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Evaluation of bio-fertilizers and synthetic fertilizers on growth, yield and quality of French bean (*Phaseolus vulgaris* L.) cv. Kashi Sampann

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Abstract

A field experiment was conducted during the rabi season of 2024-25 at Babasaheb Bhimrao Ambedkar University, Lucknow, to evaluate the effect of organic and inorganic fertilizers on French bean (*Phaseolus vulgaris* L.) cv. Kashi Sampann. The experiment comprised eleven treatments arranged in a Randomized Block Design with three replications. Results revealed that treatment T₇ (50% RDF + 50% *Azotobacter*) recorded significantly superior performance across all parameters. Maximum plant height (38.81 cm at 60 DAS), number of leaves (34.96), leaf length (10.98 cm), leaf width (7.74 cm), and branches (15.36) were observed in T₇. Early flowering (34.12 days to first flowering), maximum pod length (15.14 cm), pod width (1.57 cm), pod weight (8.54 g), green pods per plant (35.62), and seeds per pod (6.73) were recorded under T₇. The highest pod yield (240.96 q/ha) and quality parameters including TSS (7.41 °Brix) and ascorbic acid (15.32 mg/100g) were also achieved with T₇. The control treatment (T₁) consistently showed the lowest values across all parameters. The study demonstrates that integrated application of 50% RDF with 50% *Azotobacter* optimizes nutrient availability, enhances growth, maximizes yield and improves quality attributes in French bean cultivation.

Keywords: French bean, *Azotobacter*, bio-fertilizers, integrated nutrient management, yield and quality

Introduction

French bean (*Phaseolus vulgaris* L., 2n = 22) is a globally important leguminous crop known by various names depending on its use i.e., French bean, snap bean, or green bean when consumed as fresh pods, and haricot bean, Rajma, or navy bean when harvested as dry seeds. Originating from Central and South America, this versatile crop has spread worldwide due to its high nutritional value and adaptability to diverse climatic conditions. These herbaceous annual produces tender green pods containing seeds and exhibits either climbing or bushy growth habits. The plant features trifoliate leaves and flowers ranging from white to pink or purple. French bean thrives in moderate climates with well-distributed rainfall and warm temperatures, requiring frost-free growing periods. Optimal growth occurs in well-drained loamy soils with pH 5.5-6.0 and temperatures between 10°C and 27°C, making it suitable for both tropical and temperate regions. China dominates global production with 81.5% of total output (24.13 million metric tons in 2023), followed by Indonesia and India. India ranks third with 2.6% of global production (774,620 metric tons). During 2021-22, India produced 2.12 million metric tons, with Gujarat leading at 29.84% (751,990 metric tons), followed by Bihar (9.70%), Jharkhand (7.97%), Karnataka (6.62%), and Uttar Pradesh (6.46%). The crop is cultivated across diverse agro-climatic zones, particularly during the rabi season in northeast plains and Maharashtra's hilly regions.

Bio-fertilizers—natural substances containing living microorganisms—enhance nutrient availability and soil fertility when applied to soil or plants. These environmentally friendly alternatives to synthetic fertilizers are crucial for sustainable agriculture. Three bio-fertilizers are particularly significant for French bean cultivation: Vesicular-Arbuscular Mycorrhiza (VAM),

Rhizobium, and *Azotobacter*. VAM, a symbiotic fungus, forms mutualistic relationships with plant roots, extending fungal hyphae into soil to enhance nutrient absorption, especially phosphorus, and water uptake. This is particularly valuable in phosphorus-deficient soils, reducing synthetic fertilizer requirements while improving soil structure, drought tolerance, and plant health. Rhizobium, a nitrogen-fixing bacterium, forms root nodules on leguminous plants, converting atmospheric nitrogen into plant-usable forms. This symbiotic process is vital in organic farming systems, improving soil nitrogen availability and resulting in healthier plants, higher yields, and enhanced long-term soil fertility. *Azotobacter*, a free-living nitrogen-fixing bacterium, operates independently while fixing atmospheric nitrogen. It produces growth-promoting substances including vitamins and enzymes that support plant development. When combined with Rhizobium and VAM, *Azotobacter* significantly improves crop productivity and sustainability. Integrating organic and inorganic fertilizers optimizes French bean cultivation by addressing complementary nutritional needs. Organic fertilizers improve soil structure, increase microbial activity, and provide slow-release nutrients, while inorganic fertilizers supply readily available essential nutrients meeting immediate crop demands. This balanced approach reduces environmental impact while promoting long-term soil fertility and productivity. Despite extensive research on French bean production, limited exploration exists regarding organic and inorganic fertilizer effects on growth, yield, and quality. This knowledge gap necessitates identifying economically viable, environmentally safe, and sustainable nutrient management practices. Understanding the synergistic effects of bio-fertilizers combined with organic and inorganic inputs will provide valuable insights for developing comprehensive fertilization strategies that maximize crop performance while maintaining ecological balance and agricultural sustainability.

