toward more efficient use of limited feed resources (Khaskheli *et al*., 2020).

The present study was undertaken to evaluate the effects of replacing maize with varying levels of ground whole *Ziziphus mauritiana* (ber) fruit in the concentrate mixtures on growth performance, feed utilization, blood biochemical parameters and oxidative stress indices in Osmanabadi goat kids.

MATERIALS AND METHODS

The first experimental trial on Osmanabadi goat kids (age 4-5 months) was performed to assess the effect of selected concentrate mixtures by the replacement of maize with ground whole ber fruit on growth performance, blood biochemistry and oxidative Stress Indices of goat production. Detail of experimental trials are given below.

Selection of experimental goat kids

Twenty-four Osmanabadi goat kids (4-5 months) with approximately similar body weights (Table 1) were selected for each group from Directorate Research Service (DRS) Farm Seed Centre Osmanabadi Goat, College of Veterinary Science and A.H., Anjora, Durg. The goats were randomly divided into four groups, each consisting of six animals. Prior to the start of the experiment, all goats were dewormed as per standard protocol. Throughout the study, the goats were maintained under standard, similar intensive management system.

Collection and processing of *Ziziphus mauritiana* (Ber) fruit

Whole ber fruit was purchased from Hariom Trading Company, Bhilai Dist. of Chhattisgarh and grinding of *Ziziphus mauritiana* (Ber) fruit after collection, after grinding dry *Ziziphus mauritiana* (Ber) fruit stored in gunny bags for further use.

Housing, feeding and management of experimental goat kids

The goats were housed in well-ventilated sheds, equipped with proper flooring, tying provisions and adequate feeding and watering facilities. Throughout the experimental period, all goats were managed under standard husbandry practices. Hay was prepared using green Berseem harvested at 40-45 days of growth, following standard hay-making procedures. The selected goat kids were reared under an intensive management system, with all kids receiving feed formulated according to ICAR (2013) specifications.

The control group (T0) was provided a concentrate mixture without the inclusion of ground whole ber fruit (0%). In contrast, the kids in the T2 group received a concentrate mixture formulated with inclusion of 30% ground whole ber fruit by replacement of maize. Meanwhile, the T1 and T3 groups were fed concentrate mixtures containing ground whole ber fruit with inclusion of 20% and 40% by the replacement of maize respectively. The duration of the experiment was for 90 days and performed in the year 2024-2025. Concentrate mixtures containing an equal crude protein level (18.5%) were developed by substituting maize with ground whole ber fruit in goat feed. The replacement levels of maize with ber fruit were as follows: 0% (C0), 20% (C2), 30% (C3) and 40% (C4), shown in Table 2. Chemical composition of different concentrate mixtures and berseem hay are presented in Table 3.

Experimental design of *in vivo* study

The *in vivo* experiment was conducted in goat kids by feeding as per experimental the design given in Table 4.

Chemical composition

The nutritional analysis of ingredients used to prepare concentrate mixtures, ground whole *Ziziphus mauritiana* and representative samples from the different concentrate mixtures were analysed for various proximate principles (Moisture, CP, EE, CF, Total ash and acid insoluble ash) as per AOAC (2007).

Growth parameters

The body weight of the experimental animals were recorded at fortnightly interval and average daily gain calculated.

Table 1: Average initial body weights (kg) of goat kids in experimental groups.

Experimental groups	Control (T0)	T1	T2	T3
Avg. initial body weight in (kg)	8.90±0.62	8.96±0.70	8.94±0.70	8.90±0.33

Weighed quantity of green fodder and concentrate were offered to the kids individually, left over feed were recorded and average dry matter intake and feed conversion ratio were calculated.

Serum biochemical parameters

For the estimation of biochemical parameters, blood samples were collected from the jugular vein of each animal without the use of an anticoagulant. The serum was separated and analyzed on the same day to determine levels of glucose (mg/dl), total protein (g/dl), albumin (g/dl), globulin (g/dl), total cholesterol (mg/dl), SGOT (AST), SGPT (ALT), creatinine and blood urea nitrogen. All analyses were performed using diagnostic kits purchased by Beacon Diagnostics PVT. LTD. on a semi-automated analyzer.

Oxidative stress indices

Reduced Glutathione activity in RBC suspension was measured by the method of Prins and Loos (1969). Lipid peroxidation in terms of malondialdehyde concentration in haemolysed sample was measured by the method of Placer *et al*. (1966).

Table 2: Feed ingredients inclusion (%) in different concentrate mixture.

