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EFFECT OF BIOFERTILIZERS AND ARBUSCULAR MYCORRHIZAL FUNGI ON YIELD ATTRIBUTING TRAITS OF FRENCH BEAN (*Phaseolus vulgaris* L.)

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ABSTRACT

The field experiment was conducted during the winter season of 2025 at the Crop Research Centre (CRC-3), Department of Horticulture, ITM University, Gwalior, Madhya Pradesh, to assess the influence of Arbuscular Mycorrhizal Fungi (AMF) and diverse biofertilizer treatments on the yield attributing traits of French bean cv. Arka Suvidha. The trial was laid out in a Factorial Randomized Block Design encompassing two AMF levels (with and without) crossed with five biofertilizer treatments-control (no biofertilizer), Rhizobium, Phosphorus Solubilizing Bacteria (PSB), Potassium Solubilizing Bacteria (KSB) and Zinc Solubilizing Bacteria (ZSB) - each replicated three times. Yield attributing parameters including days to 50% flowering, number of green pods per plant, pod length, pod diameter, pod weight, pod yield per plant, total pod yield per plot and pod yield per hectare were systematically recorded. AMF inoculation markedly enhanced all measured yield traits relative to uninoculated plants, reducing days to flowering and substantially boosting pod number, dimensions and biomass. Among the biofertilizer treatments, Rhizobium consistently outperformed the remaining treatments across nearly all yield-related parameters. The combined treatment of AMF with Rhizobium (A_2B_2) proved superior, registering the maximum values for green pods per plant (30.80), pod length (14.70 cm), pod diameter (1.33 cm), individual pod weight (7.60 g), pod yield per plant (234.27 g), plot-level yield (5.60 kg) and pod yield per hectare (149.90 q ha^{-1}). These outcomes underscore the synergistic potential of co-inoculation with AMF and Rhizobium as a cost-effective, eco-friendly and sustainable approach to maximize French bean productivity under the prevailing agro-climatic conditions of central India.

***Keywords* :** Arbuscular Mycorrhizal Fungi, Biofertilizers, French bean and Yield attributes

Introduction

French bean (*Phaseolus vulgaris* L.) occupies a premier position among leguminous vegetable crops cultivated across tropical, subtropical, and temperate zones of the world. Belonging to family Fabaceae, it is prized for the nutritional density of its green pods, which serve as valuable sources of protein, complex carbohydrates, dietary fibre, and essential micronutrients for millions of households globally. Dry seeds of the crop contain approximately 22.9% protein, 60.6% carbohydrate, and 1.2% fat along with significant amounts of calcium, phosphorus, and iron, lending the crop immense importance in food and nutritional security (Das and Bandyopadhyay, 2011). China leads global production of green bean, followed by India, Indonesia, and Turkey. Worldwide, the crop is cultivated across approximately 1.5 million hectares with an annual output exceeding 21 million tonnes (FAOSTAT, 2024). In India, French bean is grown in diverse agro-climatic zones spanning Maharashtra, Karnataka, Tamil Nadu, Himachal Pradesh, Uttar Pradesh, and West Bengal during both kharif and rabi seasons. The crop's short duration, high yield potential, and soil nitrogen enrichment through biological nitrogen fixation (BNF) make it an ideal candidate for integration into sustainable cropping systems.

Despite its agronomic and nutritional significance, French bean productivity across many growing regions remains constrained by suboptimal soil fertility and an imbalanced reliance on inorganic fertilizers. Prolonged and intensive use of synthetic nitrogen and phosphorus fertilizers has progressively degraded soil biological properties, eroded microbial diversity, and diminished nutrient-use efficiency - ultimately suppressing yield and increasing the environmental footprint of cultivation (Mahdi *et al*., 2010; Sharma *et al*., 2013). Against this backdrop, biological nutrient management strategies centred on beneficial soil microorganisms have attracted considerable research attention as feasible and sustainable alternatives.

