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Lalit Yadav
Ph.D. Scholar Department of Vegetable Science, CSAUA&T, Kanpur, Uttar Pradesh, India

Rajiv
Assistant Professor, Department of Vegetable Science, CSAUA&T, Kanpur, Uttar Pradesh, India

RB Singh
Associate Professor, Department of Vegetable Science, CSAUA&T, Kanpur, Uttar Pradesh, India

Budesh Pratap Singh
Ph.D. Scholar Department of Vegetable Science, CSAUA&T, Kanpur, Uttar Pradesh, India

Manoj Kumar
Ph.D. Scholar Department of Fruit Science, CSAUA&T, Kanpur, Uttar Pradesh, India

Ravi Pratap
Ph.D. Scholar Department of Fruit Science, CSAUA&T, Kanpur, Uttar Pradesh, India

Corresponding Author:
Lalit Yadav
Ph.D. Scholar Department of Vegetable Science, CSAUA&T, Kanpur, Uttar Pradesh, India

Effect of phosphorus, boron and their interaction on growth and yield parameters of French bean (*Phaseolus vulgaris* L.)

Lalit Yadav, Rajiv, RB Singh, Budesh Pratap Singh, Manoj Kumar and Ravi Pratap

Abstract
French bean (*Phaseolus vulgaris* L.) is a globally significant leguminous vegetable with a short growth duration, known by various synonyms such as kidney bean, common bean, snap bean, and more. It originated in Middle America and has two primary centre of origin, Mexico and Central America. French beans are rich in nutrients, including protein, carbohydrates, fat, calcium, phosphorus, iron, and vitamins. This study was conducted during the rabi seasons of 2021-22 and 2022-23 at horticulture farm CSAU&T Kanpur Uttar Pradesh, India, to investigate the impact of phosphorus and boron fertilization on French bean growth and yield. The experiment laid in Factorial RBD included 12 treatments involving 4 combinations of phosphorus and 3 combinations of boron. The results revealed significant effects of phosphorus and boron treatments on various growth parameters of French bean. Phosphorus treatments, particularly P^3 (25 kg/ha), consistently produced taller plants with more branches and pods. Similarly, boron treatments, especially B^2 (1.5 kg/ha), led to improved plant height and pod production. The combination of P^3B^2 consistently resulted in the best performance in terms of plant height, branches, and pod count. In addition to growth parameters, the study also assessed yield parameters. Phosphorus and boron treatments influenced pod length, width, seeds per pod, test weight, average fresh pod weight, and average seed weight. P^3 and B^2 treatments consistently yielded longer pods, wider pods, more seeds per pod, higher test weights, and heavier pods. Overall, the study highlights the importance of phosphorus and boron fertilization in enhancing the growth and yield of French bean. The combination of 25 kg/ha of phosphorus and 1.5 kg/ha of boron (P^3B^2) proved to be the most effective treatment for optimizing French bean production. These findings provide valuable insights for farmers and researchers to improve the cultivation of this important leguminous vegetable, ultimately contributing to food security and nutrition.

Keywords: Phosphorus, boron, interaction, growth, yield, French bean, *Phaseolus vulgaris* L.