Feeding redients	C0	C2	C3	C4
De-oiled rice bran	16	16.5	17	16
Maize	40	32	28	24
Rapeseed Meal	5	5	5	5
Soybean de-oiled cake	20	20.5	21	21.5
Wheat Bran	16	15	14	14.5
Ground whole ber fruit	0	8	12	16
Mineral mixture	2	2	2	2
Salt	1	1	1	1

RESULTS AND DISCUSSION

Chemical composition of ground whole ber fruit and ingredients

The nutritional analysis of ingredients used to prepare concentrate mixtures and ground whole *Ziziphus mauritiana* (Ber) fruit is presented in Table 5. Ground whole ber fruit contained 79.53% dry matter and 20.47% moisture. It had a moderate crude protein content of 7.45% and a low ether extract (fat) level of 0.17%. The crude fibre content was relatively high at 10%, while the nitrogen-free extract (NFE), representing digestible carbohydrates, was significantly high at 77.92%. The total ash content, indicating overall mineral presence, was 4.46%, with acid-insoluble ash (AIA) at 0.55%. The ground ber fruit also provided small amounts of essential minerals, including calcium (0.14%) and phosphorus (0.05%).

Growth parameters

Fortnightly body weight (kg)

The fortnightly body weights of experimental animals in various treatment groups (T0, T1, T2 and T3) are summarized in Table 6. At the start of the experiment the mean body weights were nearly identical across all groups, with no significant difference (P = 1.000). A gradual and consistent increase in body weight was observed in all the groups throughout the 90-days study period, indicating normal growth and satisfactory health status of the animals. By day 15, mean body weights had increased to 9.70–9.79 kg, maintaining uniformity across treatments (P = 1.000). At 30 days, the average body weights ranged from 10.52±0.56 kg (T0) to 10.68 ± 0.32 kg (T3), with no significant differences among the groups (P = 0.998). At 45 days, all groups showed continued growth, with mean

Table 3: Chemical composition of different concentrate mixtures and berseem hay.

Constituent (%)	C0	C2	C3	C4	Berseem hay
DM	90.08	90.78	90.10	90.54	88.61
Moisture	9.92	9.22	9.90	9.46	11.39
Crude protein	18.75	18.70	18.65	18.72	15.6
Ether extract	2.14	1.87	1.73	1.60	2.30
Crude fibre	6.71	7.29	7.56	7.86	26.8
NFE	64.42	63.52	63.01	62.37	41.70
Total ash	7.98	8.62	9.05	9.45	13.60
AIA	0.98	1.15	1.49	1.81	7.03
Calcium (mg%)	1.02	1.16	1.02	0.92	1.5
Phosphorus (mg%)	0.48	0.60	0.56	0.59	0.5

Table 4: Design of experiment.

Particulars	Control group (T0)	T1	T2	T3
No of animals	6	6	6	6
Green fodder	As per requirement	As per requirement	As per requirement	As per requirement
Concentrate	C0 200 g	C2 200 g	C3 200 g	C4 200 g
Inclusion level (%) of ground whole ber fruit	0%	20%	30%	40%

body weights ranging from 11.30 ± 0.72 kg (T2) to 11.67 ±0.35 kg (T3) (P = 0.972). The upward trend persisted through the subsequent intervals, with average weights reaching 12.15±0.61 kg (T0) to 12.52±0.34 kg (T3) at 60 days and 12.72±0.69 kg (T2) to 13.34±0.34 kg (T3) at 75 days. At the end of the experimental period (90 days), the animals in all groups exhibited substantial weight gain relative to baseline. The highest mean body weight was recorded in the T3 group (14.22±0.37 kg), while the lowest was observed in T2 (13.46±0.69 kg). Despite the apparent trend of slightly higher body weights in the T3 group, statistical analysis revealed no significant differences (P = 0.805) among the groups throughout the experiment.

Average daily gain (g/day)

The average daily gain (ADG) of animals recorded at fortnightly intervals for each treatment group (T0, T1, T2 and T3) is presented in Table 7. Across all experimental groups, the ADG values reflected a consistent pattern of growth throughout the 90-day experimental period, with no statistically significant differences (P>0.05) observed at any time point.

During the initial 0-15 days, the average daily gain ranged from 49.60±6.44 g/day (T1) to 59.33±3.40 g/day (T3), indicating uniform early growth across treatments (P = 0.529). Similar results were recorded during the 15-30 day period, where ADG values varied between 51.60± 4.11 g/day (T2) and 59.33±3.40 g/day (T3), showing no significant difference among the groups (P = 0.529). Between 30 and 45 days, the T3 group exhibited a higher ADG (65.73±5.41 g/day) compared to the other groups (50.53-54.53 g/day). Although this difference approached significance (P = 0.052), it did not reach the threshold for statistical significance, suggesting only a slight trend toward improved growth in T3 during this period.

Table 5: Chemical composition of ingredients used to prepare concentrate mixtures.

