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Utilization of Industrial Marine-Derived *Turbinella pyrum* Shell By-Product as a Sustainable Source of Calcium for Growing Black Bengal Goats

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ABSTRACT

Background: Rising costs of conventional calcium (Ca) sources like dicalcium phosphate (DCP) have prompted interest in alternative Ca sources. Marine conch (*Turbinella pyrum*) shell by-products, rich in bioavailable biogenic calcium, may offer a potential eco-friendly mineral supplement for small ruminant nutrition.

Methods: Twenty-seven growing female Black Bengal goats were randomly allotted to three dietary treatments. A di-calcium phosphate (DCP)-based mineral mixture served as control (T_0), while DCP was replaced by conch shell powder (CSP) at 100% (T_1) or 50% (T_2), with phosphorus balanced using diammonium phosphate and triple superphosphate. All mineral mixtures were formulated to provide comparable calcium (~21%) and phosphorus (~11.5%) levels, ensuring uniform mineral supply across treatments. A growth trial with 195 days observation was conducted to test the potential of CSP-sourced Ca in growing goats.

Result: CSP, an abundant industrial by-product in West Bengal, was evaluated as a sustainable alternative Ca source for goats. Complete (T_1) or partial (T_2; 50:50) replacement of DCP with CSP, balanced for phosphorus, produced diets with Ca, P and Ca:P ratios comparable to the control (T_0). CSP-based mineral mixtures improved dry matter and crude protein intake, indicating enhanced voluntary intake and feed efficiency. However, growth rate remained similar across treatments. Ca and P levels were unaffected, as reflected by comparable urinary excretion. Observed temporal variations were physiological rather than dietary. The study concludes that CSP can fully replace DCP, with balanced P supplementation, without adverse effects on intake, mineral balance, or growth performance in goats.

Key words: Black bengal goat, Calcium, Conch shell powder, Growth, Intake, *Turbinella pyrum*.

INTRODUCTION

India's 11,099 km coastline (PIB, 2026) provides abundant marine mineral resources, including shells that are increasingly generated as industrial waste. Among these, *Turbinella pyrum* (conch) shells processed by MSMEs in West Bengal produce large quantities of conch shell powder (CSP), which is often disposed of improperly, creating environmental and occupational concerns (Bhagat *et al.,* 2024). Marine shells contain >95% calcium carbonate ($CaCO_3$), mainly as calcite and aragonite forms in adult organisms, with some amorphous $CaCO_3$ in younger shells (Xu *et al*., 2020; McDougall and Degnan, 2018). Compared with inorganic limestone, shell-derived $CaCO_3$ is biogenic and marine in origin, potentially offering advantages in biological safety and mineral composition (Barros *et al.,* 2009). Shell-based Ca sources are also considered safer than bone-derived minerals because of potential prion risks (Kim *et al.,* 2013; 2016). Fresh CSP is rich in Ca and contains trace minerals such as Zn, Fe, Cu, Co, Mg and Mn (Bhagat *et al.,* 2024).

Calcium is essential for skeletal integrity, metabolism and productive performance in livestock (NRC, 2005; Kim *et al.,* 2020). However, Ca bioavailability is influenced by dietary antinutrients such as phytic and oxalic acids (Kiarie and Nyachoti, 2010). Although dicalcium phosphate (DCP) is widely used in livestock diets, its rising cost has increased interest in locally available alternatives. Recent work showed that fresh *T. pyrum* shell powder supplies essential minerals for livestock and supports sustainable use of marine by-products (Bhagat *et al.,* 2025). *T. pyrum* shell powder, previously evaluated only in calves, may also serve as a viable calcium source for mineral mixtures in small ruminants.

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The Black Bengal goat, indigenous to eastern India and Bangladesh, is valued for high prolificacy, superior meat quality, early maturity and strong adaptability under low-input systems. Therefore, this study evaluated industrial marine-derived *T. pyrum* shell by-product (CSP) as a sustainable alternative Ca source by replacing DCP in mineral mixtures (with balanced phosphorus) in diets of growing Black Bengal goats, assessing voluntary intake, growth performance and Ca-P status in urine.