Materials and Methods

Experimental site: The field experiment was conducted on French bean during the rabi season of 2024-25 at the Horticulture Research Farm of Department of Horticulture, Babasaheb Bhimrao Ambedkar University (A Central University), Lucknow, Uttar Pradesh. The experimental farm is located within the university campus at Vidya Vihar, Raebareli Road, Lucknow. The site is situated at 26.85°N latitude and 80.95°E longitude, at an altitude of approximately 123 meters above mean sea level. Lucknow falls under the Indo-Gangetic Plain region and belongs to the sub-tropical zone of the Central Plain Zone of Uttar Pradesh, characterized by hot summers, cool winters, and moderate monsoon rainfall.

Experimental design and analysis

The experiment consisted of two factors, organic and inorganic fertilizers, there were 11 treatments [T₁ (Control), T₂ (100% Recommended Dose of Fertilizers (RDF)), T₃ (100% *Vesicular Arbuscular Mycorrhiza* (VAM)), T₄ (100% *Azotobacter*), T₅ (100% *Rhizobium*), T₆ (50% RDF + 50% VAM), T₇ (50% RDF + 50% *Azotobacter*), T₈ (50% RDF + 50% *Rhizobium*), T₉ (50% VAM + 50% *Azotobacter*), T₁₀ (50% *Azotobacter* + 50% *Rhizobium*), T₁₁ (50% VAM + 50% *Rhizobium*)] each being replicated thrice and laid out in Randomized Block Design with three replications. The variety 'Kashi Sampann' was selected for the study.

Data collection: The experiment, observations on growth and yield parameters were systematically recorded. For each

treatment combination, five representative plants were randomly selected and tagged to monitor various growth and yield characteristics. Observations on growth parameters viz., Plant Height (cm), Number of leaf per plant, Leaf length (cm), Leaf width (cm), and Number of branches per plant; yield attributes viz., Days taken to 1st flowering, Days taken to 50% flowering, Pod weight (g), Pod width (cm), Pod length (cm), Number of green pod per plant, Seed weight (g), Number of seed per pod, Test weight (g), Green pod yield/plant (g), Pod yield (kg/plot), and Pod Yield (q/ha); and quality characters viz., Total Soluble Solids (°Brix), and Vitamin C (Ascorbic acid) (mg/100 g) were recorded.

Statistical analysis: Recorded data was statistical analysed applying the analysis of variance technique (Gomez and Gomez, 1984) [4]. The critical difference (5% level of probability) was computed for comparing treatment means in cases where effect came out to be significant by F-test.

Results and Discussion

Growth Parameters: (Depicted in Tables 1 and Fig. 1)

Plant height: The maximum plant height of 26.88, 33.84, and 38.81 cm at 30, 45, and 60 days after sowing (DAS), respectively, was recorded under treatment T₇ (50% RDF + 50% *Azotobacter*), while the minimum plant height of 12.77, 19.67, and 24.12 cm was recorded in the control treatment (T₁). The significant increase in plant height under T₇ suggests a synergistic effect between chemical fertilizers and *Azotobacter*. *Azotobacter* is known for its nitrogen-fixing capabilities and production of phytohormones like indole-3-acetic acid (IAA), which promote root development and overall plant growth. The combination of *Azotobacter* with a reduced chemical fertilizer dose not only enhances growth but also offers a sustainable approach to nutrient management in French bean. These findings are in close conformity with those reported by Prabhakar *et al.*, (2011) [18], Singh *et al.*, (2011) [28], Kumar *et al.*, (2019), Jena *et al.*, (2020) [7], Parry *et al.*, (2021) [15], Sachan and Krishna (2021) [22], Kumar and Puri (2002) [11], Gopal *et al.* (2015) [5], and Ramana *et al.* (2010) [20] in French bean.

