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Effect of nutrients combination on yield & quality of okra [*Abelmoschus esculentus* (L.) Moench cv.Kashi Kranti]

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Abstract
The present study evaluated the interactive effects of inorganic fertilizer (NPK), bio-inoculants, and micronutrient supplementation okra (*Abelmoschus esculentus* L. 'Kashi Kranti') cultivation in the year 2024. A factorial randomized block design with 64 treatment combinations was implemented: four NPK levels (80:40:40, 100:50:50, 120:60:60, 140:70:70 kg/ha), four bio-inoculant regimes (none, *Azotobacter* 1000 ml/ha, PSB 1000 ml/ha, *Azotobacter* + PSB 1000 + 1000 ml/ha), and four micronutrient treatments (none, Zn 50 ppm, Fe 100 ppm, Zn + Fe 150 ppm) with the objective of effects of nutrient combination on quantitative & qualitative characters in okra.Most of the result shown significant three-way interactions for Plant height (115.3 cm) in F4B4M4, Inter-nodal length (7.98 cm) in F4B4M4 while the other parameters like Number of primary branches per plant (6.20), Number of days to 50% flowering (45.11), Average diameter of fruit (2.47 cm), Average length of fruit (12.72 cm), Fruit yield per plant (233 g), Yield (15.56 T/ha) & Ascorbic acid (16.8 mg/100 g) was best in (F2B4M4) combination of NPK (100:50:50 kg/ha), *Azotobacter* + PSB (1000 + 1000 = 2000 ml/hBa), and Zn + Fe (150 ppm) consistently produced the most favorable quantitative & qualitative parameters in okra. These findings highlight the potential of integrated nutrient management for sustainable okra production.

Keywords: Okra, Kashi Kranti, NPK, *Azotobacter*, PSB, micronutrients (Fe & Zn), factorial RBD

Introduction
Okra [*Abelmoschus esculentus* (L.) Moench] is an important annual herbaceous vegetable crop, primarily cultivated during the kharif season. It belongs to the family Malvaceae and is grown for its tender pods (Benchasri, 2012; Chattopadhyay *et al.*, 2011; Onyenuga, 1968) [5, 8, 33]. India leads the world in okra production, cultivating approximately 544, 000 hectares and producing around 6.89 million tonnes annually. In Bihar alone, okra is grown over 60, 758 hectares, yielding about 124, 314.65 tonnes per year. Okra thrives in warm temperatures, and its seeds fail to germinate below 16 °C. Severe frost conditions can also damage the pods (Muluken *et al.*, 2016) [32]. Nutritionally, okra is a valuable source of vitamins A, B, C, E, and K, along with essential minerals such as calcium, magnesium, and iron. It is a multipurpose crop, with various plant parts including leaves, buds, flowers, pods, stems, and seeds having culinary and medicinal uses (Mihretu *et al.*, 2014) [31]. The alcohol extract of okra leaves has shown potential in reducing proteinuria and improving renal function by eliminating free radicals and alleviating renal tubular-interstitial diseases. The leaves also contain more protein, riboflavin, and folic acid than the pods (Adelusi *et al.*, 2006; Liu *et al.*, 2005; Kumar *et al.*, 2009) [1, 26, 25]. Okra mucilage has been used as a plasma substitute and blood volume expander. It also binds with cholesterol and bile acids to aid in toxin removal by the liver (Gemede *et al.*, 2014) [17]. Traditional medicine systems in several countries use okra for its anti-ulcerogenic, gastroprotective, and diuretic properties (Gurbuz *et al.*, 2003) [20]. Tender pods are commonly consumed fried or cooked, and are also used in soups, salads, and stews. The leaves are used medicinally to treat cardiovascular disorders, diabetes, digestive ailments, and certain cancers (Gemede *et al.*, 2015) [18]. To enhance the qualitative and quantitative traits of okra, balanced fertilization is essential. Overreliance on inorganic fertilizers has led to nutrient imbalances and degradation of soil health.