Nutrients (%)	De-oiled rice bran	Maize	Rapeseed	Soybean meal	Wheat bran	Ground whole ber fruit
DM	91.10	88.90	92.0	90.0	92.60	79.53
Moisture	8.90	11.10	8.0	10.0	7.40	20.47
Crude protein	14.0	9.0	37.0	45.0	13.0	7.45
Ether extract	1.23	3.5	1.34	1.01	1.74	0.17
Crude fibre	11.20	2.25	9.07	7.35	13.07	10
NFE	60.77	79.25	45.47	38.92	65.63	77.92
Total ash	12.80	6.0	7.12	7.72	6.56	4.46
AIA	6.02	0.35	0.77	0.80	1.56	0.55
Calcium	0.36	0.33	0.59	0.36	0.53	0.14
Phosphorus	0.84	0.42	1.25	0.63	0.64	0.05

Table 6: Effect of dietary replacement of maize with ground whole ber fruit on fortnightly body weight (kg) of goat kids.

Particular	Group				P value
	T0	T1	T2	T3	
0 day	8.90±0.62	8.96±0.70	8.94±0.70	8.90±0.33	1.000
15 days	9.73±0.53	9.70±0.73	9.77±0.73	9.79±0.32	1.000
30 days	10.52±0.56	10.56±0.76	10.55±0.75	10.68±0.32	0.998
45 days	11.34±0.59	11.33±0.74	11.30±0.72	11.67±0.35	0.972
60 days	12.15±0.61	12.04±0.72	11.98±0.70	12.52±0.34	0.925
75 days	12.82±0.60	12.84±0.73	12.72±0.69	13.34±0.34	0.887
90 days	13.64±0.55	13.52±0.75	13.46±0.69	14.22±0.37	0.805

Table 7: Effect of dietary replacement of maize with ground whole *Ziziphus mauritiana* fruit on average daily gain (g/day).

Particular	Group				P value
	T0	T1	T2	T3	
0-15 days	55.20±3.23	49.60±6.44	55.46±4.51	59.33±3.40	0.529
15-30 days	52.80±4.63	57.06±4.29	51.60±4.11	59.33±3.40	0.529
30-45 days	54.53±2.24	51.33±2.91	50.53±3.70	65.73±5.41	0.052
45-60 days	54.27±9.47	47.33±2.67	45.33±3.68	56.93±9.38	0.615
60-75 days	44.67±1.79	53.33±9.19	48.80±3.29	54.67±4.90	0.578
75-90 days	56.53±2.98	53.33±4.22	52.27±2.36	58.67±2.94	0.464

In the 45-60 day interval, ADG ranged from 45.33±3.68 g/day (T2) to 56.93±9.38 g/day (T3), showing a modest decline compared to earlier periods but maintaining similar growth rates across all groups. During the 60-75 day interval, daily gains varied between 44.67±1.79 g/day (T0) and 54.67±4.90 g/day (T3) (P = 0.578). In the final 75-90 day period, the animals continued to gain weight steadily, with ADG values ranging from 52.27±2.36 g/day (T2) to 58.67±2.94 g/day (T3) (P = 0.464). Although the T3 group consistently showed slightly higher mean daily gains across most periods, these differences were not statistically significant.

Dry matter intake

The average daily dry matter intake (DMI) of animals in various treatment groups (T0, T1, T2 and T3) over successive 15-day intervals is presented in Table 8. During the initial 0–15 days, mean DMI values ranged from 363.60 ±19.31 g/day (T1) to 398.20±16.40 g/day (T3), with no significant differences observed among treatments. A similar pattern was noted during the 15-30 day interval, where intake varied between 393.20± 20.42 g/day (T1) and 429.60±14.24 g/day (T3).

Between 30 and 45 days, the DMI increased steadily, ranging from 426.80±16.61 g/day (T1) to 470.20±13.03 g/day (T3), though the variation among groups remained statistically non-significant (P = 0.262). During the 45-60 day period, mean DMI values further increased to between 468.00±18.38 g/day (T1) and 497.60±3.28 g/day (T3), variation among the group was statistically non-significant. In the 60-75 day phase, animals exhibited higher feed consumption, with mean DMI ranging from 485.00±21.91 g/day (T0) to 540.00±7.07 g/day (T2). Although the differences approached statistical significance (P = 0.075), however no significant treatment effect was observed. The final 75-90 day period recorded the highest dry matter intake across all groups, varying from 522.80 ± 22.96 g/day (T0) to 580.00±5.48 g/day (T2). The difference during this period was close to significance (P = 0.052), suggesting a tendency toward higher DMI in the T2 and T3 groups.

Overall, DMI increased progressively over time in all groups, consistent with the animals' growth and increasing nutrient requirements. Although the T2 and T3 groups tended to consume slightly more feed, the differences were not statistically significant (P>0.05).

Feed conversion ratio (FCR)

The feed conversion ratio (FCR) of animals in different treatment groups (T0, T1, T2 and T3) recorded at fortnightly intervals is presented in Table 9. The FCR values reflect the efficiency with which animals converted feed into body weight gain during each period.