Biofertilizers-comprising living cultures of microorganisms such as Rhizobium, Phosphorus Solubilizing Bacteria (PSB), Potassium Solubilizing Bacteria (KSB), and Zinc Solubilizing Bacteria (ZSB) - improve nutrient availability through biological nitrogen fixation, solubilization of bound mineral nutrients, and synthesis of plant growth-promoting substances. These agents stimulate root development, augment soil microbial biomass, and enhance the overall physiological performance of crops, thereby reducing dependence on chemical inputs (Vessey, 2003; Bhattacharyya and Jha, 2012).

Arbuscular Mycorrhizal Fungi (AMF) represent the most widespread beneficial soil symbiont, forming mutualistic associations with a vast majority of terrestrial plant species. AMF networks extend the functional root surface area by developing extraradical hyphae that penetrate beyond the phosphorus depletion zone, dramatically improving the uptake of sparingly soluble nutrients, especially phosphorus. In addition to nutritional benefits, AMF confer tolerance to drought, heat, and soil-borne pathogens, while improving soil aggregation and carbon sequestration (Smith and Read, 2008; Rouphael *et al*., 2015). The co-application of AMF and rhizosphere bacteria has been demonstrated to produce synergistic improvements in legume growth and productivity, attributable to complementary nutrient-mobilizing mechanisms and enhanced hormonal signalling within the plant-microbe interface (Sagar *et al*., 2021; Singh *et al*., 2024).

Although several researchers have investigated the individual effects of AMF or biofertilizers on French bean, comprehensive information on the interactive influence of these two biological inputs, specifically on yield attributing traits under the semi-arid conditions of Madhya Pradesh, remains limited. The present study was therefore undertaken to evaluate the effect of AMF inoculation and various biofertilizer treatments, and their interactions, on yield-related traits of French bean cv. Arka Suvidha, with the aim of identifying the most effective biological nutrient management combination for improving pod productivity under field conditions.

Materials and Methods

The field experiment was conducted at Crop Research Centre-III (CRC-3), Department of Horticulture, School of Agriculture, ITM University, Turari, Gwalior, Madhya Pradesh, India (26.13°N latitude, 78.20°E longitude; altitude 211.5 m above mean sea level) during the winter season of 2025. Gwalior falls within a semi-arid to sub-humid agro-climatic zone characterized by hot summers, moderate monsoon rainfall (600–900 mm, predominantly June–September) and cool, dry winters. Prevailing meteorological conditions during the experimental period - September 2025 to January 2026-encompassed maximum temperatures declining from approximately 43°C to 44°C and minimum temperatures ranging from 9°C to 32°C, with morning relative humidity fluctuating between 70 and 89%. These conditions broadly favored the growth and development of the selected French bean genotype.

Composite soil samples were drawn from a depth of 0-20 cm prior to field preparation for physico-chemical characterization. The experimental soil was classified as sandy clay loam in texture (sand 25%, silt 37%, clay 38%) with a bulk density of 1.41 g cm^{-3}. Key chemical properties included soil pH 6.12 (slightly acidic), organic carbon 0.695%, electrical conductivity 0.45 dSm^{-1}, available nitrogen 222.4 kg ha^{-1}, available P_2O_5 14.16 kg ha^{-1} and available K_2O 158.0 kg ha^{-1}. The relatively low phosphorus status of the field provided a suitable environment for evaluating the phosphorus-mobilizing effects of AMF and PSB inoculants.