The rising costs of chemical fertilizers also pose a challenge for small-scale farmers. Integrating bio-inoculants with inorganic fertilizers offers a sustainable solution for improving soil fertility and crop productivity. The use of organic inputs such as biofertilizers represents a viable alternative for efficient nutrient management in okra cultivation (Choudhary *et al.*, 2015) [10]. Chemical fertilizers—especially nitrogen and phosphorus—are key to plant growth and development. Nitrogen is vital for forming amino acids, proteins, chlorophyll, and protoplasm, promoting vigorous vegetative growth. Phosphorus is essential for energy transfer, photosynthesis, respiration, and synthesis of nucleic acids, proteins, and phospholipids (Sharma *et al.*, 2016; Dissanayaka *et al.*, 2021) [47, 11]. Phosphorus deficiencies in soil can be addressed through chemical sources like di-ammonium phosphate (DAP), which contains 46% P_2O_5 (Rashid, 2005) [42]. Sustainable productivity in vegetable crops like okra demands adequate application of manures and fertilizers. Bio-inoculants such as phosphate-solubilizing bacteria (PSB) enhance phosphorus uptake and contribute to improved crop yields. Genera such as Pseudomonas, Bacillus, and Rhizobium are commonly used for their phosphate solubilization abilities, primarily through organic acid production and the activity of acid phosphatases (Rodríguez & Fraga, 1999) [43]. PSB also promotes plant growth through nitrogen fixation, siderophore production, ACC deaminase activity, and secretion of phytohormones like indole-3-acetic acid (IAA) (Emami *et al.*, 2020) [14]. *Azotobacter* spp., in addition to fixing atmospheric nitrogen, synthesize plant growth regulators such as IAA and gibberellic acid (GA), and can reduce nitrogen fertilizer requirements by 10-20% per season in many vegetable crops (Pathak *et al.*, 2017) [38]. Micronutrients like iron (Fe) and zinc (Zn) are essential for optimal plant growth and are crucial in various physiological and biochemical processes. The integrated application of organic and inorganic nutrients, including compost, farmyard manure, bio-inoculants, and chemical fertilizers, offers a promising approach to sustainable nutrient management (Choudhary *et al.*, 2015) [10]. Such practices help address economic concerns of farmers while also ensuring environmental sustainability (Chahal *et al.*, 2019) [7]. However, sole reliance on either bio-inoculants or inorganic fertilizers is often insufficient to maintain optimal crop growth and yield. Therefore, the present study was undertaken in 2024 to assess the combined effects of NPK fertilizers, bio-fertilizers, and micronutrients on various growth and yield parameters of okra, including plant height, number of primary branches, days to 50% flowering, internodal length, number of fruits per plant, days to first harvest, average fruit diameter and length, number of pickings, fruit yield per plant, and overall yield per hectare. The objective of the study was to determine the most effective combination of chemical and bio-fertilizers for optimal okra growth and productivity in the agro-climatic conditions of BAU, Sabour, Bihar. Furthermore, this research aims to raise awareness among students, researchers, extension workers, and farmers about the benefits of using bio-fertilizers, thereby promoting sustainable and holistic farming practices.

Materials and Methods

The experiment was carried out at the research farm of Vegetable sciences, BAU Sabour, Bhagalpur, Bihar, India during kharif seassion of the year 2024. Geographically, the research farm is located at latitude and longitude 25.23409' N and 87.045942' E. In this region the minimum and maximum temperature varies from 25 °C to 48 °C in kharif, with average annual rain fall of 1000-1200 mm.

(i) Plant material: Plant material, *i.e*. okra *cv*. Kashi kranti. Before priming, the seeds were treated with Bavistin @ 2g/kg.

(ii) Fertilizers and Bio-fertilizers: formulations of NPK (Iffco), *Azotobacter* (*Sabour azoto*, BAU Sabour), PSB (BAU Sabour) were procured from the BAU Sabour bio lab, Bhagalpur, Bihar, India and tested along with the experimental formulations.

iii) Micronutrients: FeSo4 and ZnSo4

(iv) Experimental design: The experiment was laid out in Factorial Randomized Block Design (FRBD) with three replications and 64 treatment combinations represented in Table 1.

