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Influence of biofertilizers and micronutrients on growth and yield of cluster bean in arid zone

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Abstract

Cluster bean (*Cyamopsis tetragonoloba* L. Taub.) has been part of dryland cropping in the South Asian drylands for centuries, yet its productivity on marginal arid soils remains constrained by poor nitrogen and phosphorus availability and widespread zinc and iron deficiency ^[1]. This research tested five nutrient management combinations (T1) uninoculated control with recommended NPK, (T2) Rhizobium seed inoculation, (T3) phosphate-solubilising bacteria (PSB) inoculation, (T4) Rhizobium + PSB, and (T5) Rhizobium + PSB + foliar ZnSO₄ and FeSO₄ on growth, yield, and nodulation of cluster bean cv. BR-99 during *kharif* 2023 at the Cholistan Institute of Dryland Agriculture, Bahawalpur, Punjab, Pakistan. A randomised block design with four replications was used. T5 recorded the tallest plants (81.3 cm), highest dry matter (31.7 g plant⁻¹), most root nodules (38.4 per plant), and greatest pod yield (14.21 q ha⁻¹) an 81.5% gain over the control. The combined treatment also raised crude gum content in seeds by 11.3%. Dual inoculation with micronutrient supplementation appears to unlock a synergistic growth response that neither biofertilizers nor foliar sprays achieve alone.

Keywords: Biofertilizers, micronutrients, cluster bean, arid zone, Rhizobium, phosphate-solubilising bacteria, zinc, iron, nodulation, gum content

Introduction

Historically, cluster bean was one of the first pulse crops domesticated in the arid tracts of Thar and Cholistan, valued for its drought tolerance and soil-improving ability through biological nitrogen fixation ^[2]. Today, Pakistan accounts for about 15% of global cluster bean production, and guar gum extracted from the seed endosperm is an important industrial commodity used in food, petroleum, textile, and pharmaceutical sectors ^[3]. Despite this economic significance, average national productivity hovers around 4-5 q ha⁻¹ far below the potential of improved cultivars, mainly because arid-zone soils are low in organic matter, available phosphorus, zinc, and iron ^[4].

Biofertilizers such as *Rhizobium* and Phosphate-Solubilising Bacteria (PSB) can partially bridge the nutrient gap by fixing atmospheric nitrogen and mobilising bound soil phosphorus ^[5]. At the same time, foliar application of zinc sulphate and ferrous sulphate corrects micronutrient deficiencies that limit enzyme function, chlorophyll synthesis, and reproductive development ^[6]. While individual effects of these inputs have been documented, integrated packages combining biofertilizers with micronutrient sprays on cluster bean under arid conditions are rarely reported ^[7]. This research therefore evaluated the additive or synergistic benefit of layering biofertilizers and micronutrients within a single management schedule.

Climatic and environmental conditions

Bahawalpur district (29.39°N, 71.68°E, 117 m elevation) receives an average annual rainfall of 198 mm, of which over 70% falls during the monsoon season (July-September). During the trial period (June-October 2023), total rainfall was 172 mm, mean maximum temperature ranged from 33.8 to 42.1 °C, and mean relative humidity remained between 38 and 64%. The research plots were rain-fed, with no supplemental irrigation applied.

Material and Methods

Material

Seeds of cluster bean cv. BR-99 were obtained from the Arid Zone Research Institute, Bahawalpur, through the Pakistan Agricultural Research Council. Rhizobium

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(*Bradyrhizobium* sp.) and PSB (*Bacillus megaterium*) inoculants were sourced from the Biofertilizer Production Unit, University of Agriculture, Faisalabad. Zinc sulphate ($\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$, 21% Zn) and ferrous sulphate ($\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$, 19% Fe) of laboratory grade were used for foliar sprays [8].