During the first 15 days of the experimental period, FCR values ranged from 6.74±0.24 (T3) to 7.79±0.96 (T1), though the FCR was better in group fed concentrate with 40% level of whole ber fruit powder however the variation among the group was non-significant (P = 0.631). Similarly, between 15 and 30 days, the mean FCR varied from 7.05±0.64 (T1) to 8.20±0.62 (T0) with non-significant variation among the treatment groups. During 3rd fortnight the FCR values ranged between 7.37±0.69 (T3) and 9.12±0.68 (T2) (P = 0.297), suggesting comparable feed conversion efficiency among the treatments. During the 45-60 day period, FCR values were slightly higher, varying from 9.51±1.19 (T3) to 11.16±0.89 (T2), though the differences remained statistically non-significant (P = 0.737). In the 60-75 day phase, mean FCR ranged from 9.58±0.75 (T3) to 11.23±0.63 (T2) (P = 0.635), indicating a marginal decline in feed efficiency compared to the earlier stages of growth. During the final 75-90 day period, FCR values ranged

Table 8: Effect of dietary replacement of maize with ground whole *Ziziphus mauritiana* fruit on dry matter intake (g/day).

Particular	Group				P value
	T0	T1	T2	T3	
0-15 days	392.80±19.81	363.60±19.31	370.00±13.32	398.20±16.40	0.442
15-30 days	423.20±17.88	393.20±20.42	411.20±12.04	429.60±14.24	0.442
30-45 days	458.20±17.89	426.80±16.61	451.40±12.26	470.20±13.03	0.262
45-60 days	488.80±18.79	468.00±18.38	493.40±7.15	497.60±3.28	0.455
60-75 days	485.00±21.91	502.80±14.66	540.00±7.07	509.00±3.32	0.075
75-90 days	522.80±22.96	537.20±16.07	580.00±5.48	573.00±8.00	0.052

Table 9: Effect of dietary replacement of maize with ground whole *Ziziphus mauritiana* fruit on feed conversion ratio (FCR).

Particular	Group				P value
	T0	T1	T2	T3	
0-15 days	7.18±0.47	7.79±0.96	6.84±0.55	6.74±0.24	0.631
15-30 days	8.20±0.62	7.05±0.64	8.12±0.51	7.31±0.40	0.378
30-45 days	8.45±0.48	8.44±0.64	9.12±0.68	7.37±0.69	0.297
45-60 days	10.00±1.46	9.99±0.56	11.16±0.89	9.51±1.19	0.737
60-75 days	10.92±0.62	10.40±1.49	11.23±0.63	9.58±0.75	0.635
75-90 days	9.35±0.63	10.32±0.81	11.19±0.50	9.83±0.38	0.210

between 9.35±0.63 (T0) and 11.19±0.50 (T2) (P = 0.210), with the T3 group maintaining relatively better FCR, suggesting efficient feed utilization.

Overall, the FCR values showed normal variation across the growth periods and among the groups, but no statistically significant differences (P>0.05) were observed throughout the experiment. The consistent trend of slightly lower FCR values in the T3 group suggests a tendency toward improved feed efficiency, although not at a statistically significant level.

Serum biochemical parameters

The present study evaluated key biochemical indicators at both Day 0 and Day 90, including glucose, protein fractions, lipid profile and renal and hepatic function markers. The results are mentioned in detail below in Table 10 and Table 11.

Glucose (mg/dl)

At day 0, serum glucose levels did not differ significantly across the groups (p = 0.406), with values ranging from 52.95 to 54.35 mg/dl. However, by Day 90, a significant difference emerged (p = 0.033), with T3 (56.53 mg/dl) showing the highest glucose level, significantly higher than T0 and T1. This suggests an improvement in energy status or glucose metabolism in animals receiving higher treatment levels.

Total protein (g/dl)

Initial total protein levels were statistically similar across all groups (p = 0.669). However, by Day 90, a significant increase was observed (p = 0.017), particularly in T3 (7.66 g/dl) compared to T0 (6.78 g/dl) and T1 (6.58 g/dl). This reflects enhanced protein metabolism and possibly

Table 10: Serum biochemical parameters.

Days	Group				P value
	T0	T1	T2	T3	
			Glucose (mg/dl)		
0	52.95±0.25	53.59±0.38	53.21±0.77	54.35±0.79	0.406
90th	53.29^{b}±0.55	53.95^{b}±0.48	55.31^{ab}±0.38	56.53^{a}±1.17	0.033
			Total protein (g/dl)		
0	7.07±0.27	7.33±0.29	7.15±0.25	6.92±0.07	0.669
90th	6.78^{b}±0.09	6.58^{b}±0.21	7.27^{ab}±0.28	7.66^{a}±0.24	0.017
			Albumin (g/dl)		
0	3.33±0.08	2.98±0.09	3.43±0.20	3.22±0.15	0.164
90th	3.18±0.12	3.13±0.14	3.14±0.16	3.21±0.20	0.978
			Globulin (g/dl)		
0	3.74±0.28	4.36±0.37	3.72±0.29	3.69±0.16	0.330
90th	3.60±0.21	3.45±0.17	4.13±0.37	4.45±0.31	0.085

Table 11: Serum biochemical parameters.