Table 1: The experiment was laid out in Factorial Randomized Block Design (FRBD) with three replications and 64 treatment combinations represented

Notation	NPK Treatment levels	Dose
F_1	80: 40: 40	kg NPK /ha
F_2	100: 50: 50	kg NPK /ha
F_3	120: 60: 60	kg NPK /ha
F_4	140: 70: 70	kg NPK /ha
	Bio inoculants	
B_1	No inoculants	(0 ml/ha)
B_2	*Azotobacter*	(1000 ml/ha)
B_3	PSB (Phosphate solubilising bacteria)	(1000 ml/ha)
B_4	*Azotobacter* + PSB	(1000 + 1000 = 2000 ml/ha)
	Micronutrients	
M_1	No micro-nutrients	(0 ppm)
M_2	Zn	(50 ppm)
M_3	Fe	(100 ppm)
M_4	$M_2 + M_3$	(50 + 100 = 150 ppm)

Table 1: Soil details before sowing

The land was prepared to tilth by repeated ploughing and harrowing. The mechanical composition of soil was *viz*., fine sand (45%), silt (35.5%), clay (21%) and chemical composition as available nitrogen (219.62 kg/ha), available phosphorous (23.10 kg/ha), available potassium (27.00 kg/ha), organic carbon (0.31%) and soil pH 7.6. The seeds of okra @ 15 kg/hectare were manually sown in lines at a depth of 3-4 cm with a spacing of 50 cm between rows and 30 cm between plants.

Table 1: Details of all treatments

Inter-cultural operations: Sowing was done on 8th July, 2024 and seedlings emerged after 3-5 days of sowing. Light irrigation was given after the sowing. All other recommended inter-cultural practices (recommended package of practices, BAU Sabour 2024) were followed to raise the crop.

(v) Treatments with biofertilizers, micronutrients & NPK: The bio-fertilizers *viz*., *Azotobacter* spp. and PSB

were applied in the form of their commercially available formulation, through soil application near the root zone area of the plants, according to the treatment details/guidelines supplied by the manufacturer. The chemical fertilizers were applied in split doses following during cropping period. Micro-nutrients were applied in the foliar application. Observations with respect to growth and yield were recorded during the growth period of the crop.

(vi) Statistical analysis: The data collected was subjected to Analysis of Variance (ANOVA) in FRBD with Fisher's post-hoc test to find the critical difference (CD) ammong different treatment means using SPSS software (version 15.0) to check the significant differences among treatments at $p \leq 0.01$, according to Gomez and Gomez (1984) [19] and OPSTAT (Sheoran *et al*., 1998) [45].

Results and Discussion

A. Effect of various combinations of NPK, Micro-nutrients and biofertilizers on the growth of okra

The growth characteristic recorded in the present study *viz*., Plant height (cm), Number of primary branches per plant, Number of days to 50% flowering, Inter-nodal length(cm), Average diameter of fruit (cm), Average length of fruit (cm), Fruit yield per plant (kg), Yield (T/ha) & Ascorbic acid are presented in Table 2.

The application of chemical fertilizers and their different combinations with the bio-fertilizers significantly increased the Plant height (cm), Number of primary branches per plant, Number of days to 50% flowering, Inter-nodal length(cm), Average diameter of fruit (cm), Average length of fruit (cm), Fruit yield per plant (kg), Yield (T/ha) & Ascorbic acid, (F-test; $p \leq 0.05$).

The effects of the different treatments of chemical and bio-fertilizers on the height of okra plant shows that the combination treatment T64 [(Fe + Zn = 150 ppm) + (PSB + *Azotobacter* = 2000 ml/ha) + NPK (140:70:70 Kg/ha)] had maximum plant height (115.34 cm) on 90 DAS.

The mean data pertaining number of primary branches per plant was highest 6.20 in T_{32} [(Fe + Zn = 150 ppm) + (PSB + *Azotobacter* = 2000 ml/ha) + NPK (100:50:50 Kg/ha)] at 90 DAS, are presented in Table 1. Also, there was significant differences in number of primary branches among the treatments, showed a significant difference $F_2B_4M_4$.

The combination treatment T_{32} [(Fe + Zn = 150 ppm) + (PSB + *Azotobacter* = 2000 ml/ha) + NPK (100:50:50 Kg/ha)] shows Number of days to 50% flowering, (45.11). The number of Number of days to 50% flowering data was found significant.

The Inter-nodal length (7.982 cm) found maximum in T64 [(Fe + Zn = 150 ppm) + (PSB + *Azotobacter* = 2000 ml/ha) + NPK (140:70:70 Kg/ha)]. Therefore, a non significant improvement was recorded in okra, suggesting the efficacy of incorporation of bio-inoculants, micronutrients and NPK.

The Average diameter of fruit found highest (2.477 cm) in T_{32} [(Fe + Zn = 150 ppm) + (PSB + *Azotobacter* = 2000 ml/ha) + NPK (100:50:50 Kg/ha)] and was significant, whereas Average length of fruit increased upto (12.718 cm).