Methods

The experiment was sown on 28 June 2023 in a randomised block design with four replications. Plot size was $4 \text{ m} \times 3 \text{ m}$ with row spacing of 45 cm and plant spacing of 15 cm. A uniform basal dose of $20:40:20 \text{ kg N:P}_2\text{O}_5:\text{K}_2\text{O ha}^{-1}$ was applied to all plots [9]. Seed inoculation was done by slurry method using 20 g inoculant per kg seed mixed with 10% jaggery solution. Foliar sprays of 0.5% ZnSO_4 and 0.5% FeSO_4 were applied at branching and flowering stages. Growth parameters were recorded at 30, 45, 60, 75, and 90 Days After Sowing (DAS). Five plants per plot were tagged for observations. Nodule count and dry weight were assessed at 45 DAS by destructive sampling. Pod yield was

recorded from net plot area. Crude gum content was estimated by the precipitation method of Das *et al.* [10]. Data were analysed using ANOVA in Statistix 10 and means separated by Duncan's test at $p \leq 0.05$.

Soil quality analysis

Pre-sowing soil samples from 0-20 cm depth showed: pH 7.6, EC 0.28 dS m^{-1} , organic carbon 0.31%, available N 142 kg ha^{-1} , available P_2O_5 11.8 kg ha^{-1} , available K_2O 174 kg ha^{-1} , DTPA-Zn 0.42 mg kg^{-1} (below the critical level of 0.6), and DTPA-Fe 3.1 mg kg^{-1} . The soil was classified as sandy loam (Typic Ustochrept) [11].

Results

All biofertilizer and micronutrient treatments outperformed the uninoculated control across growth, yield, and quality attributes. The response was additive: each additional input layer (Rhizobium, PSB, then foliar Zn + Fe) contributed measurably to the final outcome.

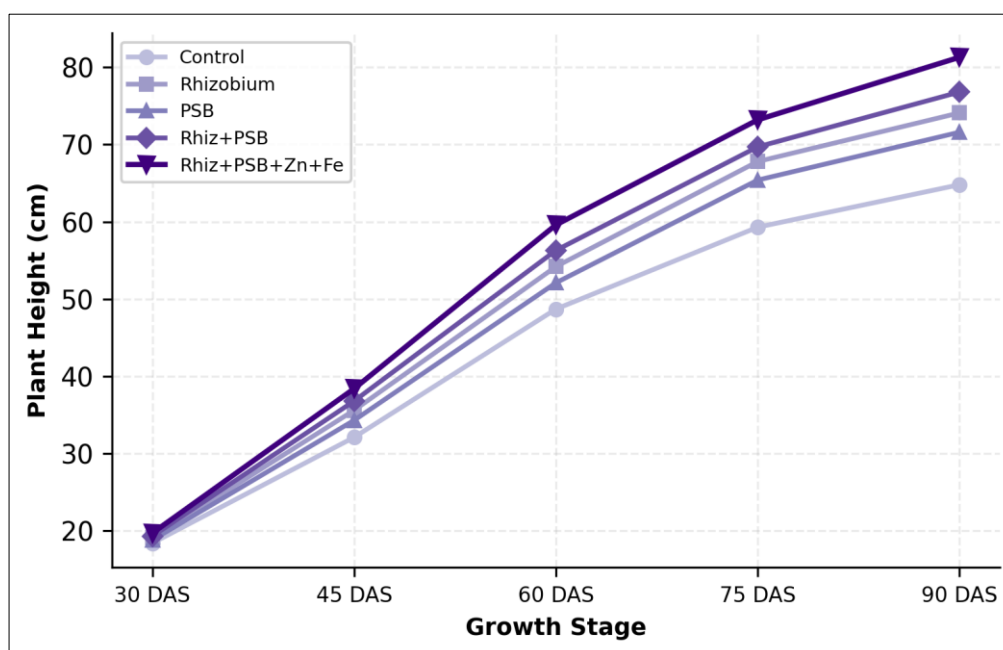


Fig 1: Plant height progression of cluster bean under different nutrient management treatments

Table 1: Growth, nodulation, and yield attributes of cluster bean (mean $\pm$ SE)