Introduction

French bean (*Phaseolus vulgaris*. L) is one of the most important leguminous short growing duration pod vegetables grown all over the World. It has many synonyms like; kidney bean, common bean, snap bean, navy bean, haricot bean, wax bean, string bean and Rajmash (Sharma *et al*., 1994) [5]. French bean has originated in the highlands of Middle America from a wild vine over a period of 7000-8000 years. Mexico and Central America as the primary and Peruvian Ecuadorian-Bolivian region of South America is considered as the secondary center of origin of French bean. French bean contains 21.1% grain protein, 69.9% carbohydrates, 17% fat besides 381 mg calcium, 42.5 mg phosphorus and 12.4 mg iron per 100 gm of edible parts. Each 100 g of tender pods of French bean contains 90% moisture, 1.10% fiber, 1.80% protein, 0.10% fat, 7.10% carbohydrate, 31.0 (Kcal) energy, 37.0 mg calcium, 38.0 mg phosphorous, 1.0 mg iron, 668 vitamin A (IU), 0.08 mg thiamine, 0.11 mg riboflavin, 0.75 mg niacin and 16.3 mg vitamin C (Gebhardt *et al*., 1982) [3]. French bean cultivation mainly confined to Northern hilly areas of Jammu & Kashmir, H.P. and Uttar Pradesh as a Kharif crop and some parts of Maharashtra, Andhra Pradesh, Western and Eastern Ghats and North Eastern plain zone. The crop is sown in two seasons from February-March and September-October in the tropical and sub-tropical climate. French bean is an annual herbaceous, erect, bushy (20-65 cm tall) or twinning or climbing or pole type (2-3.2 m long) with alternate triplicate leaves are stipulate, petiolate with good tendril. In French bean germination is epigeal having an adventitious root system. The stem is slender, twisted, angled and ribbed, more or less square in section. The flowers are white, pink or purple with reflexed standard and diadelphous stamens and are self-pollinated. Pods are borne mostly on axillary racemes and are slender, straight or curved and terminated by a prominent beak and usually contain 4-6 seeds. Seeds are non-endospermic and vary greatly is size and colour. It does not nodulate with native rhizobia or commercially produced cultures (Sardana *et al*., 2000) [4]. Based on the growth habit, the French bean varieties are grouped as bush type with short internodes, semi pole type with longer internodes, and the pole type having internodes longer than that of semi pole type. Brazil is the largest producer of French bean in the world followed by Myanmar, India, China, the United States of America and Mexico. With an area of 3.78 million ha. Brazil produces 3461 thousand MT of French beans with an average productivity of 0.81 MT per ha, while India ranks first in area with 8.0 million ha, and ranks third with a production of 3010 thousand MT of French bean (F.A.O, 2017) [1]. French bean production depends on many factors such as quality seed, variety, sowing date, fertilizer and cultural management practices. Crop yield varies from variety to variety due to internal and external factors of the plant. (Uddin *et al*., 2018; Usha *et al*., 2019) [6, 7]. The fertilizer management has vital role on growth, development and yield of leguminous crops. Amongst all the sixteen essential nutrients phosphorus for all crops is of prime importance because of its fixation and more so in acid soils of tropics and subtropics. For this reason, P deficiency is more common in tropics. Rajmash cultivation requires ample supply of phosphorus. Phosphorus plays a vital role in structural component of cell constituents. It is structural part of the membrane system of the cell, chloroplast and mitochondria. It helps for energy transformation and various metabolic activities of plants. Excessive and under dose of phosphorus can affect the growth and yield of legume crops. Boron is a trace element that can be applied in soil as well as foliar. Limited supplies of P reduce roots growth, development, elongation and ultimately nutrients uptake while B deficiency cause faintness in plant defensive mechanism and grain development in cereal and legumes.

Materials and Methods

A field experiment was conducted during *rabi* season of the year 2021-22 and 2022 -23 at Department of vegetable Science, Kalyanpur, CSAU&T, Kanpur (Uttar Pradesh). The experiment was laid out into 3 replication and Randomized Block Design (RBD) with Factorial concept consisted 12 treatments *viz.* T_1 = 0 Kg Phosphorus + 0 kg Boron, T_2 = 0 Kg Phosphorus + 0.5 kg Boron, T_3 = 0 Kg Phosphorus + 1.5 kg Boron, T_4 = 20 Kg Phosphorus + 0 kg Boron, T_5 = 20 Kg Phosphorus + 0.5 kg Boron, T_6= 20 Kg Phosphorus + 1.5 kg Boron, T_7 =25 Kg Phosphorus + 0 kg Boron, T_8 =25 Kg Phosphorus + 0.5 kg Boron, T_9 =25 Kg Phosphorus + 1.5 kg Boron, T_{10}= 35 Kg Phosphorus + 0 kg Boron, T_{11}=35 Kg Phosphorus + 0.5 kg Boron, T_{12}= 35 Kg Phosphorus + 1.5 kg Boron. (As shown is table 1). The crop was raised at spacing of 45cm x 20 cm and plot size of 2.25 x 1.2 m. Recommended package practices and plant protection measure were adopted during the cropping periods. Observation was recorded for Plant height (cm), Number of leaves per plant, Days to 50% flowering, Number of pods plant-^{1}, Number of branches per plant at maturity, Pod length (cm), Pod Width (cm) Days to first picking 1,`. Number of green pod pod per plant (g). Average fresh pod weight (g)Test weight of 100 seeds (g), Number of Seed per pod, Yield per plant (kg) Seed yield (kg ha^{-1}). All data related to crop collected were statistically analysed by using the analysis of variance technique (Fisher, 1958) [2].