Both the yield parameter raised the Fruit yield per plant (233 g) maximum in T_{32} and lead to the final Yield 15.56 (T/ha)

Qualitative parameters were also influenced in which Ascorbic acid content was 16.8 mg/100 g. it was also measured significant in T_{32}

In okra, the highest plant height, greatest number of branches and leaves, and the earliest flowering were observed following the application of *Azotobacter* and Phosphate Solubilizing Bacteria (PSB), as reported by Manivannan and Singh (2004) [29]. Enhanced vegetative growth in related crops such as *Hibiscus sabdariffa* (L.) and broccoli has also been linked to increased soil microbial activity resulting from bio-fertilization (Hassan, 2009; Zaki *et al.*, 2012) [22, 51]. The microorganisms present in bio-inoculants produce organic acids that act as potent chelating agents, facilitating the solubilization and availability of phosphorus to plants (Randhawa, 1962; Majanbu, 1986) [41, 28]. Furthermore, *Azotobacter* can enhance the population of beneficial soil microorganisms and improve nutrient availability, thereby promoting overall plant growth (Hamidi *et al.*, 2006) [21].

Table 2: Best Effects among various treatments on yield & quality of okra.

Treatments	Plant Height (cm)	Days to 50% flowering	No of branches	Inter-nodal length	Average dia of fruit (cm)	Avg.length of fruit (cm)	Fruit yield/plant (g)	Fruit Yield (T/ha)	Ascorbic Acid (mg/100 g)
$F_2B_4M_4$		45.11	6.20		2.47	12.718	233	15.56	16.8
$F_4B_4M_4$	115.3			7.98					
C.D. (5%)	5.213	3.951	0.195	0.443	0.167	0.687	0.012	0.789	
S.E. (m±)	2.234	1.693	0.084	0.190	0.071	0.294	0.005	0.338	0.393
C.D. (1%)									1.306

Values are represented as means of three independent replicates (n = 3) for yield parameters; for the comparison of means, the critical difference (CD) and S.E. (m±) were calculated (at $p \leq 0.05$) while for qualitative parameters calculated (at $p \leq 0.01$).

Discussion

The effects of various treatments involving chemical fertilizers, bio-fertilizers, and micronutrients on the height and internodal length of okra plants revealed that the treatment combination T_{64} recorded the highest values. This was primarily due to enhanced nitrogen availability along with the positive influence of zinc and iron, which together promoted vegetative growth. A similar experiment using four organic nutrient sources—FYM, NPK, *Azotobacter*, and phosphate-solubilizing bacteria (PSB)—either individually or in combination, showed promising results. FYM, *Azotobacter*, and PSB were applied as seed treatments prior to sowing. Among the treatments, T_5 (NPK at 100:50:50 kg/ha + PSB at 7.5 kg/ha) was notably superior, significantly improving parameters such as number of fruits per plant (12.51), fresh fruit length (21.15 cm), average fresh fruit weight (13.79 g), fruit yield per plant (180.47 g), and overall yield per hectare (132.26 q/ha), as reported by Singh *et al.* (2020) [52]. Similar improvements in yield were also observed in Hibiscus sabdariffa L. when bio-fertilizers were applied in conjunction with chemical fertilizers (Youssef *et al.*, 2014) [50]. Likewise, the integration of bio-fertilizers and effective microorganisms was shown to enhance the yield of *Vigna radiata* (L.) by up

to 84% (Javaid & Bajwa, 2011) [23]. Other studies have also highlighted the positive impact of PSB application on the growth and yield of okra (Anandan, 2000; Prabhu *et al.*, 2003) [2, 40]. The combined use of *Azospirillum* and PSB has also been found effective in increasing okra yield (Gaur, 1990) [16]. The inoculation with PSB leads to the production of both organic and inorganic acids—such as citric, formic, and acetic acids—which help solubilize otherwise insoluble forms of phosphorus, thereby enhancing its bioavailability (Bora *et al.*, 2002) [6].