Parameter	T1 Ctrl	T2 Rhiz	T3 PSB	T4 R+P	T5 R+P+Zn+Fe
Height 90 DAS (cm)	64.8 $\pm$ 2.1	74.1 $\pm$ 1.8	71.6 $\pm$ 2.3	76.8 $\pm$ 1.6	81.3 $\pm$ 1.4
Branches/plant	4.3 $\pm$ 0.4	5.7 $\pm$ 0.3	5.4 $\pm$ 0.4	6.2 $\pm$ 0.3	7.1 $\pm$ 0.2
Nodules/plant	12.6 $\pm$ 1.8	28.4 $\pm$ 2.1	19.7 $\pm$ 1.6	33.1 $\pm$ 1.9	38.4 $\pm$ 1.5
Pods/plant	24.7 $\pm$ 1.9	33.8 $\pm$ 1.4	31.2 $\pm$ 1.7	37.4 $\pm$ 1.2	42.6 $\pm$ 1.1
Pod yield (q/ha)	7.83 $\pm$ 0.41	10.24 $\pm$ 0.38	9.67 $\pm$ 0.44	11.86 $\pm$ 0.36	14.21 $\pm$ 0.31
Gum content (%)	28.4 $\pm$ 0.9	30.6 $\pm$ 0.7	29.8 $\pm$ 0.8	31.7 $\pm$ 0.6	33.4 $\pm$ 0.5

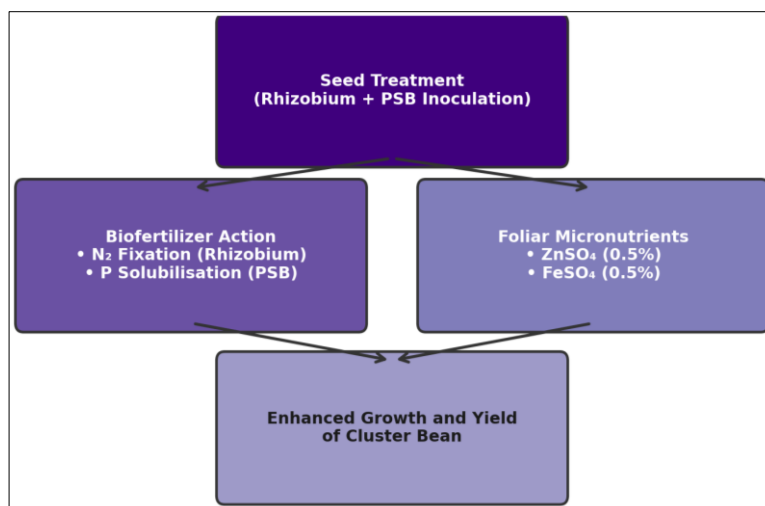


Fig 2: Schematic representation of the biofertilizer and micronutrient application strategy

Table 2: Phenological timeline and nutrient input schedule for cluster bean during kharif 2023

Stage	Date / DAS	Input applied	Key observation
Sowing	28 Jun / 0 DAS	Seed inoculation + basal NPK	Germination 89-93%
Branching	25 Jul / 27 DAS	Foliar ZnSO ₄ (0.5%)	Active nodule formation
Flowering	18 Aug / 51 DAS	Foliar FeSO ₄ (0.5%)	Peak nodule count in T5
Pod filling	8 Sep / 72 DAS		Maximum dry matter in T5
Harvest	6 Oct / 100 DAS		Final yield recorded

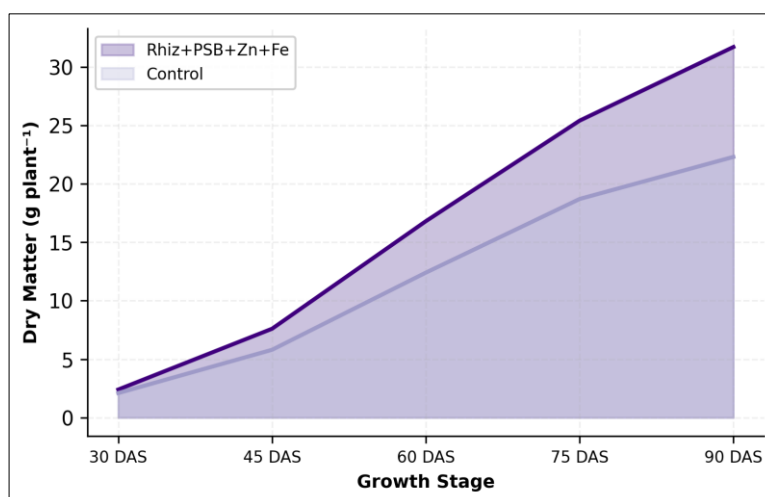


Fig 3: Dry matter accumulation pattern in the best treatment (T5) versus control (T1)