Days	Group				P value
	T0	T1	T2	T3	
			Total cholesterol (mg/dl)		
0	67.42±1.27	70.40±1.63	70.63±1.83	69.07±2.43	0.602
90th	71.68^{a}±2.62	68.10^{ab}±1.21	68.05^{ab}±1.72	63.27^{b}±0.91	0.037
			ALT (IU/L)		
0	20.15±0.64	19.84±0.45	20.22±0.74	20.58±0.80	0.891
90th	20.03±0.46	20.20±0.63	20.58±0.78	20.13±0.47	0.921
			AST (IU/L)		
0	64.65±1.89	64.17±1.43	61.25±2.00	64.02±0.98	0.470
90th	63.84±1.87	64.64±1.17	60.61±1.91	65.05±0.94	0.216
			BUN (mg/dl)		
0	19.75±0.31	19.93±0.47	20.12±0.36	19.86±0.45	0.930
90th	19.76^{a}±0.24	19.61^{a}±0.25	18.91^{a}±0.65	16.65^{b}±0.51	0.002
			Creatinine (mg/dl)		
0	0.99±0.09	1.02±0.10	1.12±0.19	0.76±0.26	0.527
90th	1.25±0.13	0.98±0.05	1.20±0.19	1.02±0.06	0.350
			Triglyceride (mg/dl)		
0	46.69±3.74	45.46±2.88	46.31±1.53	47.29±0.83	0.962
90th	49.75^{a}±5.52	48.49^{a}±0.81	39.60^{ab}±3.63	30.53^{b}±3.52	0.012

better nitrogen retention and utilization in the higher treatment groups.

Albumin (g/dl)

Serum albumin levels remained statistically unchanged throughout the trial period (Day 0: p = 0.164; Day 90: p = 0.978). The values remained within the normal physiological range across all treatments.

Globulin (g/dl)

No significant differences were noted in globulin concentrations at either time point (Day 0: p = 0.330; Day 90: p = 0.085), although a numerical increase was observed in T2 and T3 by Day 90, with T3 reaching 4.45 g/dl.

Total cholesterol (mg/dl)

Baseline cholesterol levels showed no significant variation (p = 0.602). By Day 90, a statistically significant difference emerged (p = 0.037), with T3 showing the lowest value (63.27 mg/dl) compared to T0 (71.68 mg/dl). This reduction may reflect improved lipid metabolism or altered fat utilization patterns due to the treatments.

Liver enzymes (ALT and AST)

Serum alanine aminotransferase (ALT) and aspartate aminotransferase (AST) levels showed no significant differences at either Day 0 or Day 90 (ALT: p = 0.891 and 0.921; AST: p = 0.470 and 0.216).

Blood urea nitrogen (BUN)

Although baseline BUN levels were consistent across groups (p = 0.930), a significant reduction was observed by Day 90 (p = 0.002), particularly in T3 (16.65 mg/dl), compared to other groups T0 (19.76 mg/dl), T1 (19.61 mg/dl) and T2 (18.91 mg/dl) respectively. This suggests better nitrogen utilization in animals fed the highest treatment level.

Creatinine (mg/dl)

No significant changes in creatinine levels were noted at either time point (Day 0: p = 0.527; Day 90: p = 0.350). This indicates consistent kidney function across all groups and further confirms that none of the dietary interventions compromised renal health.

Triglycerides (mg/dl)

While Day 0 triglyceride levels were statistically similar (p = 0.962), a significant decrease was observed by Day 90 (p = 0.012). The T3 group showed the lowest triglyceride concentration (30.53 mg/dl) compared to T0 (49.75 mg/dl) and T1 (48.49 mg/dl). This reduction may be attributed to improved lipid metabolism, enhanced energy utilization, or reduced fat deposition in response to treatment.

Oxidative stress indices

Oxidative stress markers serve as critical indicators of the balance between antioxidant defence systems and free radical production in animals. In this study, reduced glutathione (GSH) and malondialdehyde (MDA) were measured to assess the antioxidant status and lipid peroxidation, respectively, at Day 0 and Day 90. Effect of dietary replacement of maize with ground whole ber fruit on oxidative stress indices are given in Table 12, given below.