The experiment was arranged in a Factorial Randomized Block Design (FRBD) with three replications. A total of ten treatment combinations were derived from two levels of AMF and five levels of biofertilizers as described below:

- Factor A (AMF): A_1 - Without AMF inoculation; A_2 - With AMF inoculation
- Factor B (Biofertilizers): B_1-Control (no biofertilizer); B_2-Rhizobium; B_3-Phosphorus Solubilizing Bacteria (PSB); B_4-Potassium Solubilizing Bacteria (KSB); B_5-Zinc Solubilizing Bacteria (ZSB)

Individual plot dimensions were 3 m × 2 m, and seeds were sown on 18 September 2025 at a uniform spacing of 40 cm × 40 cm. AMF inoculant was applied as a soil drench at sowing and at 15 and 30 days after sowing (DAS). Biofertilizer treatments were administered concurrently as seed and soil application at the time of sowing. Recommended agronomic practices, including basal FYM application, timely irrigation, mechanical weeding and integrated pest management using NSKE (5%) and fenvalerate (0.01%) were maintained uniformly across all plots throughout the crop growth period.

The French bean variety Arka Suvidha, released by ICAR-Indian Institute of Horticultural Research, Bengaluru in 2004, was used as the test crop. The variety is characterized by a compact, bushy, photo-insensitive growth habit that permits cultivation across multiple seasons. It matures early (60-70 DAS to first picking) and offers a yield potential of 9–14 t ha^{-1} under favourable conditions, making it well-suited for evaluating responses to microbial inoculants.

Results and Discussion

The analysis of variance revealed that both individual factors - AMF inoculation (Factor A) and biofertilizer treatment (Factor B) - as well as their interaction (A × B) had a statistically significant influence on all yield attributing traits of French bean examined in the study. A summary of mean treatment values is presented in Tables 1 through 7, along with corresponding CD values. The results are discussed parameter-wise below.

Days to 50% Flowering

Days to 50% flowering is a pivotal phenological parameter that directly governs the length of the vegetative phase and, consequently, the duration available for pod development and yield accumulation. A reduction in this parameter under microbial treatments indicates that inoculated plants attain reproductive maturity faster, likely due to enhanced nutrient availability and improved hormonal regulation.

In the present study, AMF-inoculated plants required significantly fewer days to achieve 50% flowering (mean 42.76 days) compared to uninoculated plants (mean 46.17 days), a difference confirmed statistically. Among the biofertilizer treatments, KSB recorded the earliest flowering with a mean of 43.33 days, followed by ZSB (43.95 days) and Rhizobium (44.05 days), while the control (without biofertilizer) showed the latest flowering at 45.83 days. Interaction effects were likewise significant: the treatment A_2B_4 (AMF + KSB) advanced flowering most, requiring only 41.10 days, whereas plants under the control treatment (A_1B_1) took the longest at 48.87 days to flower (Table 1).

The acceleration in flowering observed under AMF can be attributed to enhanced phosphorus nutrition, which is a critical driver of carbohydrate synthesis and partitioning. Adequate phosphorus supply promotes the earlier transition from vegetative to reproductive growth through modulation of sucrose-signaling pathways. Similar acceleration in flowering following AMF inoculation has been documented by Aseri *et al*. (2018) and El-Sherbeny *et al*. (2020). The role of KSB in promoting early flowering is consistent with the involvement of potassium in enzyme activation and stomatal regulation, which together facilitate efficient assimilate translocation towards floral initiation (Meena *et al*., 2017). Comparable findings were reported by Meena *et al*. (2024) and Yadav *et al*. (2022) in French bean under integrated biofertilizer management.

Table 1 : Effect of AMF and biofertilizers on days to 50% flowering of French bean

Treatment	B_1 (Control)	B_2 (Rhizobium)	B_3 (PSB)	B_4 (KSB)	B_5 (ZSB)	Mean (A)
A_1 (Without AMF)	48.87	44.53	46.00	45.57	45.87	46.17
A_2 (With AMF)	42.80	43.57	44.30	41.10	42.03	42.76
Mean (B)	45.83	44.05	45.15	43.33	43.95	—
CD (5%): Factor A = 0.039	Factor B = 0.062		Factor A×B = 0.088			

Number of Green Pods per Plant

The number of pods borne per plant is one of the most decisive yield components in French bean, as it directly determines the quantum of harvestable produce. Results of the present investigation revealed that AMF inoculation resulted in a significantly higher mean pod count per plant (28.13) compared to non-inoculated plants (22.47), representing an enhancement of about 25% (Table 2). This improvement can be ascribed to the role of mycorrhizal hyphae in expanding the phosphorus absorption horizon of roots, which in turn supports enhanced photosynthesis, chlorophyll synthesis and reproductive differentiation.