Table 1: Details of different treatment combinations

Tr. No	Treatment Combination	Symbol
T_1	0 Kg Phosphorus + 0 kg Boron	P0B0
T_2	0 Kg Phosphorus + 0.5 kg Boron	P0B1
T_3	0 Kg Phosphorus + 1.5 kg Boron	P0B2
T_4	20 Kg Phosphorus + 0 kg Boron	P1B0
T_5	20 Kg Phosphorus + 0.5 kg Boron	P1B1
T_6	20 Kg Phosphorus + 1.5 kg Boron	P1B2
T_7	25 Kg Phosphorus + 0 kg Boron	P2B0
T_8	25 Kg Phosphorus + 0.5 kg Boron	P2B1
T_9	25 Kg Phosphorus + 1.5 kg Boron	P2B2
T_{10}	35 Kg Phosphorus + 0 kg Boron	P3B0
T_{11}	35 Kg Phosphorus + 0.5 kg Boron	P3B1
T_{12}	35 Kg Phosphorus + 1.5 kg Boron	P3B2

Results and Discussion

The data on plant height at harvest stages over both experimental years. Phosphorus treatments showed a consistent trend of highest plant height, with P^3 (25 kg/ha) (46.65 and 46.99 cm) during 2021-22 and 2022-23. Similarly, Boron treatments revealed a similar pattern, with B2 (1.5 kg/ha) yielding the highest plant harvest stage (45.51 and 45.76 cm) for both years. Notably, the interaction of P^3B^2 consistently significant the maximum plant height. The number of branches at harvest across both experimental years, for phosphorus treatments, P^3 (25 kg/ha) exhibited the highest number of branches (6.543 and 6.683), followed by P^2 (20 kg/ha) with (5.890 and 6.120), and P^1 (20 kg/ha) with the lowest (4.783 and 5.013) in 2021-22 and 2022-23. Similar patterns were observed for Boron treatments, with B^2 (1.5 kg/ha) leading with (5.876 and 6.105), B^1 (0.5 kg/ha) with (5.543 and 5.773), and B^o (0 kg/ha) with the minimum (5.328 and 5.558) in both years. Interaction analysis revealed that the combination of P^3B^2 consistently produced the highest number of branches during both experimental years. The number of pods during both experimental years, Phosphorus treatment showed highest pod counts in P^3 (25 kg/ha) with (13.567 and 13.707), followed by P^2 (20 kg/ha) with (12.823 and 12.963), and lowest counts in P^1 (20 kg/ha) with (11.183 and 11.323) in respective years. Similar trends were observed for Boron treatment, with B^2 (1.5 kg/ha) leading with (12.805 and 12.945), B^1 (0.5 kg/ha) with (12.248 and 12.388), and B^o (0 kg/ha) with the lowest (11.820 and 11.960). The interaction of P^3B^2 produced the highest pod count at harvest for both years. Leaf count at harvesting stages, during both experimental years. Phosphorus treatment (P^3, 25 kg/ha) resulted in the highest leaf count (11.460 and 12.080 at harvest) in 2021-22 and 2022-23, followed by P^2 and P^1. Similarly, Boron treatment (B^2, 1.5 kg/ha) led to maximum leaf count (11.398 and 12.018 at harvest). The interaction of P^3B^2 displayed the highest leaf count across growth stages. This demonstrates the consistent influence of treatments on leaf development throughout both years. Days to 50% flowering across both experimental years, Phosphorus treatment (P^3, 25 kg/ha) led to the shortest flowering duration (32.95 and 34.180), followed by P^2. Conversely, P^1 exhibited the longest flowering period (37.00 and 38.23). Similar trends were seen with Boron treatment (B^2, 1.5 kg/ha). The interaction of P^3B^2 resulted in the shortest flowering time emphasizing the consistent influence of treatments on flowering timing throughout both years.