Reduced glutathione (GSH, mmol/L cells)

At Day 0, GSH levels were comparable among all groups (p = 0.951), with values ranging narrowly between 0.96 and 0.99 mmol/L, indicating a uniform antioxidant status at the start of the trial. However, by Day 90, a statistically significant increase in GSH levels was observed (p = 0.039). The control group (T0) maintained a level of 0.99 mmol/L, while T3 showed the highest concentration at 1.47 mmol/L, followed by T2 (1.25 mmol/L) and T1 (1.06 mmol/L). This progressive enhancement in GSH suggests that higher levels of the dietary treatment markedly boosted the cellular antioxidant defense capacity. The elevated GSH levels in T3 reflect a better ability to neutralize reactive oxygen species (ROS), likely contributing to improved oxidative stability and cellular protection.

Malondialdehyde (MDA, nmol/ml haemolysate)

MDA, a by-product of lipid peroxidation, serves as a reliable biomarker of oxidative damage. At Day 0, MDA levels did not differ significantly (p = 0.365), with values ranging from 3.55 to 4.16 nmol/ml haemolysate, indicating similar oxidative stress status at baseline. By Day 90, there was a statistically significant reduction in MDA levels across treatment groups (p = 0.004). The control group (T0) had the highest MDA level (3.75 nmol/ml haemolysate), while the lowest was recorded in T3 (2.33 nmol/ml haemolysate). T2 and T1 also showed intermediate values (2.79 and 3.36 nmol/ml haemolysate, respectively), demonstrating a

Table 12: Oxidative stress indices.

Days	Group				P value
	T0	T1	T2	T3	
		GSH (mmol/L cells)			
0	0.98±0.02	0.96±0.01	0.99±0.05	0.97±04	0.951
90	0.99^{b}±0.15	1.06^{b}±0.11	1.25^{ab}±0.06	1.47^{a}±0.10	0.039
		MDA (nmol/ml haemolysate)			
0	3.69±0.25	4.16±0.30	3.55±0.18	3.78±0.21	0.365
90	3.75^{a}±0.30	3.36^{ab}±0.27	2.79^{bc}±0.11	2.33^{c}±0.17	0.004

clear trend of decreasing lipid peroxidation with increasing treatment levels. The observed decline in MDA, particularly in T3, reflects lower oxidative damage to cell membranes, which may be attributed to the elevated GSH levels and overall improved antioxidant capacity in these animals.

Growth parameters

The current study evaluated the effects of ber fruit powder supplementation at different inclusion levels (20%, 30% and 40%) on growth performance, dry matter intake (DMI) and feed conversion ratio (FCR) in goat kids over a 90-day feeding trial.

The findings of the present study showed that replacing maize with whole ber (*Ziziphus mauritiana*) fruit powder up to 40% in the diets of goat kids did not significantly influence body weight, average daily gain (ADG), dry matter intake (DMI), or feed conversion ratio (FCR) throughout the 90-day experimental period. Although numerically higher values for body weight, ADG and better FCR were consistently observed in the group receiving 40% ber fruit powder (T3), these differences were not statistically significant, indicating that ber fruit powder supported normal growth but did not enhance performance markedly compared to the control. These results contrast with several studies in which jujube or jujube-derived products improved growth performance in livestock and poultry. Xie *et al*. (2018) reported significantly higher ADG, DMI and better FCR in goats fed diets containing 150 g/kg jujube meal, Liu *et al*. (2022) also observed significant increases in ADG and DMI in finishing bulls supplemented with 15% jujube powder.

Similarly, in broilers and quails, studies by Yang *et al*. (2023); Liang *et al*. (2023); Mutlu *et al*. (2025) and Cellat *et al*. (2022) consistently demonstrated significant improvements in body weight gain, feed intake and feed efficiency when diets were supplemented with varying levels of jujube fruit powder. These enhanced responses in monogastric may be attributed to their simpler digestive systems, which allow more efficient utilization of bioactive compounds in jujube compared to ruminants, where rumen fermentation may degrade these beneficial phytochemicals before absorption.

However, the results of the present study agree with those of Zhang *et al*. (2022), who observed no significant differences in ADG in bulls fed fermented jujube feed except at excessively high supplementation levels that negatively impacted performance. Likewise, Liu *et al*. (2024) found that fermented jujube powder did not significantly alter DMI, although it improved ADG and FCR in a quadratic and linear manner, respectively- effects not observed in the current study likely due to the use of whole fruit powder rather than fermented or processed forms.

The lack of significant differences in DMI and FCR in the present experiment is also consistent with results reported by Mutlu *et al*. (2025), who noted that jujube supplementation did not consistently improved feed conversion in quails across all periods. Furthermore, although Alawode *et al*. (2020) observed increased feed intake and weight gain in weaner rats fed diets containing jujube seed, these responses reflect the stronger effect jujube tends to have in monogastric systems. Overall, the comparison of findings suggests that while jujube and its derivatives often improve growth performance in many species, especially poultry and non-ruminants, their effects are more variable in ruminants. The neutral impact observed in the present study may be attributed to differences in the form of jujube used (ground whole ber fruit *vs*. fermented or meal), species-specific digestive physiology and inclusion levels. Nevertheless, the consistent numerical improvements in the T3 group indicate that ground whole ber fruit is a safe and acceptable ingredient for partial replacement of maize in goat kid diets, supporting normal growth without adverse effects, even though significant performance enhancement was not detected.