Among biofertilizer treatments, Rhizobium (B_2) produced the maximum mean number of green pods per plant (27.77), significantly superior to all other biofertilizer treatments. PSB (B_3) ranked second with 26.45 pods per plant. The synergistic interaction of

AMF and Rhizobium (A_2B_2) proved most productive, yielding 30.80 pods per plant - the highest recorded value while the unfertilized control (A_1B_1) produced the minimum (18.47 pods per plant).

Biological nitrogen fixation by Rhizobium substantially increases the nitrogen pool within the rhizosphere, enabling the synthesis of amino acids, proteins and nucleic acids essential for floral development and pod set. Enhanced pod number under combined AMF-Rhizobium inoculation has been reported in previous studies on leguminous crops by Choudhary *et al*. (2018), Bana *et al*. (2020), Mahanta *et al*. (2021) and Kumar *et al*. (2024), all of whom observed that the synergistic interaction between these two microorganisms improves reproductive growth through complementary nitrogen-fixing and phosphorus-solubilizing activities.

Table 2 : Effect of AMF and biofertilizers on number of green pods per plant of French bean

Treatment	B_1 (Control)	B_2 (Rhizobium)	B_3 (PSB)	B_4 (KSB)	B_5 (ZSB)	Mean (A)
A_1 (Without AMF)	18.47	24.73	23.20	22.57	23.40	22.47
A_2 (With AMF)	27.67	30.80	29.70	25.57	26.93	28.13
Mean (B)	23.07	27.77	26.45	24.07	25.17	—
CD (5%): Factor A = 0.072	Factor B = 0.114	Factor A×B = 0.161				

Pod Length (cm)

Pod length is a commercially significant trait in French bean, influencing both consumer preference and grading standards in fresh markets. The present findings demonstrate that AMF inoculation consistently produced longer pods (mean 13.93 cm) relative to uninoculated plants (mean 12.25 cm), with the difference statistically verified (Table 3). Enhanced pod elongation under AMF inoculation can be explained by the role of improved phosphorus and micronutrient uptake in cell expansion, turgor maintenance and the biosynthesis of cell wall precursors.

Rhizobium inoculation (B_2) registered the greatest mean pod length among biofertilizer treatments (13.83 cm), followed by PSB (B_3) at 13.25 cm. The interaction treatment A_2B_2 (AMF + Rhizobium) attained the longest pods (14.70 cm), while pods from the uninoculated control (A_1B_1) measured only 11.07 cm. The superior pod length under AMF + Rhizobium reflects the additive benefits of greater nitrogen supply from biological nitrogen fixation and improved phosphorus uptake via mycorrhizal hyphae, collectively fueling cell division and elongation in developing pods. These observations align with those reported by Bana *et al*. (2019), Kumar *et al*. (2020), and Verma *et al*. (2024) in French bean and related legume species.

Table 3 : Effect of AMF and biofertilizers on pod length (cm) of French bean

Treatment	B_1 (Control)	B_2 (Rhizobium)	B_3 (PSB)	B_4 (KSB)	B_5 (ZSB)	Mean (A)
A_1 (Without AMF)	11.07	12.97	12.20	12.47	12.53	12.25
A_2 (With AMF)	13.83	14.70	14.30	13.60	13.20	13.93
Mean (B)	12.45	13.83	13.25	13.03	12.87	—
CD (5%): Factor A = 0.106	Factor B = 0.168	Factor A×B = 0.237				

Pod Diameter (cm)

Pod diameter (girth) reflects the extent of seed and pericarp development within each pod and is directly associated with pod weight and marketable quality. In the present investigation, the mean pod diameter of AMF-inoculated plants (1.23 cm) was significantly greater than that of non-inoculated plants (Table 4). The enhanced pod girth under AMF inoculation is attributable to improved assimilate translocation driven by higher photosynthetic efficiency resulting from adequate phosphorus nutrition.