MATERIALS AND METHODS

Study location and sourcing of mineral materials

The experiment was conducted at the Animal Nutrition Laboratory and Experimental Goat Farm of ICAR-National Dairy Research Institute (NDRI), Eastern Regional Station (ERS), Kalyani, West Bengal, India (22°56′30″N; 88°32′ 04″E). The study was approved by the Scientific Committee of the Deemed University (NDRI/22-P-AN-03) and complied with institutional animal ethics guidelines. Feed-grade dicalcium phosphate (DCP) was procured from Narmada Gelatines Ltd., Jabalpur, Madhya Pradesh, whereas raw powdered conch shell (*Turbinella pyrum*; CSP) waste was obtained from a local MSME-based conch industry.

Experimental animals and management

A total of 27 female growing Black Bengal goats were randomly allocated to three dietary treatments (n = 9 per treatment) after stratification for comparable initial age and body weight (Table 3). The mean initial age was 7.56± 1.24, 7.61±1.45 and 7.89±1.27 months for T_0, T_1 and T_2, respectively. Animals were housed individually in well-ventilated pens and subjected to a 15-day adaptation before the trial. The shed was disinfected with lime, cleaned daily with phenyl and animals were vaccinated against goat pox and PPR and dewormed with albendazole and ivermectin.

Experimental design, diets, mineral sources and treatments

The growth trial lasted 195 days. Goats were fed a total mixed ration (TMR) on a dry matter basis in a 40:40:20 proportion of green fodder:concentrate mixture:paddy straw. The concentrate mixture was formulated to approximately 20.18% crude protein (CP) and 75.25% total digestible nutrients (TDN). Feed was offered twice daily *ad libitum* and fresh drinking water was provided twice daily. Treatments differed only in the mineral mixture included at 2% of the concentrate. T_0 served as the control with a conventional DCP-based mineral mixture. In T_1, DCP was completely replaced by CSP as the main Ca source, with phosphorus balanced using diammonium phosphate (DAP) and triple superphosphate (TSP). In T_2, 50% of DCP was replaced by CSP, with P similarly balanced using DAP/TSP. All mineral mixtures were formulated to be comparable in Ca (≈ 21%) and P (≈11.5%). Prior to mixing, mineral mixtures were sieved using an ASTM No. 60 (250 µm) stainless-steel test sieve.

Chemical analysis of feeds and fibre fractions

Representative samples of TMR were analyzed in quadruplicate for dry matter (DM), organic matter (OM), ether extract (EE) and total ash using AOAC (2012) procedures. Nitrogen content was determined by the Kjeldahl method (AOAC, 1995) and CP was calculated as N × 6.25. Ash was determined by incineration at 550-600°C for 3 h and OM was calculated as 100 - ash. Fibre fractions (NDF, ADF, hemicellulose, cellulose and ADL) were estimated using the Van Soest detergent system (Van Soest *et al*., 1991). Total carbohydrate (TCHO) was calculated as 100 - (CP + EE + ash) on a DM basis.

Mineral analysis and digestion procedures

Calcium was analyzed using an atomic absorption spectrophotometer (Agilent 240AA). Mineral source samples (CSP and DCP) were digested using a di-acid mixture of HNO_3:$HClO_2$ (2:1) following Palma *et al.* (2015), whereas feed/TMR were digested with a tri-acid mixture of HNO_3:$HClO_2$:H_2SO_4 (3:2:1). About 0.5-2.0 g sample was digested in a Gerhardt TT Turbotherm system, diluted to 100 mL and filtered through Whatman No. 42 paper. Lanthanum was added to all standards and samples to achieve a final concentration of 0.2% (w/v) to minimize chemical interference in Ca estimation. Phosphorus was determined colorimetrically by the method of O'Dell (1993), while urinary P was measured using a commercial photometric kit.

Urine sampling and Ca/P estimation

Urine samples were collected on Days 0, 90 and 180. Approximately 20 mL spot urine was collected by mid-stream free catch around 4 h post-feeding following validated protocols (Santos *et al*., 2017; 2018). Urinary Ca was measured by AAS and urinary P using a photometric kit.