Serum biochemical parameters

The current study evaluated the effects of different dietary treatments on serum biochemical parameters over a 90-day period. The results revealed that serum glucose levels, initially similar across all groups, significantly increased in the T3 group by Day 90, suggesting improved energy status or enhanced glucose metabolism in animals receiving the highest level of treatment. This aligns with the findings of Liu *et al*. (2022), who reported that supplementation with jujube powder and coated methionine significantly elevated serum glucose levels in finishing bulls. The observed rise in glucose levels in both studies may be attributed to enhanced carbohydrate metabolism or increased hepatic gluconeogenesis triggered by bioactive dietary components.

Similarly, total protein levels significantly increased in the T3 group by Day 90, indicating improved protein metabolism and nitrogen retention. This finding is also consistent with Liu *et al*. (2022) and Zhang *et al*. (2022), who documented elevated total protein levels in bulls supplemented with jujube-based feed additives. These consistent results across species suggest that jujube and its derivatives may support protein synthesis or reduce protein degradation through improved nutrient availability.

In contrast, serum albumin and globulin concentrations remained statistically unchanged in the present study. While some numerical increases in globulin were observed in T2 and T3, these were not significant. The stability in albumin levels indicates maintained hepatic synthetic function and protein status, which agrees with the results of Alawode *et al*. (2020), who reported no significant changes in albumin following the inclusion of Ziziphus mauritiana seed in rat diets.

Lipid metabolism also appeared to be positively influenced by the dietary treatments. A significant reduction in total cholesterol and triglyceride levels was observed in the T3 group by Day 90, suggesting enhanced lipid utilization or decreased fat deposition. These findings align with the work of Yazdanpanah *et al*. (2017), who reported improved lipid profiles- including decreased cholesterol and triglycerides in type 2 diabetic patients consuming Ziziphus jujuba infusion. Similar lipid-lowering effects were reported by Alawode *et al*. (2020), though only in the highest inclusion group. The consistent hypolipidemic effects observed across species reinforce the potential role of jujube-derived components in regulating lipid metabolism.

Regarding liver and kidney health, no significant differences were found in ALT, AST, creatinine, or albumin levels at any time point, indicating that none of the dietary interventions compromised hepatic or renal function. Alawode *et al*. (2020), where jujube-based ingredients did not negatively affect liver enzymes or renal markers.

A particularly noteworthy observation in the present study was the significant reduction in blood urea nitrogen (BUN) levels in the T3 group. This finding is indicative of improved nitrogen utilization and possibly lower protein catabolism. It closely mirrors the observations of Liu *et al*. (2022) and Zhang *et al*. (2022), who also reported decreased urea nitrogen in response to jujube supplementation. Reduced BUN levels are generally associated with more efficient dietary protein usage and lower nitrogen waste.

Collectively, the results of the present study suggest that the tested dietary treatments especially at higher inclusion levels can support improved energy metabolism, protein retention and lipid utilization without adversely affecting liver or kidney function. The consistency of these outcomes with those reported by other authors across various species further reinforces the beneficial role of jujube-based dietary components in livestock nutrition. However, discrepancies such as the unchanged albumin and creatinine levels in our study, compared to the alterations reported by some researchers, may be due to differences in species, physiological status, study duration, or the specific form of jujube used.

In conclusion, the current findings support the hypothesis that certain dietary supplements, including those derived from jujube, can enhance metabolic efficiency while maintaining health in animals. The significant improvements in glucose, total protein, lipid profile and nitrogen metabolism observed in the T3 group suggest that higher treatment levels are particularly effective.

Oxidative parameters

The present study investigated the impact of dietary treatments on oxidative stress markers- specifically reduced glutathione (GSH) and malondialdehyde (MDA), in animals over a 90-days period. Our findings demonstrated that dietary supplementation, particularly at the highest inclusion level (T3), significantly enhanced antioxidant status, as evidenced by elevated GSH levels and reduced MDA concentrations. These outcomes align closely with the growing body of literature supporting the antioxidant potential of phytochemical-rich dietary interventions, including jujube and related botanical extracts.

At baseline (Day 0), GSH and MDA levels were statistically similar across all groups, indicating homogeneity in oxidative status prior to intervention. By Day 90, a notable increase in GSH concentration was observed in the T3 group (1.47 mmol/L cells), contrasting with the control (T0), which remained nearly unchanged (0.99 mmol/L cells). Simultaneously, MDA levels were significantly lower in the T3 group (2.33 nmol/ml haemolysate) compared to T0 (3.75 nmol/ml haemolysate), suggesting a marked reduction in lipid peroxidation and oxidative damage.

