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Effect of varieties, Different Nutrient levels and Spacings on Performance of French Bean (*Phaseolus vulgaris* L.) during *Rabi* season

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A B S T R A C T

French bean (*Phaseolus vulgaris* L.) is an economically important leguminous vegetable crop with high nutritional value and short cultivation period. A comprehensive field investigation was conducted during rabi seasons 2023–24 and 2024–25 at the experimental farm of Vasantrao Naik Marathwada Krishi Vidyapeeth (VNMKV), Parbhani, to evaluate the effect of varieties, spacing, and nutrient levels on growth, phenology, and yield of French bean. The experiment was laid out in a split-plot design with three replications, comprising three varieties (Arka Suvidha, Arka Komal, and Phule Varun), three spacing levels (45 × 10, 45 × 20, and 45 × 30 cm), and three nutrient levels (100:50:50, 120:60:60, and 140:70:70 kg N:P:K ha^{-1}). Pooled results revealed that Arka Suvidha recorded maximum plant height (68.4 cm) and number of functional leaves per plant (34.1). Spacing of 45 × 30 cm produced the highest number of green pods per plant (28.3), pod length (14.4 cm), and green pod yield (10.28 t ha^{-1}). Application of 140:70:70 kg N:P:K ha^{-1} resulted in significantly superior growth and yield parameters, recording highest green pod yield (119.1 kg ha^{-1}). The interactive effect indicated that Arka Suvidha × 45 × 30 cm spacing × 140:70:70 kg N:P:K ha^{-1} delivered the most favorable performance. Cultivation of Arka Suvidha at 45 × 30 cm spacing with 140:70:70 kg N:P:K ha^{-1} is recommended for higher productivity and economic returns under Parbhani agro-climatic conditions.

Introduction

French bean (*Phaseolus vulgaris* L.), commonly known as kidney bean, snap bean, or haricot bean, is one of the most widely cultivated leguminous vegetable crops worldwide (Broughton *et al*. 2003). As a dual-purpose crop consumed for immature green pods as a vegetable and mature dry seeds as pulses, French bean serves critical roles in global food security and nutrition. The crop is ranked among the most important grain legumes globally after soybean, groundnut, and chickpea (Steele *et al*. 2009), with significant economic importance in both developed and developing nations.

Importance and Distribution

Globally, French bean is cultivated on approximately 30 million hectares with annual production of 25–28 million metric tonnes (*Food and Agriculture Organization Statistical Database. Food and Agriculture Organization of the United Nations* 2020). Major producing regions include Latin America, East Africa, and Asia, with Brazil, Mexico, China, India, and Kenya leading in production volumes. In India, French bean is cultivated over approximately 0.6–0.7 million hectares with production of 0.8–0.9 million tonnes and average productivity of 1300–1500 kg ha^{-1} ("Agricultural Statistics at a Glance 2021. Directorate of Economics and Statistics" 2021). States like Karnataka, Maharashtra, Himachal Pradesh, Uttarakhand, and Jammu & Kashmir are major producers, with particularly strong cultivation during the rabi season when climatic conditions favor pod development and market demand is elevated (Sood, Bhattacharya, and Siddiqui 2003).

Nutritional and Economic Significance

Green pods contain 1.7–2.5% protein, 4–5% carbohydrates, dietary fiber, calcium, iron, and vitamins A, B-complex, and C, making them nutritionally dense (Begum *et al*. 2003). Dry seeds are richer in protein (20–25%), carbohydrates (55–60%), and minerals, making French bean a significant plant-based protein source for populations relying on vegetarian diets. The crop contributes to soil fertility improvement through residual nitrogen effects despite relatively lower symbiotic nitrogen fixation compared to other legumes (Ribeiro *et al*. 2013).

French bean is also an important export-oriented crop, generating substantial foreign exchange for producing countries. Kenya, for example, supplies nearly 60% of French beans imported by the European Union, reflecting the crop's potential in export markets (Wanjekeche, Onyambu, and Oduor 2000). In India, rabi season cultivation is particularly profitable due to higher market demand and favorable climatic conditions, making it an attractive cash crop for smallholder and commercial farmers alike.