Recording of feed intake, digestibility and growth performance

Daily feed offered and refusals were recorded individually and DM of feeds and refusals was determined weekly for correction. Total dry matter intake (TDMI) and crude protein intake (CPI) were expressed as g/day, kg/100 kg BW and g/kg $W^{0.75}$. A digestion trial was conducted at the end of the growth trial with 6 days collection period from all experimental animals for evaluation of DM, Ca and P digestibility. Body weight was recorded fortnightly before feeding. Average daily gain (ADG) and feed conversion ratio (FCR) were calculated as:

Average daily gain (ADG) g/d =

$$\frac{\text{Final BW (kg) - Initial BW (kg)}}{\text{Total days}} \times 1000$$

$$\text{Feed conversion ratio (FCR)} = \frac{\text{Total DMI (g/d)}}{\text{ADG (g/d)}}$$

Statistical analysis

Chemical composition and growth performance data were analyzed using one-way ANOVA (Snedecor and Cochran, 1994). Intake, ADG and FCR were analyzed using two-way

ANOVA with treatment as a fixed effect and period as a random effect, including their interaction. All analyses were performed using SPSS 26.0 and mean separation was done using Tukey's HSD at p<0.05, p<0.01 and p<0.001.

RESULTS AND DISCUSSION

Mineral profile of conch shell powder and dicalcium phosphate

The chemical and mineral composition of conch shell powder (CSP) and dicalcium phosphate (DCP) is presented in Table 1. Significant differences were observed between the two mineral sources for most parameters. CSP contained significantly higher organic matter than DCP (p<0.001), whereas total ash was greater in DCP (p<0.001). Acid-insoluble ash did not differ significantly (p>0.05), indicating similar levels of indigestible mineral fractions. Calcium concentration was markedly higher in CSP (34.92%) than in DCP (23.59%; p<0.001), while phosphorus was substantially greater in DCP (18.94%) compared with CSP (0.20%; p<0.001). Magnesium content was also higher in DCP (p<0.001). Among trace minerals, DCP had significantly higher Zn, Cu, Mn and Co (p<0.01), whereas Fe was greater in CSP (p<0.001). These findings indicate that CSP is a superior source of Ca and Fe, whereas DCP provides higher P and certain trace minerals, reflecting inherent compositional differences between the two supplements.

Chemical and mineral composition of different feeds-Total mixed rations (TMR)

No significant differences were observed among T_0, T_1 and T_2 TMRs for OM, CP, EE, TCHO, total ash, or fibre fractions (NDF, ADF, cellulose, lignin, hemicellulose; p>0.05), confirming that the diets were nutritionally comparable (Table 2). Calcium and phosphorus concentrations were also similar across treatments (p>0.05), demonstrating that the TMRs were iso-mineral with respect to these macro-minerals and ensuring that any subsequent animal responses could be attributed to mineral source rather than diet composition.

Complete replacement of DCP with CSP in T_1 and 50% replacement in T_2, achieved Ca and P levels comparable to the control T_0. The calculated Ca:P ratios were 2.04 (T_0), 2.00 (T_1) and 2.21 (T_2), which lie within the recommended range for goats. A Ca:P ratio of 2:1 or higher has been recommended by NRC (1985) to reduce the risk of urinary calculi in small ruminants and balanced mineral ratios have been shown to have a protective effect against calculi formation (Gianesella *et al.,* 2010).

Voluntary intake pattern, digestibility and growth performance

Dietary treatment significantly affected voluntary feed intake, whereas growth performance traits were largely unaffected (Table 4). Total dry matter intake (DMI; g/day/goat) differed among treatments (p<0.001), with higher intake in T_1 and T_2 than in T_0. Similar trends were observed when DMI was expressed as kg/100 kg BW and g/kg $W^{0.75}$ (p<0.001). Period effects were significant for all DMI indices (p<0.001), but treatment × period interaction was not significant, indicating consistent treatment responses over time. Crude protein intake (CPI) followed a similar pattern: total CPI was highest in T_1, intermediate in T_2 and lowest in T_0 (p<0.001). When expressed relative to BW and metabolic BW, CPI was also greater in T_1 and T_2 than in T_0 (p<0.001). A significant treatment × period interaction for CPI (p<0.001) suggested differential protein intake responses across periods.