These observations are consistent with results reported by Liu *et al*. (2022), who found that dietary supplementation with jujube powder (JP) and coated methionine (CMet) significantly increased total antioxidant capacity and superoxide dismutase (SOD) activity while reducing serum MDA levels in finishing bulls in the group receiving dietary JP supplementation. Similarly, Liu *et al*. (2024) observed a dose-dependent enhancement in antioxidant parameters, including a reduction in MDA and an increase in total protein, in bulls fed fermented jujube powder (FJP), mirroring the progressive antioxidant improvement seen across treatment groups in our study.

Moreover, Mutlu *et al*. (2025) reported reduced MDA levels and increased antioxidant enzyme activity, such as catalase (CAT) and glutathione peroxidase (GPx), in quails supplemented with jujube. Our findings resonate with this, especially considering the correlation between elevated GSH levels and reduced lipid peroxidation in the T3 group, suggesting a functional relationship between enhanced endogenous antioxidants and cellular protection.

Further support comes from Yang *et al*. (2023), whose broiler study demonstrated that the inclusion of dried jujube fruit powder (DJFP) in the diet significantly enhanced the activities of key antioxidant enzymes, including superoxide dismutase (SOD), catalase (CAT) and glutathione peroxidase (GPX), compared to the control group. Significant decrease in secondary lipid peroxidation products, which recorded the lowest malondialdehyde (MDA) concentration. These mechanistic effects align with our findings, where in higher GSH levels and reduced lipid peroxidation in the T3 group suggest a robust intracellular defence system capable of counteracting oxidative damage.

The dose-responsive trend in our research is also consistent with the outcomes reported by Liang *et al*. (2023), who noted that increasing levels of jujube powder (up to 10%) led to a significant improvement in T-AOC and enzymatic antioxidants such as SOD, GSH-Px and decreasing MDA levels in broilers. The marked improvement in antioxidant indices in our highest treatment group reinforces the notion that polyphenolic constituents in plant-based feed additives enhance redox homeostasis.

Our results also find strong parallels in the work of Zhang *et al*. (2022), who observed improved antioxidant enzyme activity like significant improvements in serum superoxide dismutase (SOD), glutathione peroxidase (GSH-Px) and reduced MDA levels in dairy bulls during heat stress when their diets were supplemented with fermented jujube feed.

Khanam *et al.* (2025) provided additional mechanistic insight through a rat model, showing that seedless *Ziziphus mauritiana* extracts significantly improved GSH and other antioxidant enzymes, while reducing MDA. This supports our own findings, particularly the significant upregulation of GSH in T2 and T3 groups.

Interestingly, the meta-analysis by Zhu *et al.* (2024) consolidated results across 19 studies on oxidative stress markers in rodent models and concluded that jujube extract supplementation leads to reduced MDA and elevated antioxidant enzymes such as SOD and GSH-Px. This comprehensive evaluation reinforces the credibility and reproducibility of our findings, confirming the reliability of MDA and GSH as biomarkers for evaluating the efficacy of dietary antioxidants.

The consistency across species (bulls, broilers, quails, rodents) and study designs underscores the universal antioxidant effects of jujube and related botanicals, which appear to function via common pathways involving enhancement of GSH, SOD and GPx levels and suppression of MDA. The significant improvement in GSH and reduction in MDA observed in our study indicate enhanced redox stability and cellular protection, validating the efficacy of the dietary treatment employed.

CONCLUSION

In conclusion, the study demonstrates that ground whole ber fruit (*Ziziphus mauritiana*) can effectively replace maize in concentrate mixtures up to 40% without compromising growth performance, dry matter intake, and feed conversion ratio in Osmanabadi goat kids. Although fortnightly body weight, average daily gain, and feed conversion ratio remained statistically similar across treatments, animals receiving higher levels of ground whole ber fruit showed a consistent numerical improvement in growth and feed utilization. Significant improvements in serum glucose, total protein, lipid profile, blood urea nitrogen, and antioxidant status, along with reduced oxidative stress markers, indicate enhanced metabolic efficiency and better health status in the higher inclusion groups. The absence of adverse effects on liver and kidney function further confirms the safety of dietary ber fruit supplementation. These findings highlight the potential of ber fruit as a sustainable and nutritionally beneficial alternative feed ingredient for small ruminants.

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Consent for publication

All authors have approved the final version of the manuscript and consent to its publication.

Ethics approval consent to participate

This research was conducted in accordance with the guidelines of the Institutional Animal Ethics Committee (IAEC). All experimental procedures were performed following the recommendations approved by the IAEC having approval No. ANN-PhD-2/2025.

Conflict of interest

The authors declare that there are no conflicts of interest related to this work.

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