Number of leaves: The maximum number of leaves (22.95, 29.95, and 34.96) at 30, 45, and 60 DAS was recorded under treatment T₇ (50% RDF + 50% *Azotobacter*), while the minimum number of leaves (10.49, 16.59, and 20.49) was recorded in T₁ (control) at the respective growth stages. This superior performance in French bean is attributed to the synergistic effect of chemical fertilizers and bio-fertilizers, which enhances nutrient availability and uptake, particularly nitrogen—an essential element for vegetative growth. *Azotobacter*, a nitrogen-fixing bacterium, not only supplements nitrogen but also produces plant growth-promoting hormones like auxins and gibberellins, which stimulate cell division and leaf development. In contrast, the control treatment (T₁), lacking external nutrient supplementation, resulted in poor vegetative growth due to limited soil nutrient availability, leading to a significantly lower number of leaves at all growth stages. Similar findings were reported by Kalange (2006) [8], Band *et al.* (2007) [1], and Kumar *et al.* (2009) in French bean.

Leaf length: The maximum leaf length of 10.98 cm was recorded under treatment T₇ (50% RDF + 50% *Azotobacter*), while the minimum leaf length of 6.84 cm was observed in T₁ (control). The partial application of the Recommended Dose of

Fertilizers (RDF) provides vital nutrients, while *Azotobacter* enhances nitrogen fixation and generates phytohormones that promote cell elongation and leaf growth. This combined approach encourages longer leaves and improved vegetative development. The control treatment (T₁) exhibited the smallest leaf length (6.84 cm) due to the absence of external nutrient inputs, resulting in limited growth caused by nutrient unavailability. These findings align with those reported by Prabhakar *et al.* (2011)^[17] in French bean.

Leaf width: The maximum leaf width of 7.74 cm was recorded under treatment T₇ (50% RDF + 50% *Azotobacter*), while the minimum leaf width of 4.52 cm was observed in T₁ (control). This response in French bean results from balanced nutrition supply and enhanced microbial activity, both promoting vegetative growth. The 50% RDF supplies essential nutrients, while *Azotobacter* enhances nitrogen fixation and produces growth-promoting hormones such as cytokinins and auxins that stimulate cell division and expansion, resulting in wider leaves. The control treatment (T₁) showed minimum leaf width (4.52

cm) due to the absence of external nutrient input, leading to poor growth and limited leaf development. Similar observations were reported by Jagdale *et al.* (2005)^[6] and Dubey and Dutt (2008)^[3] in French bean.

Number of branches: The maximum number of branches per plant (8.86, 12.14, and 15.36) at 30, 45, and 60 DAS was recorded under treatment T₇ (50% RDF + 50% *Azotobacter*), while the minimum (5.14, 7.56, and 9.81) was observed in T₁ (control) at the respective growth stages. The combined application of chemical and bio-fertilizers enhances nutritional availability and hormonal stimulation in French bean. *Azotobacter* fixes atmospheric nitrogen and produces phytohormones like auxins and gibberellins that encourage cell division and shoot growth. Combined with 50% RDF, this approach ensures a steady and balanced nutrient supply, improving vegetative growth and increasing branching at all growth stages. These findings corroborate those of Gopal *et al.* (2005)^[5] and Choudhary *et al.* (2001) in French bean.

Table 1: Effect of bio-fertilizers and synthetic fertilizers on growth parameters of French bean

