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RESEARCH ARTICLE

Effect of nano urea and micronutrient foliar application on growth and yield of Bhendi [*Abelmoschus esculentus* (L.) Moench]

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Abstract

A field experiment was conducted at the Department of Horticulture, Pandit Jawaharlal Nehru College of Agriculture and Research Institute, Karaikal, U.T. of Puducherry, on bhendi [*Abelmoschus esculentus* (L.) Moench] during summer 2024 to investigate the effects of nano urea and micronutrients spray on enhancing growth and productivity. The experiment was laid out in a Randomized Block Design (RBD) with 15 treatments, each replicated twice. The study materials included nano urea, 19:19:19 NPK water soluble fertilizer (WSF), zinc, boron and Arka vegetable special, besides recommended N, P, K fertilizers. Results revealed that the foliar application of Arka vegetable special 2 g L^{-1} as foliar spray thrice at 20th, 40th and 60th day of sowing along with Recommended Dose of fertilizers (RDF - 200:100:100 kg NPK ha^{-1}) recorded significant reduction in days to flowering (33.40 days), enhanced plant growth with maximum plant height of 29.20 cm at first flowering and 131.30 cm at final harvest, increased number of primary branches at first flowering (2.50) and at final harvest (3.90), with shorter internode of 2.52 cm. Similar trends were also observed with respect to major yield attributes viz., fruit length (20.00 cm), fruit girth (7.20 cm), individual fruit weight (25.30 g), number of fruits $plant^{-1}$ (49.50) and total yield (1.00 kg $plant^{-1}$ and 20.60 t ha^{-1}) were notably improved, reflecting a 55.47 % yield increase over the control (RDF). These findings underscore the efficacy of foliar supplementation of micronutrients in enhancing the growth and productivity of bhendi.

Keywords: Arka vegetable special; bhendi; micronutrients; nano urea

Introduction

Bhendi [*Abelmoschus esculentus* (L.) Moench] is an important vegetable of tropical, subtropical and warm temperate regions. Also known as ladies' finger and it belongs to the family Malvaceae (1). Bhendi is considered an economically valuable crop worldwide due to its dietary importance. Per 100 g edible portion, contains 88.6 g water, 8.2 g carbohydrates, 2.1 g protein, 47 mg vitamin C and essential minerals like calcium (84 mg), phosphorus (90 mg) and iron (1.2 mg). Its rich content of protein, carbohydrates and vitamin C plays a key role in human nutrition. Its tender immature fruits are mainly consumed as vegetable (2). In India, it is cultivated in almost all the states throughout the year and consumed by majority of the people. India ranks first in bhendi production constituting 72 % of the total world production, with an area of 546000 ha, producing about 670000 m MT (3).

Among the multiple factors, soil degradation is a significant contributor to India's stagnant crop yields. In addition to this, factors such as imbalanced fertilizer use, declining soil organic carbon, water scarcity, increasing frequency of extreme weather events and lack of adoption of improved agronomic practices also play crucial roles. In India, urea accounts for 82 % of fertilizer consumption, compared to 55 % globally. Only around 30 %- 40 % of nitrogen from the urea applied is utilized by plants and the rest gets wasted due to quick chemical transformation resulting in leaching, volatilization, denitrification and run off, thereby registering a low use efficiency (4).

In contrast, micronutrient application has shown remarkable benefits for Indian vegetable crops. Zinc influences basic plant life processes, as it functions as a component of series of enzymes, chlorophyll synthesis and cell membrane integrity. Zinc application also helps in increasing the uptake of nitrogen and potash. Zinc provides a protective mechanism against the excessive uptake of boron and is necessary for root cell membrane integrity and its function. Boron is essential for reproductive structures, cell wall formation, stabilization and membrane integrity. Boron besides facilitating the transport of carbohydrates through cell membrane, it aids in stomatal regulation, water absorption, pollen tube formation and seed quality (5). Among various application methods, foliar spray is preferred for its convenience, reduced nutrient fixation in soil and rapid nutrient uptake. Foliar sprays of zinc, iron, copper and boron have proven more effective than soil application, particularly for elements with low soil solubility. This method also proves efficient and economical, resulting in enhanced plant growth and yield (5). Keeping the above points in view, the

present study was undertaken to evaluate the effect of foliar nutrition of nano urea and micronutrients on growth and yield of bhendi hybrid "COBh H 4".