Agronomic Challenges and Production Constraints

Despite its importance, French bean productivity remains lower than international standards due to several factors. Challenges include suboptimal nutrient management, improper plant spacing, disease and pest pressures, and lack of awareness regarding varietal performance (Dash, Mohapatra, and Behera 2019). Additionally, the crop exhibits poor natural nitrogen fixation ability, making it highly dependent on external nitrogen supplementation. High temperatures during flowering and pod setting reduce yield due to flower drop and poor pod development (S. K. Singh and Schwartz 2010), necessitating cultivation during cooler seasons like rabi in semi-arid regions.

Role of Variety Selection, Plant Spacing, and Nutrient Management

Nutrient management is critical for French bean production, as the crop is fertilizer-responsive with poor biological nitrogen fixation. Nitrogen is essential for vegetative growth and chlorophyll synthesis; phosphorus for root development and pod setting; potassium for stomatal functioning and pod quality (Khondoker *et al*. 2020). Recent studies have demonstrated significant yield improvements through integrated nutrient management combining organic and inorganic sources (Akter, Islam, and Hassan 2021).

Plant spacing directly influences light interception, water and nutrient availability, and canopy architecture. Optimization of plant geometry ensures balanced individual plant growth and adequate population density for maximum yield per unit area (Shirale *et al*. 2024). Similarly, varietal selection is paramount, as different French bean cultivars exhibit varying responses to environmental conditions, nutrient availability, and plant population density (Amanullah *et al*. 2020).

Materials and methods

Experimental site and climate

The investigation was conducted during rabi seasons 2023–24 and 2024–25 at the experimental farm of the Department of Horticulture, Vegetable Science, Vasantrao Naik Marathwada Krishi Vidyapeeth, Parbhani (19.23°N latitude, 75.75°E longitude, elevation

570 m above mean sea level). The experimental site is situated in the Parbhani district of Maharashtra in the semi-arid region of the Marathwada zone of Western India.

The soil at the experimental site was classified as clay loam with the following initial chemical properties: pH 7.2, electrical conductivity (EC) 0.38 dS m^{-1}, available nitrogen 230 kg ha^{-1}, available phosphorus 18.5 kg ha^{-1}, and available potassium 420 kg ha^{-1}. The region experiences a subtropical climate with average annual rainfall of 700–800 mm. During the rabi season (June-september), temperatures range from 10–30°C, providing ideal conditions for French bean cultivation with cool nights supporting pod development and quality.

Experimental design and treatments

A split-plot randomized block design with three replications was employed, comprising 27 treatment combinations: three varieties in main plots, three spacing levels in sub-plots, and three nutrient levels in sub-sub-plots.

Main plot factor (Varieties):

- V_1 = Arka Suvidha
- V_2 = Arka Komal
- V_3 = Phule Varun

Sub-plot factor (Spacing, cm):

- S_1 = 45 × 10
- S_2 = 45 × 20
- S_3 = 45 × 30

Sub-sub-plot factor (N:P:K, kg ha^{-1}):

- F_1 = 140:70:70
- F_2 = 120:60:60
- F_3 = 100:50:50

Each treatment combination was replicated three times, resulting in 81 observations per quantitative parameter recorded.

Agronomic practices and management

Field preparation was conducted following standard protocols. Seeds of selected varieties were sown on 15 June 2023 and 18 June 2024 respectively at predetermined spacing. A basal application of farmyard manure (10 t ha^{-1}) was incorporated into the soil during field preparation. Nutrient doses were applied in split applications: 50% as basal dose at the time of sowing and 50% as top dressing at 30 days after sowing (DAS). Three irrigations were provided at critical growth stages: at sowing, at flowering (45 DAS), and at pod filling (60 DAS). Manual weeding was conducted at 30 and 45 DAS to control weeds without damaging the crop. Bio-safety measures were implemented initially using biopesticides (neem oil 3% and Beauveria bassiana), with chemical intervention only when pest pressure exceeded economic threshold levels.

Data collection and analysis

Observations were recorded at regular intervals using five randomly selected plants per treatment:

Growth parameters: Plant height (cm), number of functional leaves, number of branches, leaf area (cm^2 $plant^{-1}$), and dry matter accumulation (g $plant^{-1}$) were recorded at 30, 45, and 60 days after sowing and at harvest.

Phenological observations: Days to 50% flowering and days to maturity were recorded on whole-plot basis.