Treatments	Plant Height (cm)			Leaf length (cm)	Leaf width (cm)	Number of leaf per plant			Number of branches per plant		
	30 DAS	45 DAS	60 DAS			30 DAS	45 DAS	60 DAS	30 DAS	45 DAS	60 DAS
T ₁	12.77	19.67	24.12	6.84	4.52	10.49	16.59	20.49	5.14	7.56	9.81
T ₂	17.83	24.81	29.77	8.78	5.88	14.98	21.12	25.18	5.42	9.76	12.21
T ₃	13.98	19.89	24.98	7.41	4.97	11.58	17.65	21.68	7.75	8.95	10.64
T ₄	16.26	23.27	27.68	8.32	5.57	13.87	19.92	23.95	5.88	9.54	11.82
T ₅	15.14	22.24	26.85	7.95	5.26	12.67	18.75	22.79	5.65	9.28	11.33
T ₆	23.08	30.13	35.64	9.91	6.95	19.45	26.39	31.49	7.25	10.78	13.41
T ₇	26.88	33.84	38.81	10.98	7.74	22.95	29.95	34.96	8.86	12.13	15.36
T ₈	24.85	31.36	36.25	10.32	7.23	20.67	27.63	32.68	7.78	11.11	13.97
T ₉	20.11	26.88	30.79	9.78	6.36	17.18	23.68	28.17	6.64	10.29	12.81
T ₁₀	21.48	27.27	31.14	9.48	6.65	18.36	24.86	29.66	6.98	10.52	13.03
T ₁₁	18.91	25.78	29.83	9.11	6.08	16.14	22.23	26.32	6.32	9.98	12.48
CD _(5%)	0.61	0.76	1.16	0.27	0.20	0.36	0.82	0.65	0.23	0.33	0.40
SE _(m)	0.20	0.25	0.39	0.09	0.07	0.12	0.27	0.22	0.08	0.11	0.13

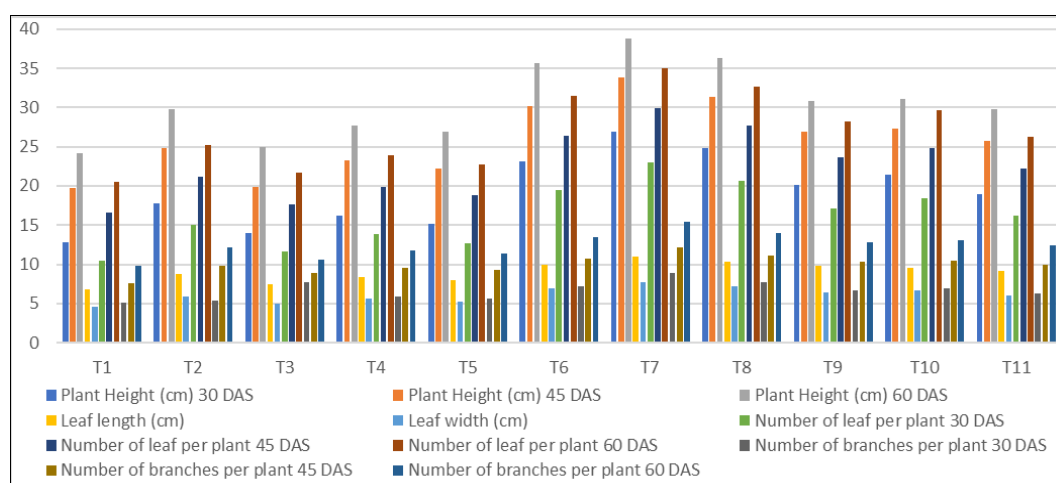


Fig 1: Effect of bio-fertilizers and synthetic fertilizers on growth parameters of French bean.

Yield Parameters: (Depicted in Table 2 and Fig. 2)

Days to first flowering: The minimum days to first flowering (34.12 days) was recorded under treatment T₇ (50% RDF + 50% *Azotobacter*), while the maximum days to flowering (41.86 days) was observed in T₁ (control). The early flowering in T₇ is attributed to the synergistic effect of integrated nutrient management, where the combined use of bio-fertilizers

(*Azotobacter*) and chemical fertilizers (RDF) enhanced nutrient availability, particularly nitrogen, facilitating a shortened vegetative phase and timely transition to the reproductive phase. Conversely, the delayed flowering in the control treatment (T₁) at 41.86 days is attributable to nutrient deficiency, which inhibits plant growth and postpones the onset of flowering. These findings are in close conformity with those reported by Singh *et al.* (2011)^[29], and Sathe (2007)^[23] in French bean.