An increase in the number of primary branches, average fruit diameter, average fruit length, fruit yield per plant, and total yield was observed in the treatment combination F2B4M4. This enhancement is attributed to the synergistic effect of micronutrients and bio-inoculants. Abdulsada *et al.* (2013) [53] conducted a study evaluating the impact of three biofertilizers—*Azotobacter*, *Azospirillum*, and *Glomus mosseae*—and their interactions on the growth, fruit yield, and quality of okra (*Abelmoschus esculentus* L. cv. Mahi 45) during the summer season. The experiment consisted of eight treatments: T_1 (Control), T_2 (*Azotobacter*), T_3 (*Azospirillum*), T_4 (Mycorrhizae-*Glomus mosseae*), T_5 (*Azotobacter* + *Azospirillum*), T_6 (*Azotobacter* + *Glomus mosseae*), T_7 (*Azospirillum* + *Glomus mosseae*), and T_8 (*Azotobacter* + *Azospirillum* + *Glomus mosseae*), with three replications. Results showed that all biofertilizer treatments and their combinations had a significant positive effect on parameters such as plant height, number of branches and leaves per plant, fruit length and diameter, number of fruits per plant, fruit yield per plant (g), and overall fruit yield (t/ha), compared to the control. The increase in vegetative growth and yield-related traits was attributed to improved nutrient translocation and enhanced photosynthetic efficiency during the growth period (Edward & Daniel, 1992) [12]. Biofertilizers have also shown to enhance yield attributes in medicinal plants such as Salvia officinalis and Echinacea purpurea (Marashi *et al.*, 2015; Jokar *et al.*, 2015) [30, 24]. Phytohormones like indole-3-acetic acid (IAA) have been linked to these effects (Phua *et al.*, 2012) [39]. When *Azospirillum* was enriched with decomposed organic manures, it further increased fruit yield in okra (Parvatham & Vijayan, 1989) [36]. Both *Azotobacter* and *Azospirillum* are free-living and endophytic nitrogen-fixing bacteria (García-Fraile *et al.*, 2015) [15]. In addition to nitrogen fixation, these microbes also secrete phytohormones such as gibberellic acid (GA_3) and IAA, which promote plant growth, nutrient uptake, photosynthetic activity, and seed germination (Umesha *et al.*, 2018) [48]. The application of *Azotobacter* spp. has been reported to significantly increase plant height, stem diameter, and fresh and dry biomass in maize seedlings. Furthermore, *Azotobacter* has shown the potential to protect plants from root pathogens, stimulate native soil microbial activity, and enhance crop yield in Zea mays (Mahato & Kafle, 2018; Vikhe, 2014) [27, 49].

The application of micronutrients, particularly zinc (Zn) and iron (Fe), had a marked influence on days to 50% flowering and ascorbic acid content in okra. These elements play a crucial role in hormone biosynthesis, thereby affecting key physiological processes. Patel *et al.* (2023) [37] reported that Zn and Fe enhance flower production, fertilization, and pollen viability, which together contribute to an increased number of pods and an extended harvesting period. Similar findings were reported by Chaudhari *et al.* (2018) [9], further supporting the positive role of micronutrients in okra productivity. The observed increase in flower and pod numbers may also be attributed to the role of Fe and Zn in tryptophan synthesis—an essential precursor for the formation of indole-3-acetic acid (IAA), a major plant growth regulator—as well as in enhancing the efficient translocation of photosynthates from source to sink tissues.

Conclusion and future scope

From the present investigation, it can be concluded that the treatment combination T_{32}—comprising foliar application of iron and zinc at 150 ppm, bio-fertilizers (Phosphate Solubilizing Bacteria and *Azotobacter* at 2000 ml/ha), along with recommended doses of NPK (100:50:50 kg/ha)—proved to be the most effective in enhancing growth, fruit yield, and quality parameters of okra. This integrated nutrient management approach, combining both bio-fertilizers and chemical fertilizers, demonstrates significant potential for adoption in sustainable and organic vegetable production systems.

The observed improvements in okra growth and nutrient uptake can be attributed to the synergistic effect of bio-fertilizers—harboring beneficial microbes—and inorganic fertilizers supplying essential macro-nutrients. These inputs not only support better plant development but may also contribute to improved soil physico-chemical properties. The findings further suggest that such integrative practices can reduce the dependency on mineral nitrogen fertilizers, particularly in soils with low organic matter content, thereby promoting long-term agricultural productivity.

Moreover, the dual benefit of maintaining crop performance while preserving soil health and ecological balance underscores the value of incorporating bio-fertilizers with reduced chemical fertilizer inputs. The wider adoption of such practices may serve as a viable strategy for sustainable, eco-friendly cultivation of okra and other vegetable crops.

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Conflict of Interest. None.

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