Floral and reproductive attributes: Number of flowers per plant at 30, 45, and 60 DAS, number of green pods per plant, pod length (cm), pod diameter (cm), pod weight (g $plant^{-1}$), number of seeds per pod, and 100-seed weight (g) were recorded at harvest.

Yield estimation: Green pods harvested at tender stage were collected plot-wise at periodic intervals until crop maturity, weighed, and total yield per hectare computed.

Quality parameters of green pods were determined following standard AOAC protocols: protein content by micro-Kjeldahl method, crude fiber by acid-detergent method, and total mineral content by dry ashing at 550±10°C (Feldsine *et al*. 2002).

Soil fertility assessment: Soil pH, electrical conductivity, available nitrogen, available phosphorus, and available potassium were measured before sowing and after harvest following standard analytical methods.

Economic analysis: Cost of cultivation (calculated from input costs), gross income (yield × market price), net income (gross income – cost of cultivation), and benefit-cost ratio (gross income ÷ cost of cultivation) were computed for each treatment combination.

Statistical analysis

Data were subjected to analysis of variance (ANOVA) following the split-plot design model. Mean comparisons were made using Duncan's multiple range test (DMRT) at 5% significance level. All computations were performed using standard statistical software.

Results and Discussion

Growth attributes

Plant height

Variety Arka Suvidha (V_1) recorded significantly maximum plant height at harvest (65.32 cm in pooled data), followed by Arka Komal (62.98 cm) and Phule Varun (60.61 cm). Progressive increase in plant height was recorded from 30 DAS to harvest stage across all varieties, indicating sustained vegetative growth throughout the crop duration (Kumar, Singh, and Verma 2022).

Regarding spacing, wider spacing of 45 × 30 cm (S_3) promoted individual plant height (63.45 cm) compared to closer spacing, due to reduced inter-plant competition for light and photosynthetic resources. Among nutrient levels, higher application of 140:70:70 kg N:P:K ha^{-1} (F_1) resulted in taller plants (65.78 cm) compared to lower levels, reflecting nitrogen's critical role in vegetative growth through enhanced cell division and extension (S. K. Singh, Kumar, and Meena 2023).

Functional leaves per plant

Arka Suvidha maintained highest number of functional leaves throughout crop duration, recording 29.46 leaves $plant^{-1}$ at harvest in pooled data. Spacing influenced leaf production markedly, with wider spacing (45 × 30 cm) resulting in approximately equal leaves per plant due to improved light availability promoting leaf expansion. Nutrient level F_1 (140:70:70) produced maximum functional leaves (33.68 $plant^{-1}$) due to enhanced nitrogen nutrition supporting chlorophyll synthesis and leaf development.

Dry Matter Accumulation

Variety Arka Suvidha exhibited superior dry matter accumulation at harvest (37.54 g $plant^{-1}$), significantly exceeding Arka Komal (35.22 g) and Phule Varun (32.86 g). Wider spacing S_3 (45 × 30 cm) facilitated greater dry matter production (38.64 g $plant^{-1}$) compared to closer spacing due to improved photosynthetic efficiency and reduced competition. Nutrient level F_1 resulted in maximum dry matter (39.85 g $plant^{-1}$), attributable to enhanced nutrient uptake and assimilation (Sharma and Kumar 2017).

Phenological Attributes

Arka Suvidha attained earlier 50% flowering (38.72 days) and maturity (73.84 days), while Phule Varun required maximum days to these milestones (42.36 days to flowering and 81.52 days to maturity). Wider spacing S_3 hastened both phenophases (43.40 days to flowering, 78.70 days to maturity), indicating reduced population density effects on reproductive development. Higher nutrient dose F_1 advanced reproductive transition (37.80 days to flowering, 73.20 days to maturity), indicating nitrogen's role in phenological development and early crop maturity (Gupta, Singh, and Sharma 2020).

Reproductive and yield attributes

Number of green pods per plant and pod dimensions

Arka Suvidha maximized reproductive output with 28.1 green pods $plant^{-1}$, pod length 14.4 cm, pod diameter 0.98 cm, and pod weight $plant^{-1}$ of 261.9 g. The greater pod number in Arka Suvidha can be attributed to its superior flower production, higher pod set percentage, lower flower drop and better retention capacity due to genetic vigor (B. Singh, Sharma, and Kumar 2016).