Materials and Methods

The present study entitled "Effect of nano urea and micronutrient spray on growth and yield of bhendi [*Abelmoschus esculentus* (L.) Moench]" was carried out during 2024 at Pandit Jawaharlal Nehru College of Agriculture and Research Institute, Karaikal, U.T. of Puducherry, India. The bhendi hybrid "COBh H 4" released by the Tamil Nadu Agricultural University with a crop duration of 110 days was used in the present study. The treatment materials for the study comprised nano urea, zinc as zinc sulphate monohydrate (33 %), boron as disodium tetraborate pentahydrate (20 %), Arka vegetable special, 19:19:19 NPK (WSF) besides recommended soil application of N, P, K (200:100:100 kg ha^{-1}) fertilizers. The field experiment was laid out in a RBD with fifteen treatments (Table 1), each replicated twice. A plot size of 20 m^2 was maintained for each treatment to accommodate 48 plants in a plot at a spacing of 60 cm X 45 cm. Nano urea was applied as a foliar spray at 500 mL $acre^{-1}$ on 20 and 40 days after sowing. Zinc and boron were applied as a foliar spray at 2 g L^{-1} of water each on 20 and 40 days after sowing. Arka vegetable special is a micronutrient formulation containing most of the micronutrients such as Zn, B, Fe, Cu, Mn, Mo and Cl and also contains most of the secondary nutrients such as Ca, Mg, S and K (6) was applied as foliar spray at 2 g L^{-1} of water on 20, 40 and 60 days after sowing. 19:19:19 NPK (WSF) was applied as a foliar spray at 0.5 % concentration on 30^{th}, 40^{th} and 50^{th} days after sowing.

Statistical analysis

The AGRES software was used to perform statistical analysis of the data. After computing the analysis of variance (ANOVA), standard deviation (SE(d)) and least significant difference (LSD) values with the critical difference set at 5 % level of significance, the mean comparisons were performed.

Results and Discussion

Effect of nano urea and micronutrients on growth parameters in COBh H 4 hybrid bhendi

The data on influence of foliar nutrition of nano urea and micronutrients on various growth parameters is presented in Table 2.

Days to flowering

Data on days taken for flowering under the influence of foliar nutrition of nano urea and micronutrients in addition to recommended dose of fertilizers were found to be insignificant. The plants which were subjected to foliar application of Arka vegetable special thrice at 20, 40 and 60 DAS along with RDF (T_4) were found to be the earliest to produce flowers (33.40 days). This was followed by T_6 (33.70 days), whereas the plants under basal NPK + Zn + B as foliar spray on 20 and 40 DAS (T_9) was late to flower and came to flowering in 34.80 days. Earliness in flowering due to foliar spray of Arka vegetable special and soil application of RDF might be attributed to uniform distribution, low application rate, quick response and also for their role in synthesis of Adenosine Triphosphate (ATP) and translocation of sugars helping in more flowering.

Plant height (cm)

Use of different fertilizer combinations was found to have significant effect on plant height. The treatment T_4, supplied with RDF + Arka vegetable special has recorded the maximum plant height at flowering and final harvest (29.20 cm and 131.30 cm). This was followed by T_6 (28.40 cm and 118.10 cm) and it was found to be on par with T_5 (27.55 and 116.50 cm), T_3 (27.50 cm and 105.40 cm), T_2 (27.10 cm and 105.30 cm) and T_{15} (26.80 cm and 102.90 cm). The plant height recorded at flowering and final harvest was minimum (23.95 cm and 91.60 cm) in T_9. This could be attributed to the absence of nitrogen top dressing, which is critical for sustained vegetative growth and reproductive development in bhendi. While the basal dose provides initial nutrition, the lack of additional nitrogen during the crop's active growth stages may have limited nutrient availability, affecting plant vigour, flowering and ultimately yield. The tallest plants recorded in the treatments