The apparent digestibility of DM was identical among three treatments (Table 3). Whereas, Ca digestibility was significantly influenced by dietary treatment (p<0.001). Treatment T_1 and T_2 exhibited significantly higher Ca digestibility compared to T_0. P digestibility was also significantly affected by treatment (p = 0.009). T_1 showed the highest P digestibility (60.73%), which was significantly greater than T_0 and T_2.

Initial and final body weights did not differ among treatments (p>0.05), confirming baseline uniformity and comparable final outcomes (Table 3). Average daily gain

Table 1: Comparative chemical and mineral composition of conch shell powder and di-calcium phosphate.

Parameters	CSP	DCP	S.E.M.	*p* value
OM (%)	4.70[b]	0.58[a]	0.786	0.001
Total ash (%)	95.30[a]	99.42[b]	0.786	0.001
AIA (%)	0.88	0.82	0.027	0.333
Calcium (%)	34.92[b]	23.59[a]	1.206	0.001
Phosphorus (%)	0.20[a]	18.94[b]	3.546	0.001
Magnesium (ppm)	604.17[a]	1415.45[b]	85.090	0.001
Zinc (ppm)	414.75[a]	459.90[b]	8.876	0.008
Copper (ppm)	26.76[a]	40.36[b]	1.564	0.001
Iron (ppm)	312.70[b]	211.78[a]	12.854	0.001
Manganese (ppm)	42.06[a]	49.07[b]	0.994	0.001
Cobalt (ppm)	5.34[a]	17.71[b]	1.472	0.001

DM: Dry matter; OM: Organic matter; AIA: Acid insoluble ash; CSP: Conch shell powder; DCP: Dicalcium Phosphate. Within a row, means bearing different superscripts (a, b) differ significantly (p<0.05). [1]Total ash was performed at 550-600°C for 3 hour.

(ADG) was numerically higher in T_1 and T_2 than in T_0 but not statistically different (p>0.05). Feed conversion ratio (FCR) differed significantly among treatments (p<0.001): T_1 showed the most efficient utilization, followed by T_2, while T_0 had the highest (poorest) FCR. Period and treatment × period effects were also significant for FCR (p<0.001), indicating temporal variation in feed efficiency. Overall, calcium source influenced nutrient intake and feed efficiency, whereas growth rate remained comparable among treatments.

Conch shell powder (CSP), an abundant industrial by-product in West Bengal, represents a promising alternative calcium source for livestock. Previous work at ICAR–NDRI, ERS Kalyani first evaluated this material in crossbred calves. Because CSP is predominantly biogenic $CaCO_3$ (Barros *et al.,* 2009), its nutritional effects are expected to be comparable to-or potentially better than-inorganic $CaCO_3$ (Bhagat *et al.,* 2025). In the present study, CSP inclusion (T_1 and T_2) increased DMI relative to the control, suggesting improved palatability and/or a more balanced mineral supply that may favor rumen function and voluntary intake. Higher CPI in T_1 and T_2 likely supported greater microbial protein synthesis, a key driver of amino acid supply in growing ruminants.

Findings align with earlier evidence that biogenic calcium sources can effectively replace conventional minerals in livestock diets (Bhagat *et al*., 2024; 2025). Similar growth responses across calcium sources were reported in pigs by Santana *et al.* (2018) and in laying hens by Safaa *et al.* (2008). Olgun *et al.* (2015) found no FCR differences when limestone was partially replaced with eggshell or oyster shell in poultry, while Badejo *et al*. (2019) observed no effects of various Ca sources on intake or FCR in spent

Table 2: Chemical composition of different treatment total mixed rations (TMRs) used during growth trial in growing goats.