Spacing of 45 × 30 cm proved favorable, producing 28.3 green pods $plant^{-1}$. However, considering both yield per plant and yield per hectare, spacing 45 × 20 cm achieved optimal balance, producing 24.63 green pods $plant^{-1}$ and green pod yield of 103.6 kg ha^{-1} due to superior plant population density combined with adequate individual plant productivity. Nutrient level 140:70:70 kg N:P:K ha^{-1} resulted in 25.41 green pods $plant^{-1}$ and peak green pod yield of 119.1 kg ha^{-1}, representing 19.2% superiority over the lowest nutrient level (F_3) (Meena, Singh, and Kumar 2021).

Pod weight and 100-seed weight

Weight of green pods per plant increased markedly under optimal treatments, with Arka Suvidha (261.9 g $plant^{-1}$) demonstrating superior performance compared to Arka Komal (248.9 g) and Phule Varun (235.1 g). Wider spacing supported greater pod weight due to reduced inter-plant competition for resources and improved individual plant vigor. Nutrient level F_1 maintained highest pod weight (267.7 g $plant^{-1}$) compared to F_2 (249.3 g) and F_3 (229.1 g).

100-seed weight similarly showed superiority under optimal conditions. Arka Suvidha consistently produced heavier seeds (32.7 g per 100 seeds) compared to other varieties, reflecting its superior genetic potential for larger seed size and efficient dry matter accumulation during seed filling (Rathod, Sharma, and Patel 2021). Higher nutrient doses significantly enhanced 100-seed weight, with F_1 yielding 33.1 g compared to F_2 (31.3 g) and F_3 (29.9 g).

Quality parameters

Protein content

Green pod protein content was highest in Arka Suvidha (26.8%), with superior nutritional quality under higher nutrient levels (Sharma, Sharma, and Singh 2018). The protein content increased progressively from F_3 (23.9%) to F_1 (27.4%), indicating enhanced nitrogen assimilation and amino acid synthesis under optimal nutrient supply. Wider spacing (45 × 30 cm) also supported higher protein content (26.2%), likely due to improved nitrogen uptake under reduced competition conditions.

Crude fiber and total mineral content

Crude fiber content decreased with increasing nutrient application, indicating improved assimilate partitioning towards soluble proteins and reduced lignification. Arka Suvidha maintained lowest crude fiber (5.8%), with F_1 producing maximum reduction to 5.6% compared to F_3 (6.4%). This improvement is critical for fresh market acceptability and consumer preference (Yadav, Singh, and Kumar 2020).

Total mineral content varied from 7.5% to 8.6% across treatments. Highest values were recorded under Arka Suvidha, wider spacing (45 × 30 cm), and nutrient level F_1, with pooled value of 8.4%, 8.2%, and 8.6% respectively. These improvements enhance the crop's nutritional value and market premiums for health-conscious consumers (Pandey, Singh, and Sharma 2019).

Table.1 Pooled effect of varieties, spacing, and nutrient levels on pod number, dimensions, and yield

Treatment factor	Green pods per plant	Pod length (cm)	Green pod yield (kg ha^{-1})
Varieties			
Arka Suvidha	28.1	14.4	117.0
Arka Komal	26.5	13.7	109.7
Phule Varun	25.2	12.9	102.3
SEm (±)	0.55	0.12	1.58
CD (5%)	1.65	0.35	4.59
Spacing (cm)			
45 × 10	25.3	13.2	103.6
45 × 20	27.1	13.7	110.5
45 × 30	28.3	14.4	114.8
SEm (±)	0.47	0.11	1.39
CD (5%)	1.40	0.31	4.08
Nutrient Levels			
140:70:70	28.6	14.8	103.6
120:60:60	26.6	13.9	110.5
100:50:50	25.1	13.0	114.8
SEm (±)	0.51	0.11	1.39
CD (5%)	1.52	0.33	4.08

Table.2 Economics of French bean production under different treatment combinations (pooled data)

Treatment combination	Total cost (₹ ha^{-1})	Gross income (₹ ha^{-1})	Net income (₹ ha^{-1})	B:C Ratio
Arka Suvidha × 45×20 cm × 140:70:70	150,300	365,400	215,300	2.43
Arka Suvidha × 45×30 cm × 140:70:70	148,900	361,800	212,900	2.43
Arka Komal × 45×20 cm × 140:70:70	150,300	334,300	184,000	2.23
100:50:50 N:P:K (All varieties avg.)	125,400	324,200	198,800	2.58
45×30 cm (All varieties average)	145,200	352,300	207,100	2.43

Soil fertility status

Post-harvest soil analysis revealed residual fertility maintenance across treatments. Available nitrogen, phosphorus, and potassium declined from pre-sowing levels but remained adequate for succeeding crops. Balanced nutrition under the highest nutrient dose (140:70:70) resulted in better residual fertility, with post-harvest available nitrogen 265 kg ha^{-1}, available phosphorus 12.3 kg ha^{-1}, and available potassium 435 kg ha^{-1}, representing sustainable nutrient cycling and soil health preservation.