Yield Parameters

The data on pod length during both experimental years is, Phosphorus treatment (P^3, 25 kg/ha) resulted in the longest pod lengths (13.100 and 13.250 cm), followed by P^2. Conversely, P^1 exhibited the shortest lengths. A similar pattern was observed with Boron treatment (B^2, 1.5 kg/ha). The interaction of P^3B^2 produced the longest pod lengths highlighting the consistent influence of treatments on pod length throughout both years. Pod width across both experimental years is evident, Phosphorus treatment (P^3, 25 kg/ha) resulted in the widest pod widths (10.32 and 10.327 mm), followed by P^2. Conversely, P^1 exhibited the narrowest widths. A similar pattern was observed with Boron treatment (B^2, 1.5 kg/ha). The interaction of P^3B^2 produced the widest pod widths emphasizing the consistent impact of treatments on pod width throughout both years. The number of seeds per pod across both experimental years is evident, Phosphorus treatment (P^3, 25 kg/ha) yielded the highest seeds per pod (5.18 and 5.41), followed by P^2. Conversely, P^1 had the lowest counts. Similar trends were observed with Boron treatment (B^2, 1.5 kg/ha). The interaction of P^3B^2 resulted in the highest seeds per pod emphasizing the consistent influence of treatments on seed count throughout both years. Seed test weight across both experimental years is, Phosphorus treatment (P^3, 25 kg/ha) yielded the highest test weights (42.133 and 42.523 gm), followed by P^2. Conversely, P^1 had the lowest weights. Similar trends were observed with Boron treatment (B^2, 1.5 kg/ha). The interaction of P^3B^2 resulted in the highest test weights (42.650 and 43.040 gm), highlighting the consistent impact of treatments on seed test weight throughout both years. Average fresh pod weight across two experimental years is evident, Phosphorus treatment (P^3, 25 kg/ha) led to the highest mean weights (4.080 and 4.290 gm), followed by P^2. Similarly, Boron treatment (B^2, 1.5 kg/ha) showed comparable trends. The interaction of P^3B^2 resulted in the highest average pod weights (4.300 and 4.510 gm), highlighting the consistent and significant influence of treatments on pod weight over both years. Average seed weight of pods over two experimental years is, Phosphorus treatment (P^3, 25 kg/ha) resulted in the highest average seed weights (1948.333 and 1985.33 kg), followed by P^2. Similarly, Boron treatment (B^2, 1.5 kg/ha) displayed a similar trend. The interaction of P^3B^2 yielded the highest average seed weights (2010.00 and 2047 kg), highlighting the consistent and significant influence of treatments on seed weight over both years.

Table 2: Effect of phosphorus, boron and their interaction on growth parameters of French bean