Days to 50% flowering: The minimum days to 50% flowering (42.56 days) was recorded under treatment T₇ (50% RDF + 50% *Azotobacter*), while the maximum (54.84 days) was observed in T₁ (control). This superior performance in French bean is attributable to the enhanced nutritional quality and hormonal stimulation provided by the integrated use of chemical and bio-fertilizers. The RDF ensures availability of essential nutrients, particularly nitrogen and phosphorus, which are vital for initiating reproductive growth. *Azotobacter* further increases nitrogen availability through biological fixation and produces phytohormones such as cytokinins and gibberellins, which accelerate plant development and promote early flowering. In contrast, the control treatment (T₁) experienced delayed flowering at 54.84 days due to nutrient deficiencies that slowed plant growth and delayed the onset of the reproductive phase. Similar findings were reported by Sharma and Verma (2011)^[25] in French bean.

Pod length: The maximum pod length of 15.14 cm was recorded under treatment T₇ (50% RDF + 50% *Azotobacter*), while the minimum pod length of 8.24 cm was observed in T₁ (control). This enhanced pod development in French bean results from the combined application of chemical and bio-fertilizers, which improves nutritional availability and hormonal stimulation. The RDF application provides essential nutrients, especially nitrogen and phosphorus, which are critical for pod development. *Azotobacter* enhances nitrogen fixation and releases growth-promoting hormones like auxins and gibberellins that support improved flower retention, ovary development, and ultimately longer pods. The control treatment (T₁) exhibited the smallest pod length (8.24 cm) due to inadequate nutrient availability, resulting in underdeveloped reproductive components and smaller pods. These findings align with those reported by Moniruzzaman *et al.* (2008)^[14], and Sen *et al.* (2010)^[24] in French bean.

Pod width: The maximum pod width of 1.57 cm was recorded under treatment T₇ (50% RDF + 50% *Azotobacter*), while the minimum pod width of 0.48 cm was observed in T₁ (control). French bean benefits from the synergistic effect of integrated nutrient management, where the combination of chemical fertilizers and bio-fertilizers improves nutrient availability, uptake, and assimilation, resulting in enhanced vegetative growth and pod development. *Azotobacter*, a nitrogen-fixing bacterium, increases nitrogen supply in the rhizosphere while encouraging cell division and elongation, which improves pod formation and increases pod width. The minimum pod width in the control treatment (T₁) is attributed to nutrient shortage, which limits plant growth and pod development. Similar findings were reported by Singh and Singh (2000)^[27], and Kumari (2017)^[12] in French bean.

Pod weight: The maximum pod weight of 8.54 g was recorded under treatment T₇ (50% RDF + 50% *Azotobacter*), while the minimum pod weight of 4.51 g was observed in T₁ (control). The superior performance in French bean is attributed to increased nutrient availability and uptake brought about by the combined application of inorganic fertilizers and bio-fertilizers. *Azotobacter* not only fixes atmospheric nitrogen but also produces growth-promoting substances that enhance plant vigour, photosynthetic efficiency, and ultimately pod filling, resulting in increased pod weight. The lowest pod weight (4.51 g) in the control treatment (T₁) is due to low nutrient availability, leading to suboptimal plant growth and pod

development. These findings are in close conformity with those reported by Moniruzzaman *et al.* (2008)^[14] in French bean.

Number of green pods per plant: The maximum number of green pods per plant (35.62) was recorded under treatment T₇ (50% RDF + 50% *Azotobacter*), while the minimum (19.34) was observed in T₁ (control). This enhancement is attributed to the beneficial impact of bio-fertilizers like *Azotobacter*, a free-living nitrogen-fixing bacterium that improves nutrient uptake, encourages root growth, and increases nitrogen availability in the rhizosphere, all of which stimulate plant growth and pod production. The combination of 50% RDF with *Azotobacter* ensures a balanced nutrient supply and sustained soil health, promoting higher pod numbers. Similar findings were reported by Shwetha *et al.* (2012)^[26] in French bean.

Number of seeds per pod: The maximum number of seeds per pod (6.73) was recorded under treatment T₇ (50% RDF + 50% *Azotobacter*), while the minimum (3.95) was observed in T₁ (control). This superior performance is attributed to improved physiological processes and enhanced nutrient availability brought about by the combined use of chemical and bio-fertilizers. *Azotobacter* aids in atmospheric nitrogen fixation and produces growth-promoting substances like auxins and cytokinins that improve flowering, fertilization efficiency, and seed development. When combined with 50% RDF, it ensures an optimal and sustained nutrient supply, enhancing reproductive performance and increasing the number of seeds per pod. These findings corroborate those reported by Patel *et al.* (2010)^[16] in French bean.