Table 1. Treatment particulars

Sl. No.	Treatment	Treatment details
1.	T_1	RDF
2.	T_2	RDF + 19:19:19 NPK (WSF)
3.	T_3	RDF + Zn + B
4.	T_4	RDF + Arka vegetable special
5.	T_5	RDF + 19:19:19 NPK (WSF) + Zn + B
6.	T_6	RDF + 19:19:19 NPK (WSF) + Arka vegetable special
7.	T_7	Basal NPK + 19:19:19 NPK (WSF)
8.	T_8	Basal NPK + Nano urea
9.	T_9	Basal NPK + Zn + B
10.	T_{10}	Basal NPK + Arka vegetable special
11	T_{11}	Basal NPK + 19:19:19 NPK (WSF) + Nano urea
12.	T_{12}	Basal NPK + 19:19:19 NPK (WSF) + Zn + B
13.	T_{13}	Basal NPK + 19:19:19 NPK (WSF) + Nano urea + Zn + B
14.	T_{14}	Basal NPK + 19:19:19 NPK (WSF) + Arka vegetable special
15.	T_{15}	Basal NPK + 19:19:19 NPK (WSF) + Nano urea + Arka vegetable special

RDF- Recommended Dose of Fertilizer (N - 100 kg, P - 100 kg and K - 100 kg ha^{-1} as basal and N - 100 kg ha^{-1} as top dressing on 30 DAS)

Table 2. Effect of nano urea and micronutrients on growth parameters in bhendi hybrid

	Days to flowering	Plant height at flowering (cm)	Number of primary branches at flowering	Plant height at final harvest (cm)	Number of primary branches at final harvest	Node of first flower anthesis	Internodal length (cm)
T_1	34.00	26.25	2.20	100.50	3.50	5.00	3.05
T_2	33.90	27.10	2.20	105.30	3.70	4.90	3.00
T_3	33.80	27.50	2.30	105.40	3.70	4.90	2.96
T_4	33.40	29.20	2.50	131.30	3.90	4.70	2.52
T_5	33.80	27.55	2.30	116.50	3.80	4.90	2.88
T_6	33.70	28.40	2.50	118.10	3.80	4.90	2.85
T_7	34.70	24.20	2.00	92.50	3.20	5.00	3.22
T_8	34.50	24.60	2.10	92.70	3.30	5.00	3.20
T_9	34.80	23.95	2.00	91.60	3.20	5.00	3.25
T_{10}	34.50	25.05	2.10	93.20	3.40	5.00	3.10
T_{11}	34.30	25.10	2.10	95.50	3.40	5.00	3.09
T_{12}	34.10	25.25	2.10	95.50	3.40	5.00	3.08
T_{13}	34.10	25.55	2.10	97.00	3.50	5.00	3.08
T_{14}	34.00	26.50	2.20	101.50	3.60	5.00	3.02
T_{15}	33.90	26.80	2.20	102.90	3.60	5.00	3.02
Mean	**34.10**	**26.20**	**2.19**	**102.63**	**3.53**	**4.95**	**3.02**
SEd	**0.47**	**1.25**	**1.25**	**6.58**	**0.19**	**0.06**	**0.14**
CD (0.05)	**NS**	**2.67**	**NS**	**14.10**	**0.40**	**0.14**	**0.29**

T_4, T_6 and T_5 might have stemmed from the synergistic action of foliar application of Arka vegetable special in addition to the soil application of recommended dose of fertilizer NPK, resulting in increased crop growth might be due to supply of key micronutrients like zinc, iron, boron and manganese, which enhance auxin synthesis, photosynthesis and cell development. Its balanced composition ensures efficient nutrient uptake and metabolic activity, while foliar application enables quick absorption, leading to improved vegetative growth and taller plants (1, 5, 7).

Number of primary branches

The effect of various fertilizer treatments with regard to number of primary branches at flowering were found to be insignificant while, number of primary branches at final harvest was found significant. The application of RDF + Arka vegetable special (T_4) was found to record the maximum number of primary branches at flowering and final harvest (2.50 and 3.90) for this important growth trait and was closely followed by T_6(RDF + 19:19:19 NPK (WSF) + Arka vegetable special) with 2.50 and 3.80 branches. The minimum number of primary branches at flowering and final harvest (2.00 and 3.20) was recorded in T_9. The number of branches on a plant significantly impacts fruit production, as more branches usually lead to more flowering nodes and subsequently more fruits. Adequate nitrogen and phosphorous in the early stages likely stimulated the growth of auxiliary bud, resulting in a higher number of primary branches per plant, consistent with findings in tomato (9) and potato (10).