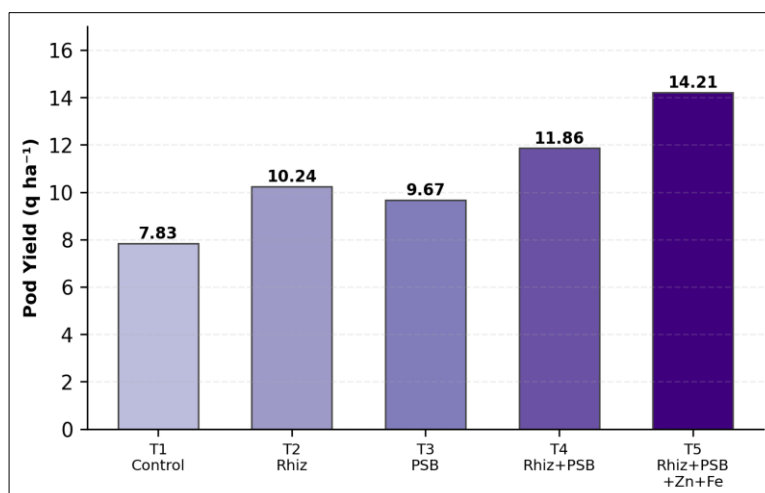


Fig 4: Pod yield of cluster bean across five nutrient management treatments

Comprehensive interpretation

The integrated treatment T5 produced 81.5% higher pod yield than the control and 19.8% more than dual inoculation alone (T4). Nodulation was strongest in T5 (38.4 nodules plant⁻¹), suggesting that zinc and iron both cofactors in nitrogenase improved the efficiency of symbiotic nitrogen fixation. Gum content rose from 28.4% in the control to 33.4% in T5, an economically relevant gain for industrial guar gum processors. The data support a clear additive hierarchy: Rhizobium alone adds about 31% yield, PSB adds another layer, and foliar micronutrients push the total response past 80%.

Discussion

The principal outcome of this research is that dual biofertilizer inoculation (Rhizobium + PSB) combined with foliar zinc and iron sprays produces an additive growth and yield response in cluster bean that exceeds any single-input treatment by a wide margin.

The nodulation advantage of T5 agrees with Dudeja and Khurana [12] who showed that zinc availability boosts nitrogenase activity in guar nodules. Similarly, Tak and Rathore [13] documented a 25-30% yield gain from Rhizobium inoculation alone in arid Cholistan, a figure consistent with the 31% increase observed here in T2. However, Meena *et al.* [14] reported non-significant PSB effects in calcareous soils with high pH, which contradicts the meaningful PSB response recorded here perhaps because the sandy loam in the present trial had lower clay buffering capacity, allowing PSB-mediated phosphorus release to reach roots more readily [15].

The finding that zinc-deficient soils limit both biological nitrogen fixation and vegetative growth ties together two commonly separate research strands legume microbiology and micronutrient agronomy. For arid-zone farmers, the practical message is that a low-cost combination of Rhizobium, PSB, and two foliar sprays can nearly double yield compared to conventional fertiliser-only management [16, 17].

Conclusion

This research aimed to determine whether combining biofertilizers with foliar micronutrients could lift cluster bean productivity on nutrient-poor arid soils. The 12-week field trial confirmed that Rhizobium + PSB inoculation supplemented with foliar ZnSO₄ and FeSO₄ at branching and flowering stages raised pod yield to 14.21 q ha⁻¹, an 81.5% increase over the uninoculated control. Nodule number, dry matter, branches per plant, and seed gum content all peaked under this integrated treatment. Farmers in arid and semi-arid regions are encouraged to adopt dual inoculation plus micronutrient sprays as a cost-effective complement to basal fertiliser. Longer-term trials spanning multiple seasons and soil types would clarify whether the synergy persists under varying rainfall patterns and help fine-tune spray concentrations for maximum economic return [18, 19, 20, 21].

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