Green pod yield per plant: The maximum green pod yield per plant of 325.30 g was recorded under treatment T₇ (50% RDF + 50% *Azotobacter*), while the minimum of 135.67 g was observed in T₁ (control). This demonstrates the benefits of integrated nutrient management for plant productivity and growth. *Azotobacter* not only fixes atmospheric nitrogen but also promotes phytohormone synthesis, strengthens root systems, and facilitates nutrient absorption. When paired with 50% RDF, this balanced approach ensures consistent nutrient availability throughout the crop growth cycle, promoting better vegetative growth, increased pod numbers, and ultimately higher pod yield per plant. These findings align with those reported by Singh *et al.* (2019)^[30] in French bean.

Seed weight: The maximum seed weight of 38.17 g was recorded under treatment T₇ (50% RDF + 50% *Azotobacter*), while the minimum of 26.42 g was observed in T₁ (control). This enhancement is attributed to increased physiological efficiency and improved nutrient absorption made possible by integrated nutrient management. *Azotobacter* enhances photosynthesis, seed filling, and overall plant vigour by increasing nitrogen fixation and releasing growth-promoting substances. When paired with 50% RDF, it ensures a steady and efficient nutrient supply, improving seed development and increasing seed weight. Similar findings were reported by Meena *et al.* (2015)^[13] in French bean.

Pod yield per plot: The maximum pod yield per plot of 5.207 kg was recorded under treatment T₇ (50% RDF + 50% *Azotobacter*), while the minimum of 2.17 kg was observed in T₁ (control). This improvement reflects the combined impact of chemical and bio-fertilizers on plant development and yield. *Azotobacter* not only fixes atmospheric nitrogen but also

secretes growth-promoting substances that enhance nutrient uptake, root development, and overall plant vigour. When paired with 50% RDF, it ensures balanced and continuous nutrient availability throughout the growing season, improving flowering, pod development, and ultimately yield per plot. These findings are in close conformity with those reported by Choudhari *et al.* (2001) ^[2] and Sharma and Verma (2011) ^[25] in French bean.

Test weight: The maximum test weight of 389.56 g was recorded under treatment T₇ (50% RDF + 50% *Azotobacter*), while the minimum of 273.35 g was observed in T₁ (control). This superior performance is attributed to enhanced metabolic activity and increased nutrient absorption brought about by comprehensive nutrient management. *Azotobacter* aids in nitrogen fixation and produces growth-promoting substances that enhance photosynthetic efficiency, seed development, and nutrient translocation, resulting in heavier and more robust seeds. The combination with 50% RDF ensures a balanced

nutrient supply, positively impacting test weight and other seed quality characteristics. Similar findings were reported by Kumar *et al.* (2019) in French bean.

Pod yield per hectare: The maximum pod yield of 240.96 q/ha was recorded under treatment T₇ (50% RDF + 50% *Azotobacter*), while the minimum of 100.49 q/ha was observed in T₁ (control). Studies indicate that incorporating *Azotobacter* with reduced RDF levels can maintain or even increase crop yields. Research on pearl millet demonstrated that *Azotobacter* seed inoculation dramatically increased plant height, dry matter accumulation, and grain production compared to the control, demonstrating its efficacy in improving crop performance with lower chemical fertilizer inputs. Similarly, using *Azotobacter* in conjunction with RDF in maize significantly enhanced growth metrics and yield characteristics, demonstrating *Azotobacter*'s potential as a bio-fertilizer in integrated nutrient management strategies. Similar findings were reported by Moniruzzaman *et al.* (2008) ^[14] in French bean.