Node of first flower anthesis

The various fertilizer combinations used were found to have significant influence on node of first flower anthesis (Fig. 1). The appearance of flower at the lowermost node with RDF + Arka vegetable special (T_4 - 4.70), followed by T_2, T_3, T_5 and T_6 all recording a value of 4.90. The influence of node of first flower anthesis with the application of micronutrients might be attributed to the role of zinc in enhancing auxin synthesis, which supports faster vegetative growth and earlier flower initiation, while boron is essential for meristematic activity and pollen development. Additionally, the balanced micronutrient composition of Arka vegetable special improves overall nutrient efficiency, more specifically N, P and K in combined application of micronutrients in okra (11).

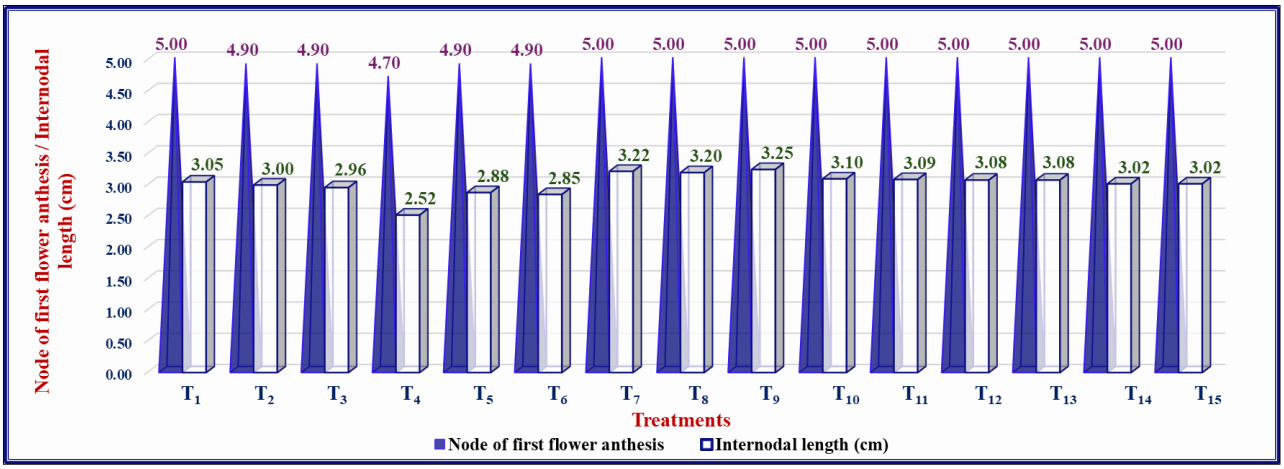

Fig. 1. Effect of nano urea and micronutrients on node of first flower anthesis and internodal length (cm) in bhendi hybrid "COBh H 4".

Internodal length (cm)

The differences observed in internodal length of bhendi among the different fertilizer combinations were found significant (Fig. 1). In bhendi, shorter internodal length is considered agronomically desirable, as it leads to an increased number of fruits bearing nodes, thereby enhancing fruit count and overall yield. The treatment of Arka vegetable special as foliar spray on 20, 40 and 60 DAS along with recommended dose of fertilizer (T_4) was observed to produce the shortest internode of 2.52 cm and it was found to be statistically on par with the next best treatment T_6 (RDF + 19:19:19 NPK (WSF) + Arka vegetable special) with an internodal length of 2.85 cm, whereas the foliar application of Zn and B on 20 and 40 DAS along with basal NPK (T_9) produced the maximum internodal length (3.25 cm) and this was followed by T_7 (3.22cm) and T_8 (3.20 cm), which received basal NPK + 19:19:19 NPK (WSF) and basal NPK + nano urea, respectively. Foliar spray of micronutrients and soil application of nitrogen and phosphorus, accelerate synthesis of growth hormones in plants which indirectly exhibited in enhanced growth of the plants and also involved in synthesis of carbohydrates which are utilized in building up of new cells and energy transformation in plant cells, cell division and development of meristematic tissues (12).