Among biofertilizer treatments, Rhizobium (B_2) produced the thickest pods (mean 1.23 cm), followed by PSB (B_3) at 1.15 cm, while the control (B_1) recorded the narrowest pods (1.05 cm). The treatment combination A_2B_2 (AMF + Rhizobium) again emerged as the most productive, recording a pod diameter of 1.33 cm, whereas A_1B_1 yielded pods of only 0.87 cm diameter. These findings corroborate reports by Mehta *et al*. (2019), who observed expanded pod girth under mycorrhizal association in legumes and Kumar and Singh (2018) and Patel *et al*. (2020), who documented increased pod diameter with Rhizobium inoculation.

Table 4 : Effect of AMF and biofertilizers on pod diameter (cm) of French bean

Treatment	B_1 (Control)	B_2 (Rhizobium)	B_3 (PSB)	B_4 (KSB)	B_5 (ZSB)	Mean (A)
A_1 (Without AMF)	0.87	1.13	1.03	1.07	1.13	1.05
A_2 (With AMF)	1.23	1.33	1.27	1.17	1.13	1.23
Mean (B)	1.05	1.23	1.15	1.12	1.13	—
CD (5%): Factor A = 0.042 Factor B = 0.066 Factor A×B = 0.094						

Pod Weight (g)

The individual pod weight integrates the combined effects of pod length, diameter, seed development and pericarp thickness and is therefore a comprehensive indicator of sink strength and overall reproductive vigour. AMF inoculation resulted in a significantly higher mean pod weight (7.09 g) compared to uninoculated plants (5.91 g; Table 5), reflecting the positive impact of mycorrhizal nutrition on assimilate accumulation and translocation towards developing reproductive structures.

Rhizobium (B_2) was the most effective biofertilizer treatment, recording a mean pod weight of 7.03 g, followed by PSB (B_3) at 6.62 g, KSB (B_4) at 6.50 g, ZSB (B_5) at 6.32 g, and the control (B_1) at 6.05 g. The interaction treatment A_2B_2 (AMF + Rhizobium) produced the heaviest individual pods (7.60 g), significantly surpassing all other treatment combinations. The lowest pod weight (5.00 g) was noted under the unfertilized control A_1B_1. The superiority of the A_2B_2 combination for this trait is consistent with findings reported by Ghosh *et al*. (2018), Yadav and Singh (2019), Bana *et al*. (2020), Mahanta *et al*. (2021) and Kumawat *et al*. (2023).

Table 5 : Effect of AMF and biofertilizers on pod weight (g) of French bean

Treatment	B_1 (Control)	B_2 (Rhizobium)	B_3 (PSB)	B_4 (KSB)	B_5 (ZSB)	Mean (A)
A_1 (Without AMF)	5.00	6.47	5.87	6.13	6.10	5.91
A_2 (With AMF)	7.10	7.60	7.37	6.87	6.53	7.09
Mean (B)	6.05	7.03	6.62	6.50	6.32	—
CD (5%): Factor A = 0.05 Factor B = 0.078 Factor A×B = 0.111						

Pod Yield per Plant (g)

Pod yield per plant represents the most direct plant-level measure of overall productivity, integrating the combined contributions of pod number, individual pod weight and harvest efficiency. The present study recorded a marked and significant effect of both AMF and biofertilizer treatments on this parameter. AMF-inoculated plants produced a substantially higher mean pod yield per plant (200.11 g) compared to plants grown without AMF (133.78 g; Table 6), underscoring the pivotal role of mycorrhizal symbiosis in enhancing reproductive growth and yield accumulation.