Table 2: Effect of bio-fertilizers and synthetic fertilizers on yield parameters of French bean

Treatments	Days taken to 1 st flowering	Days taken to 50% flowering	Pod length (cm)	Pod width (cm)	Pod weight (g)	Number of green pods per plant	Number of seed per pod	Seed weight (g)	Green pod yield/ plant (g)	Pod yield (kg/plot)	Pod Yield (q/ha)	Test weight (g)
T ₁	41.85	54.84	8.95	0.51	4.51	19.39	3.95	26.42	135.67	2.17	273.35	100.49
T ₂	38.89	50.28	10.18	0.95	6.78	24.95	4.78	31.85	214.50	3.43	326.12	158.89
T ₃	40.43	53.87	9.32	0.64	5.61	21.94	4.17	27.75	150.50	2.41	289.22	111.48
T ₄	39.23	51.16	9.92	0.82	6.44	23.48	4.61	29.95	198.80	3.18	315.36	147.26
T ₅	39.97	52.98	9.54	0.71	5.95	22.18	4.51	29.11	152.60	2.44	303.58	113.04
T ₆	36.21	46.18	12.58	1.26	7.94	32.25	6.10	35.15	278.70	4.46	367.45	206.44
T ₇	34.12	42.56	15.14	1.57	8.54	35.62	6.73	38.17	325.30	5.21	389.56	240.96
T ₈	35.54	44.58	13.64	1.37	8.19	33.55	6.38	36.18	318.90	5.10	378.58	236.22
T ₉	37.42	48.42	10.98	1.08	7.51	28.58	4.98	33.47	254.20	4.07	342.61	188.29
T ₁₀	36.98	47.58	11.49	1.18	7.78	30.82	6.04	34.25	255.20	4.08	355.36	189.04
T ₁₁	38.10	49.36	10.38	1.01	7.33	26.25	4.93	32.38	233.90	3.74	339.28	173.26
CD (5%)	1.43	1.61	0.35	0.04	0.29	1.17	0.56	1.16	5.878	0.094	12.00	4.36
SE _(m)	0.48	0.54	0.11	0.02	0.09	0.39	0.19	0.39	1.979	0.032	4.04	1.47

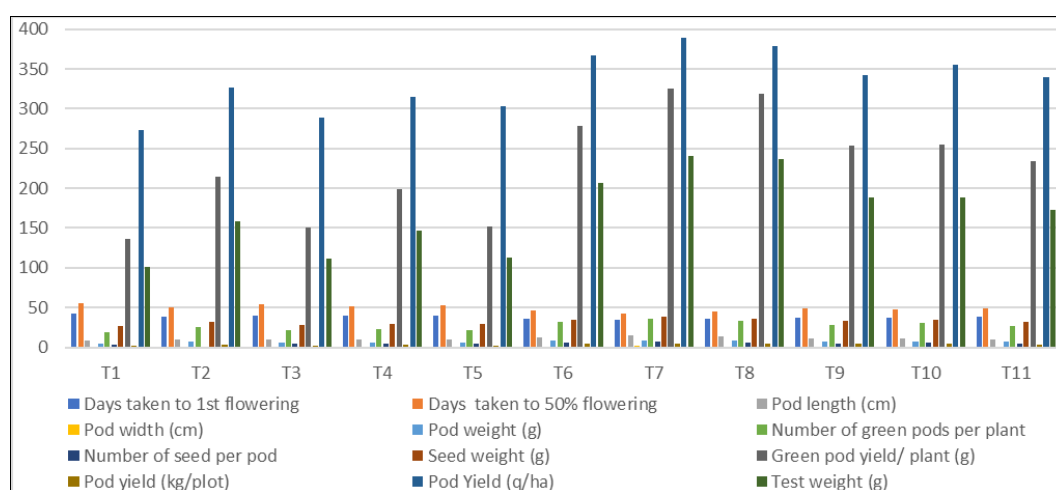


Fig 2: Effect of bio-fertilizers and synthetic fertilizers on yield parameters of French bean.

Quality Parameters: (Depicted in Table 3 and Fig. 3)

Total Soluble Solids (TSS): The maximum TSS of 7.41 °Brix was recorded under treatment T₇ (50% RDF + 50% *Azotobacter*), while the minimum TSS of 4.93 °Brix was observed in T₁ (control). The superior TSS content in T₇ is attributed to enhanced nutrient uptake and increased metabolic activity resulting from the combined application of *Azotobacter*

and chemical fertilizers. *Azotobacter* improves nitrogen fixation and enhances photosynthetic efficiency, leading to greater production and accumulation of sugars and other soluble solids in the fruit. Conversely, the minimum TSS (4.93 °Brix) in the control treatment (T₁) is due to low nutrient availability, resulting in poor carbohydrate metabolism and reduced sugar accumulation. These findings corroborate those reported by Kumar *et al.* (2019) in French bean.