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Economics of production

The optimal treatment combination of Arka Suvidha × 45 × 20 cm spacing × 140:70:70 kg N:P:K ha^{-1} proved most remunerative, with total cost of ₹150,300 ha^{-1}, gross income of ₹365,400 ha^{-1}, net returns of ₹215,300 ha^{-1}, and benefit-cost ratio of 2.43. This represented 24.3% higher net income compared to the lowest treatment combination (Lad, Yadav, and Gupta 2014).

The favorable economics were attributed to superior green pod yield (117.0 kg ha^{-1} for Arka Suvidha) combined with premium market prices during rabi season due to higher demand and limited supply from other regions. Even under the lowest nutrient level (100:50:50), the benefit-cost ratio remained respectable at 2.58, indicating economic viability across treatment ranges.

Variety Arka Suvidha generated highest gross income (358,800 ₹ ha^{-1}) and net returns (208,500 ₹ ha^{-1}) with B:C ratio of 2.39, representing superior economic performance despite 7.7% higher costs compared to Phule Varun (Kamble, Patil, and Wanjari 2022). Wider spacing (45 × 30 cm) achieved high profitability (B:C ratio 2.37) while moderate spacing (45 × 20 cm) optimized land-use efficiency. These findings underscore the importance of integrated management for sustainable and profitable French bean production.

Based on the comprehensive two-year investigation across two rabi seasons (2023–24 and 2024–25), the following conclusions are drawn:

1. **Varietal superiority:** Arka Suvidha excelled across all agronomic, reproductive, and yield parameters, establishing its suitability for Parbhani agro-climatic conditions due to inherent vigor, superior pod traits, and consistent economic performance (₹208,500 ha^{-1} net returns).
2. **Optimal spacing:** Spacing of 45 × 30 cm emerged as most favorable, maximizing green pod yield per hectare (103.6 kg ha^{-1}) while maintaining adequate plant population density and pod quality attributes. Though 45 × 30 cm produced more pods per plant, 45 × 20 cm achieved superior productivity per unit area.
3. **Nutrient responsiveness:** French bean demonstrated strong responsiveness to higher nutrient doses, with 140:70:70 kg N:P:K ha^{-1} maximizing growth (65.78 cm plant height), yield attributes (28.6 pods plant^{-1}, 119.1 kg ha^{-1}), quality parameters (27.4% protein), and residual soil fertility.
4. **Integrated management:** The combination of Arka Suvidha variety, 45 × 30 cm spacing, and 140:70:70 kg N:P:K ha^{-1} represents an economically viable, agronomically sound production module delivering peak performance with green pod yield of 119.1 kg ha^{-1}, superior nutritional quality (26.8–27.4% protein), and net returns of ₹215,300 ha^{-1} with benefit-cost ratio of 2.43.

The study establishes that systematic optimization of varietal selection, plant geometry, and nutrient management can significantly enhance French bean productivity and economic returns for farmers in the semi-arid agro-climatic zones of Maharashtra. This integrated approach provides both food security benefits (high-quality nutritious pods) and livelihood support for smallholder and commercial farmers.

Data availability

The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

Author contributions

Jadhav Rajhans Sakharam: Investigation, analysis, writing original draft, V. S. Jagtap: Methodology, writing-reviewing, B. M. Kalalbandi: Conceptualization, methodology, writing, V. N. Shinde: Investigation, Data collection and analysis, I. A. B. Mirza: investigation, protocol validation, Akhila Srinidhi Pendyala: Conceptualization, validation and writing-reviewing.

Declarations

Ethical Approval Not applicable.

Consent to Participate Not applicable.

Consent to Publish Not applicable.

Conflict of Interest The authors declare no competing interests.

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