The biofertilizer treatment with Rhizobium (B_2) proved unequivocally superior, registering a mean pod yield of 197.00 g per plant. PSB (B_3) ranked second (177.12 g per plant), followed by ZSB (B_5; 159.13 g) and KSB (B_4; 157.02 g), while the control treatment produced the lowest plant-level yield (144.47 g). The highest pod yield per plant (234.27 g) was achieved under the integrated treatment A_2B_2 (AMF + Rhizobium), which was significantly superior to all remaining combinations. The control treatment A_1B_1 registered the minimum value (92.53 g per plant), representing less than 40% of the maximum recorded value. These results are in agreement with Kumar and Meena (2021), Singh *et al*. (2020), Mahanta *et al*. (2021), Jat *et al*. (2023), and Kumar *et al*. (2024), all of whom reported marked improvements in plant-level pod yield under integrated microbial inoculation with AMF and Rhizobium in French bean and related crops.

Table 6 : Effect of AMF and biofertilizers on pod yield per plant (g) of French bean

Treatment	B_1 (Control)	B_2 (Rhizobium)	B_3 (PSB)	B_4 (KSB)	B_5 (ZSB)	Mean (A)
A_1 (Without AMF)	92.53	159.73	135.97	138.60	142.07	133.78
A_2 (With AMF)	196.40	234.27	218.27	175.43	176.20	200.11
Mean (B)	144.47	197.00	177.12	157.02	159.13	—
CD (5%): Factor A = 1.467 Factor B = 2.319 Factor A×B = 3.28						

Total Pod Yield per Plot (kg)

Plot-level pod yield is the aggregate of all pickings from a given plot area and provides a practical measure of field productivity. AMF inoculation significantly elevated plot-level yield from 3.21 kg (without AMF) to 4.79 kg (with AMF; Table 7), corresponding to an increase of approximately 49%. Among biofertilizer treatments, Rhizobium (B_2) registered the maximum plot yield (4.72 kg per plot), trailed by PSB (B_3) at 4.23 kg. The control yielded the least at 3.45 kg.

The combined treatment A_2B_2 (AMF + Rhizobium) recorded the maximum plot yield of 5.60 kg, while A_2B_3 (AMF + PSB) ranked second at 5.20 kg. The lowest plot-level yield (2.20 kg) was observed in the unfertilized control A_1B. The enhanced plot productivity under AMF + Rhizobium can be mechanistically linked to the complementary roles of mycorrhizal hyphae in phosphorus delivery and Rhizobium in biological nitrogen fixation, which together optimize the nutritional environment for sustained pod set across multiple pickings. Comparable results have been documented by Deka and Shadeque (2017), Bana *et al*. (2020), Mahanta *et al*. (2021), Yadav *et al*. (2022) and Jat *et al*. (2023) in French bean and other pulse crops.

Table 7 : Effect of AMF and biofertilizers on total pod yield per plot (kg) of French bean

Treatment	B_1 (Control)	B_2 (Rhizobium)	B_3 (PSB)	B_4 (KSB)	B_5 (ZSB)	Mean (A)
A_1 (Without AMF)	2.20	3.83	3.27	3.33	3.43	3.21
A_2 (With AMF)	4.70	5.60	5.20	4.20	4.23	4.79
Mean (B)	3.45	4.72	4.23	3.77	3.83	—
CD (5%): Factor A = 0.036 Factor B = 0.057 Factor A×B = 0.08						

Pod Yield per Hectare (q ha^{-1})

Pod yield per hectare is the ultimate agro-economic parameter, translating individual plant and plot-level gains into field-scale productivity estimates that guide farming decisions. In the present investigation, AMF inoculation produced a markedly higher yield (mean 128.07 q ha^{-1}) than uninoculated plants (mean 85.62 q ha^{-1}; Table 8), translating to an approximate 50% productivity gain attributable solely to mycorrhizal inoculation. This substantial yield advantage underscores the potential of AMF inoculants as low-cost, high-impact biological inputs for French bean cultivation.