Effect of nano urea and micronutrients on yield parameters in bhendi hybrid "COBh H 4"

The data on influence of foliar nutrition of nano urea and micronutrients on various yield parameter is presented in Table 3.

Fruit length (cm)

The study revealed the presence of significant differences in fruit length among the various fertilizers' treatments tried with the longest fruits observed in RDF + Arka vegetable special (T_4 - 20.00 cm) (Fig. 2). It was however found to be on par with T_6 (19.71 cm) and T_5(18.93 cm), while the shortest fruits were observed in T_9 (17.73 cm). Foliar application of vegetable special could have improved pod length by ensuring a steady and enhanced supply of nutrients and the consistent nutrient availability would have supported the delivery of essential assimilates to the developing pods, resulting in increased fruit size and overall yield (13). Further enhanced accumulation of photosynthesis would have resulted from vigorous plant growth with foliar feeding of nutrients (14).

Fruit girth (cm)

There was a significant difference in fruit girth across the treatments, with measurements ranging from 6.19 cm to 7.20 cm (Fig. 2). The minimum fruit girth, of 6.19 cm, was observed in the treatment involving basal NPK + Zn + B (T_9). In contrast, the maximum girth, (7.20 cm) was recorded in T_4. Increased fruit girth with the application RDF + Foliar spray of WSF and IIHR Vegetable Special might be due to increased uptake of nutrients and better utilization of photosynthates resulting in better food accumulation in edible parts (9). Throughout the crop's growth period, nutrients were applied in split forms continuously, which improved the crop's growth attributes and increased physiological activity and absorbed photosynthetically active radiation (PAR). Further a higher photosynthetic rate and the translocation of nutrients towards the reproductive parts due to enhanced par absorption could have also led to increased fruit girth (15). While fruit girth is critical for market preference and yield as it directly correlates with fruit weight and consumer appeal.

Individual fruit weight (g)

Among the treatment showing significant differences for fruit weight maximum fruit weight was noticed in the treatment T_4 (25.30 g), receiving foliar spray of Arka vegetable special thrice along with RDF (Fig. 3). This was followed by T_6 (23.21 g) and T_5 (22.25 g). The fruit weight recorded in T_9 (17.73 g) was the least. The increased fruit weight in T_4 could have resulted from improved micronutrient absorption, which in turn caused the fruits to accumulate more carbohydrates and offered a better assimilate status for growth and development (13, 16). This was further strengthened due to the increased and continuous availability of K with its split application and supplementation of secondary and micronutrients, all enhancing the fruit size (9).

Number of fruits plant^{-1}

The number of fruits plant^{-1}recorded was the highest (49.50) in RDF + Arka vegetable special (T_4), which was subsequently followed by T_6(47.10) and T_5 (42.70), while minimum number of fruits (34.70) were recorded in T_9(Fig. 3). The increase in number of fruits plant^{-1} through enhanced fruit setting and retention might be due to the availability of secondary and micronutrients applied via foliar treatment (16). Further, higher metabolic activity

Table 3. Effect of nano urea and micronutrients on yield parameters in bhendi hybrid "COBh H 4"

	Fruit length (cm)	Fruit girth (cm)	Individual fruit weight (g)	Number of fruits plant^{-1}	Fruit yield plant^{-1} (g)	Estimated yield ha^{-1} (kg)
T_1	17.08	6.51	19.89	39.30	766.60	13.25
T_2	17.67	6.59	20.64	40.90	812.80	14.33
T_3	17.84	6.64	20.69	41.40	812.80	15.09
T_4	20.00	7.20	25.30	49.50	1000.00	20.60
T_5	18.93	6.71	22.25	42.70	816.70	15.22
T_6	19.71	6.79	23.21	47.10	818.30	17.50
T_7	16.22	6.25	18.55	35.50	690.50	11.55
T_8	16.35	6.25	19.25	35.90	739.80	11.06
T_9	15.97	6.19	17.73	34.70	683.75	11.06
T_{10}	16.57	6.27	19.20	36.30	794.00	12.02
T_{11}	16.98	6.33	19.53	36.55	757.00	12.47
T_{12}	17.11	6.36	19.78	37.00	761.75	13.12
T_{13}	17.06	6.48	19.86	37.10	765.15	13.19
T_{14}	17.18	6.53	20.02	39.50	788.45	13.95
T_{15}	17.42	6.58	20.14	40.70	794.00	14.29
Mean	**17.47**	**6.51**	**20.40**	**39.61**	**786.77**	**13.91**
SEd	**0.63**	**0.19**	**0.94**	**0.83**	**23.22**	**0.54**
CD (0.05)	**1.35**	**0.41**	**2.02**	**1.78**	**49.81**	**1.15**