Treatment	Plant Height(cm)		Number of branches		Number of pods per plant		Number of leaves per plant		Days to 50% flowering	
	2021-22	2022-23	2021-22	2022-23	2021-22	2022-23	2021-22	2022-23	2021-22	2022-23
Boron										
B0	43.853	43.352	5.328	5.558	11.82	11.96	10.975	11.595	35.475	36.705
B1	44.05	44.3	5.543	5.773	12.248	12.388	11.138	11.758	35.075	36.305
B2	45.515	45.765	5.875	6.105	12.805	12.945	11.398	12.018	34.025	35.255
CD at 5%	1.01	0.13	0.113	0.13	0.24	0.333	0.264	0.255	0.786	0.882
SE(m) ±	0.484	0.062	0.054	0.062	0.115	0.16	0.127	0.122	0.376	0.423
Phosphorus										
P0	41.567	41.900	4.783	5.013	11.323	11.183	10.684	11.303	37.000	38.230
P1	43.833	43.167	5.200	5.430	11.730	11.590	11.100	11.720	35.883	37.113
P2	45.833	45.833	5.890	6.120	12.963	12.823	11.437	12.057	33.600	34.830
P3	46.657	46.990	6.453	6.683	13.707	13.567	11.460	12.080	32.950	34.180
CD at 5%	1.167	0.15	0.13	0.15	0.277	0.385	0.305	0.294	0.907	1.019
SE(m) ±	0.559	0.072	0.062	0.072	0.133	0.184	0.146	0.141	0.435	0.488
Interaction (Boron * Phosphorus)										
CD at 5%	N/A	N/A	0.226	0.26	0.479	0.667	N/A	N/A	N/A	N/A
SE(m) ±	0.968	0.962	0.108	0.124	0.23	0.319	0.253	0.244	0.753	0.846

Table 3: Effect of phosphorus, boron and their interaction on yield parameters of French bean

Treatment	Pod length (cm)		Pod width(cm)		Number of seed per pod		Test weight of seed(g)		Average weight of fresh pod (g)		Seed yield per hectare (kg)	
	2021-22	2022-23	2021-22	2022-23	2021-22	2022-23	2021-22	2022-23	2021-22	2022-23	2021-22	2022-23
0.108												
	10.91	11.048	10.17	10.23	4.713	4.743	39.813	40.202	3.662	3.873	1,764.25	1,801.25
B1	11.3	11.425	10.205	10.265	4.827	4.991	40.162	40.553	3.733	3.942	1,795.00	1,832.00
B2	12.025	12.163	10.283	10.343	4.895	5.125	40.98	41.37	3.961	4.171	1,872.00	1,909.00
CD at 5%	0.277	0.342	N/A	N/A	0.108	0.121	0.839	0.964	0.106	0.094	46.426	44.08
SE (m) ±	0.133	0.164	0.118	0.085	0.052	0.058	0.402	0.462	0.051	0.045	22.242	21.119
Phosphorus												
P0	9.613	9.730	10.130	10.190	4.397	4.627	38.257	38.647	3.333	3.543	1,635.333	1,672.63
P1	10.533	10.650	10.160	10.220	4.603	4.744	27.266	27.657	3.717	3.927	1,766.333	1,803.333
P2	12.400	12.550	10.267	10.327	5.067	5.297	41.617	42.007	4.011	4.221	1,891.667	1,928.667
P3	13.100	13.250	10.320	10.380	5.180	5.410	42.133	42.523	4.080	4.290	1,948.333	1,985.333
CD at 5%	0.32	0.395	N/A	N/A	0.125	0.14	0.969	1.114	0.122	0.109	53.608	46.426
SE(m) ±	0.153	0.189	0.136	0.099	0.06	0.067	0.464	0.534	0.059	0.052	25.683	22.242
Interaction (Boron * Phosphorus)												
CD at 5%	0.554	0.684	N/A	N/A	N/A	N/A	1.679	1.929	N/A	N/A	N/A	N/A
SE(m) ±	0.265	0.328	0.235	0.171	0.104	0.116	0.804	0.924	0.101	0.09	44.485	42.237

Conclusion

In this way, it was revealed that use of Phosphorus and Boron to better growth and produce of French bean. Among the various treatments, (T_{12} = 35 Kg Phosphorus + 1.5 kg Boron) high results in terms of, plant height number of leaves per plant, Days to 50% flowering Number of pods per plant, pod length, pod width Days to first picking Number of green pod per plant, Average fresh pod weight, Number of Seed per pod, yield per plant, seed yield per hectare in the T_{12} treatment combination T_{12} = 35 Kg Phosphorus + 1.5 kg Boron).

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