Among biofertilizer treatments, Rhizobium (B_2) again ranked first with a mean pod yield of 126.07 q ha^{-1}, followed by PSB (B_3) at 113.35 q ha^{-1}. KSB (B_4) and ZSB (B_5) recorded intermediate yields of 100.52 and 101.83 q ha^{-1}, respectively. The control treatment produced the lowest hectare yield at 92.47 q ha^{-1}. The treatment combination A_2B_2 (AMF + Rhizobium) achieved the highest pod yield per hectare (149.90 q ha^{-1}), which was significantly superior to all other combinations tested. The AMF + PSB combination (A_2B_3) produced the second-highest yield (139.70 q ha^{-1}). The minimum yield was recorded in the control treatment A_1B_1 (59.23 q ha^{-1}).

The yield advantage observed under A_2B_2 can be attributed to the well-documented synergistic interactions between AMF and Rhizobium, wherein AMF colonization of root cortex cells provides the physical infrastructure for enhanced phosphorus uptake while simultaneously supporting the carbon supply to Rhizobium nodules, thereby augmenting biological nitrogen fixation efficiency. The resulting improvements in overall nutrient status, chlorophyll synthesis, photosynthetic rate and assimilate partitioning collectively drive greater pod number, heavier individual pod weight and ultimately higher hectare yield. These findings are broadly consistent with earlier reports by Kumar *et al*. (2018), Patel and Chaudhary (2020), Mahanta *et al*. (2021), Yadav *et al*. (2022), Jat *et al*. (2023) and Verma *et al*. (2024) in French bean and allied leguminous species.

Table 8 : Effect of AMF and biofertilizers on pod yield per hectare (q ha^{-1}) of French bean

Treatment	B_1 (Control)	B_2 (Rhizobium)	B_3 (PSB)	B_4 (KSB)	B_5 (ZSB)	Mean (A)
A_1 (Without AMF)	59.23	102.23	87.00	88.73	90.90	85.62
A_2 (With AMF)	125.70	149.90	139.70	112.30	112.77	128.07
Mean (B)	92.47	126.07	113.35	100.52	101.83	—
CD (5%): Factor A = 0.934		Factor B = 1.476		Factor A×B = 2.088		

Conclusion

The present investigation firmly establishes that the application of Arbuscular Mycorrhizal Fungi and biofertilizers, individually and in combination, exerts a significant and beneficial influence on yield attributing traits of French bean (*Phaseolus vulgaris* L.) cv. Arka Suvidha under the semi-arid agro-climatic conditions of Gwalior, Madhya Pradesh. AMF inoculation alone substantially improved all measured yield components, including days to flowering, number of pods per plant, pod dimensions and pod yield across all spatial scales assessed. Among the biofertilizers evaluated, Rhizobium demonstrated the most consistent and pronounced yield-promoting effects, attributable to its capacity for biological nitrogen fixation and its positive influence on reproductive growth.

The co-application of AMF with Rhizobium (A_2B_2) proved to be the most productive treatment combination in the present study, delivering the maximum values for all eight yield-related parameters - including a peak pod yield of 149.90 q ha^{-1} and surpassing all other treatments by statistically significant margins. AMF + PSB (A_2B_3) emerged as a competitive second-best alternative, warranting further field validation. The synergistic mechanism underlying the AMF + Rhizobium combination rests on the complementary supply of phosphorus via fungal hyphae and nitrogen via rhizobial nodules, which together optimize the nutritional milieu for sustained vegetative growth, timely flowering and robust pod development.

From a practical standpoint, the findings strongly recommend the combined inoculation of AMF and Rhizobium as a sustainable, environment-friendly and economically viable nutrient management strategy for French bean cultivation. Such an approach can meaningfully reduce dependence on synthetic nitrogen and phosphorus fertilizers, improve soil biological health, enhance nutrient-use efficiency and support long-term agricultural sustainability. Future research should focus on multi-location validation of these treatments across diverse soil types and agro-climatic zones, as well as economic analysis and shelf-life optimization of combined microbial inoculant formulations.

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