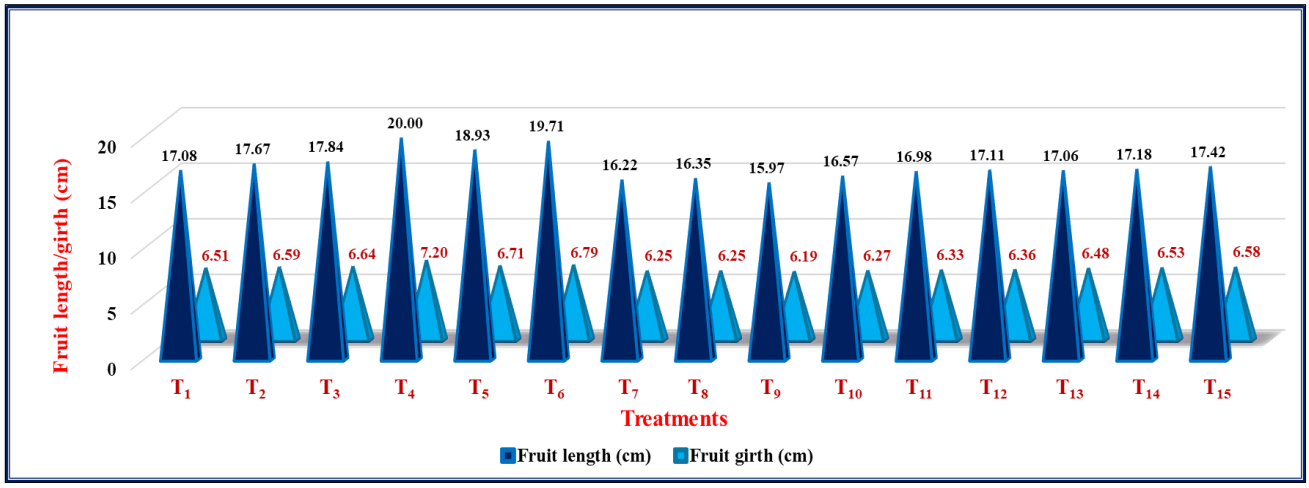

Fig. 2. Effect of nano urea and micronutrients on fruit length (cm) and fruit girth (cm) in bhendi hybrid "COBh H 4".

resulting from optimum 'N' supply could have resulted in higher production of carbohydrates and phytohormones (17). This improvement could also be attributed to the enhanced cytokinin synthesis from optimal nitrogen and phosphorus supply creating a favourable environment for producing more productive flowers and consequently resulting in a higher fruit set plant^{-1} in tomato (9).

Fruit yield plant^{-1} (g)

The treatment applied with basal NPK + Zn + B (T_9) had the lowest yield (683.75 g) among all the treatments, whereas T_4 (RDF + Arka Vegetable special thrice at 20, 40 and 60 DAS) produced maximum yield plant^{-1} of 1000.00 g (Fig. 3). This was followed by T_6 (818.30 g) and T_5 (816.70 g) which were found to significantly differ from each other. The increased fruit yield plant^{-1} is attributable to enhanced vegetative growth, a balanced carbon-to-nitrogen ratio and the influence of coenzymes in regulating various physiological processes facilitated through better nutrient transport within the plant (15).