Ascorbic acid content: The maximum ascorbic acid content of 15.32 mg/100g was recorded under treatment T₇ (50% RDF + 50% *Azotobacter*), while the minimum of 10.64 mg/100g was observed in T₁ (control). The enhanced ascorbic acid content in T₇ results from improved physiological functions and better nutrient efficiency through the combined application of chemical fertilizers and *Azotobacter*. This bio-fertilizer stimulates nitrogen fixation, root growth, and microbial activity, improving nutrient uptake and metabolic processes that increase ascorbic acid (vitamin C) synthesis. The minimum ascorbic acid level (10.64 mg/100g) in the control treatment (T₁) is attributed to nutrient deficiency, which restricts the plant's ability to produce vital biochemical compounds. These findings align with those reported by Sharma and Verma (2011) [25] in French bean.

Table 3: Effect of bio-fertilizers and synthetic fertilizers on quality parameters of French bean

Treatments	Total Soluble Solids (°Brix)	Ascorbic acid (mg/100 g)
T ₁	4.93	10.64
T ₂	5.96	11.84
T ₃	5.15	10.98
T ₄	5.69	11.52
T ₅	5.36	11.18
T ₆	6.97	13.62
T ₇	7.41	15.32
T ₈	7.19	14.71
T ₉	6.48	12.49
T ₁₀	6.76	12.91
T ₁₁	6.23	12.08
CD(5%)	0.25	0.49
SE(m)	0.09	0.17

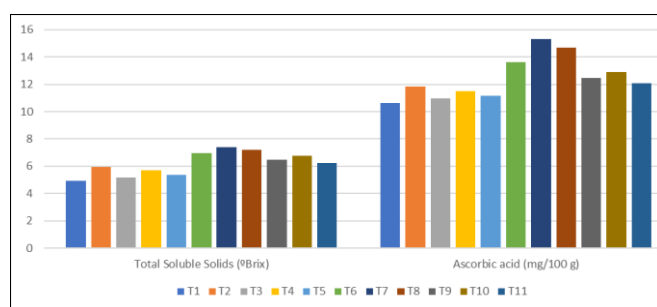


Fig 3: Effect of bio-fertilizers and synthetic fertilizers on quality parameters of French bean.

Conclusion

The present investigation conclusively demonstrates that integrated nutrient management through the combination of 50% Recommended Dose of Fertilizers with 50% *Azotobacter* (T₇) emerged as the most effective treatment for French bean cultivation. This treatment significantly enhanced all growth parameters including plant height (38.81 cm at 60 DAS), number of leaves (34.96), leaf length (10.98 cm), leaf width (7.74 cm), and branches (15.36) compared to the control and other treatments. Treatment T₇ recorded superior yield attributes with early flowering (34.12 days), maximum pod length (15.14 cm), pod width (1.57 cm), pod weight (8.54 g), green pods per plant (35.62), and seeds per pod (6.73), culminating in the highest pod yield of 240.96 q/ha—representing a 139.8% increase over the control (100.49 q/ha). Quality parameters including total soluble solids (7.41 °Brix) and ascorbic acid content (15.32 mg/100g) were also maximized under this treatment. The synergistic effect of chemical fertilizers and *Azotobacter* improved nutrient availability, particularly nitrogen

through biological fixation, and production of growth-promoting phytohormones such as auxins, gibberellins, and cytokinins. This integration presents a sustainable and economically viable approach, reducing chemical fertilizer dependence by 50% while maintaining superior productivity. *Azotobacter*'s nitrogen-fixing capability, coupled with growth-promoting substance production, complements the balanced nutrient supply from reduced RDF, ensuring optimal plant growth, enhanced photosynthetic efficiency, and superior yield outcomes. Therefore, farmers are recommended to adopt the integrated application of 50% RDF + 50% *Azotobacter* for achieving maximum productivity, superior quality, and sustainable French bean cultivation while reducing production costs and promoting environmental conservation.

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