Nutrient (%)	TMR-T_0	TMR-T_1	TMR-T_2	S.E.M.	*p* value
DM	61.11	61.34	62.00	0.339	0.581
OM	88.57	88.89	88.42	0.113	0.240
CP	12.91	12.92	12.86	0.132	0.983
EE	2.85	2.93	2.93	0.095	0.948
TCHO	72.81	73.04	72.63	0.237	0.811
Total ash	11.43	11.11	11.58	0.113	0.240
NDF	57.34	56.85	57.80	0.199	0.151
ADF	32.74	32.61	31.44	0.360	0.289
Cellulose	29.29	29.67	29.86	0.191	0.508
ADL	2.95	3.18	3.15	0.155	0.832
Hemicellulose	24.60	24.24	26.36	0.460	0.126
Calcium	1.00	0.98	1.06	0.024	0.389
Phosphorus	0.49	0.49	0.48	0.004	0.134
Ca:P ratio	2.04:1	2.00:1	2.21:1	-	-

DM: Dry matter; OM: Organic matter; CP: Crude protein; EE: Ether extract; TCHO: Total carbohydrate; NDF: Neutral detergent fiber; ADF: Acid detergent fiber; ADL: Acid detergent lignin.

Table 3: Voluntary intake pattern of different nutrients and growth performance in growing goats under different treatments.

Nutrient (%)	T_0	T_1	T_2	S.E.M.	*p* value		
					T effect	P effect	T × P effect
Total DMI (g/day/goat)	366.06^a	375.79^b	371.63^b	1.817	0.001	0.001	0.908
DMI (kg/100 kg BW)	3.35^a	3.43^b	3.41^b	0.013	0.001	0.001	0.977
DMI (g/kg $W^{0.75}$)	60.68^a	62.21^b	61.80^b	0.171	0.001	0.001	0.969
Total CPI (g/day/goat)	51.58^a	53.23c	52.61^b	0.33	0.001	0.001	0.001
CPI (g/100 kg BW)	468.43^a	482.01^b	479.82^b	1.29	0.001	0.001	0.001
CPI (g/kg $W^{0.75}$)	8.51^a	8.76^b	8.71^b	0.02	0.001	0.001	0.001
DM digestibility (%)	60.89	62.15	61.42	0.33	0.300	-	-
Ca digestibility (%)	58.81^a	62.74^b	61.65^b	0.50	< 0.001	-	-
P digestibility (%)	57.58^a	60.73^b	58.29^a	0.48	0.009	-	-
Initial BW (kg)	7.70	7.69	7.70	0.292	1.000	-	-
Final BW (kg)	14.02	14.14	14.01	0.272	0.979	-	-
ADG (g/day/goat)	31.62	33.11	32.39	0.428	0.067	0.134	1.00
FCR (kg DMI/kg gain)	11.72^c	11.36^a	11.54^b	11.54	0.001	0.001	0.001

The values with different superscripts (a, b, c) among different treatments differ significantly. DMI: Dry matter intake; CPI: Crude protein intake; BW: Body weight; ADG: Average daily (body weight) gain; FCR: Feed conversion ratio.

Table 4: Calcium and phosphorus concentration in urine of growing goats affected by different treatments.

Days	T_0	T_1	T_2	Mean ± S.E.M.	Significance
Urine calcium (mg/dl)					
Day 0	128.40	124.20	130.60	127.73^b±1.976	Treatment effect (T),
Day 90	121.30	116.70	121.80	119.93^a±1.815	*p* = 0.105; Period effect
Day180	118.60	113.40	117.10	116.37^a±1.702	(P), *p*< 0.001; T×P,
Mean ± S.E.M.	122.77±1.990	118.10±1.905	123.17±2.119	121.35±1.173	*p* = 0.985
Urine phosphorus (µg/ml)					
Day 0	10.29	10.26	9.95	10.17^a±0.183	Treatment effect (T),
Day 90	11.08	10.65	11.52	11.08^b±0.281	*p* = 0.083; Period effect
Day 180	11.05	9.93	11.29	10.76^{ab}±0.180	(P), *p* = 0.011; T×P,
Mean ± S.E.M.	10.81±0.207	10.28±0.193	10.92±0.269	10.67±0.132	*p* = 0.218

The values with different superscripts (a, b) among different periods differ significantly.

layers. Conversely, Oso *et al.* (2011) reported higher intake and gain in broilers fed oyster shell versus limestone, indicating species- and stage-dependent responses. The enhanced feed efficiency in T_1 and T_2 observed in the present study may be explained by greater feed intake coupled with a marginal improvement in growth performance compared with the control group (T_0).

Overall, replacing DCP with CSP enhanced nutrient intake and feed efficiency without altering growth rate, indicating that growing goats maintained growth within physiological limits while effectively utilizing the alternative Ca source. These results support the strategic use of locally available CSP as a sustainable mineral supplement to optimize nutrient utilization in small ruminants.

Calcium and phosphorus concentration in urine

Urinary calcium concentration declined significantly over time (p<0.001), with higher values on Day 0 than on Days 90 and 180, irrespective of dietary treatment (Table 4). No significant treatment effect or treatment × period interaction was observed, indicating similar patterns of urinary Ca excretion across groups. Urinary phosphorus was influenced by period (p = 0.011), being highest on Day 90, lowest on Day 0 and intermediate on Day 180, while dietary treatment and interaction effects were non-significant, suggesting comparable P availability among treatments.

Livestock productivity depends on the understanding of diverse production systems and socio-economic conditions. With growing industrialization, developing green and innovative feed formulations is essential to improve growth performance, feed efficiency and sustainability in livestock production systems (Awad *et al*., 2025; Du *et al*., 2025; Rajeev *et al*., 2025). Hence, replacing conventional DCP-sourced Ca with biogenic conch shell powder (as new Ca source) in the present study increased Ca and P digestibility and had no adverse effect on Ca and P excretion pattern through urine in growing goats. The temporal decline in urinary Ca likely reflects physiological adaptation and improved mineral utilization over time, while the mid-trial rise in urinary P (Day 90) suggests dynamic but well-regulated P metabolism. Consistent with this, Bhagat *et al.* (2025) reported reduced fecal excretion of Ca and P in heifers fed CSP, indicating improved mineral digestibility compared with DCP.

This study, along with earlier reports (Bhagat *et al*., 2024; 2025), confirms conch shell powder (CSP), an MSME by-product, as a high-calcium (>34%) resource suitable for livestock mineral mixtures. Its use recycles shell waste and reduces environmental pollution. Future work should assess nutrient utilization, blood minerals, CSP particle size differences and creatinine-normalized urine analysis.

CONCLUSION

Conch shell powder (CSP), an abundant industrial by-product in West Bengal, emerges as a sustainable and economical alternative source of calcium and trace minerals (Mg, Zn, Mn, Cu, Fe) for goat nutrition. Complete replacement of dicalcium phosphate (DCP) with CSP (T_1) and partial replacement (50:50; T_2) maintained dietary Ca and P concentrations and optimal Ca:P ratios comparable to the control. CSP-based mineral supplementation improved DM and CP intake with increased Ca and P digestibility and enhanced feed efficiency without affecting growth performance. Urinary Ca and P levels remained within normal physiological limits, indicating no adverse metabolic effects. Overall, CSP can safely and effectively replace DCP, when appropriately balanced with phosphorus, without compromising intake, mineral balance, or growth performance in goats.

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Disclaimers

The views and conclusions expressed in this article are solely those of the authors and do not necessarily represent the views of their affiliated institutions. The authors are responsible for the accuracy and completeness of the information provided but do not accept any liability for any direct or indirect losses resulting from the use of this content.

Ethics statement

The study was approved by the Scientific Committee of ICAR–National Dairy Research Institute (Deemed University) under approval number NDRI/22-P-AN-03.

Conflict of interest

The authors declare that there are no conflicts of interest regarding the publication of this article. No funding or sponsorship influenced the design of the study, data collection, analysis, decision to publish, or preparation of the manuscript.

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