Fruit yield ha^{-1} (t)

There were significant differences across the fertilizer combinations tried on yield of bhendi as furnished in Table 2 and the treatment receiving soil application of RDF + Arka Vegetable special foliar spray thrice at 20, 40 and 60 DAS (T_4) was found the best (20.60 t ha^{-1}) and was significantly superior to rest of the treatments, with a benefit-cost ratio of 2.18. The treatment T_6 (17.50 t ha^{-1}) was the next best, followed by T_5 (15.22 t ha^{-1}), while the treatment receiving basal NPK + Zn + B (T_9) had the lowest yield (11.06 t ha^{-1}) among all the treatments. The increase in fruit yield might be the result of better absorption of all the secondary and micronutrients by foliage at critical growth stages. This absorption could have helped in accumulation of carbohydrates in the final produce of the crop (9, 10, 16). Moreover, the increased leaf area leading to absorption of more nutrients, greater availability of nutrients for better growth and development would have also contributed ultimately for the enhanced yield.

Conclusion

The study revealed not only the potential benefits of foliar application of micronutrients but also highlighted the importance of top-dressing nitrogen in the soil for hybrid bhendi. Treatments where top dressing of nitrogen was replaced with foliar spraying of nano urea did not perform well. Their yields were lower compared to those that received nitrogenous fertilizer as a top dressing. It is concluded that applying the recommended dose of NPK (200:100:100 kg ha^{-1}) along with foliar sprays of Arka vegetable special thrice at 20, 40 and 60 DAS ensures a continuous and stable nutrient supply to meet the growth and yield requirements of hybrid bhendi. Moreover, the uptake and assimilation of micronutrients through foliar application is faster than soil application, which proves beneficial in the long run-in sustaining crop productivity.

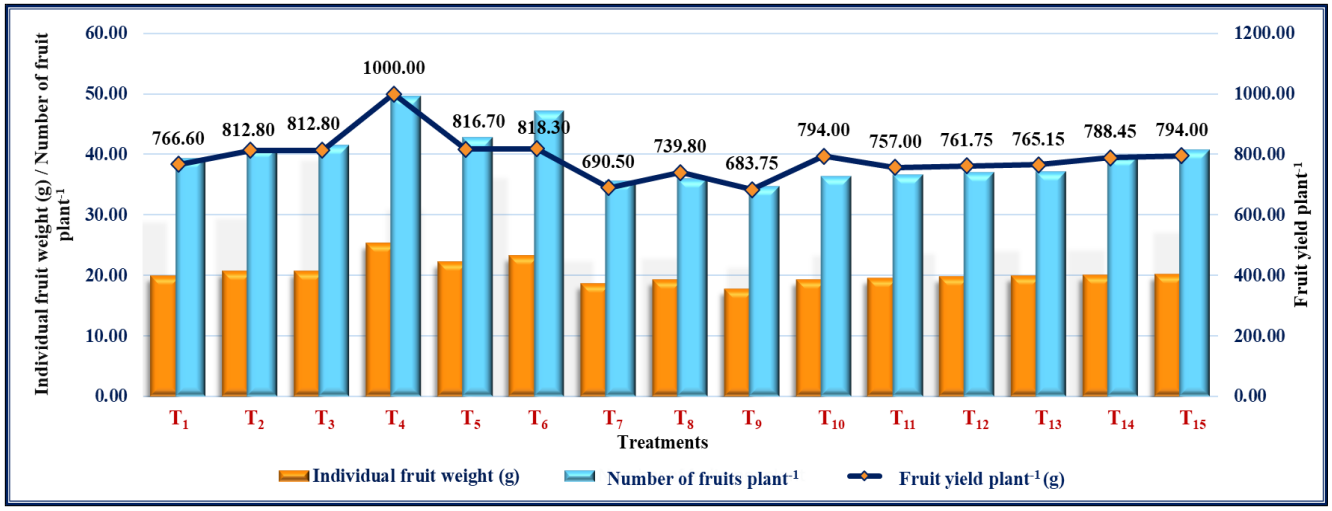

Fig. 3. Effect of nano urea and micronutrients on individual fruit weight (g), number of fruits plant^{-1} and fruit yield plant^{-1} (g) in bhendi hybrid "COBh H 4".

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Authors' contributions

MM carried out the experiment on nano urea and micronutrients on okra, collected and analysed the data and drafted the manuscript. VS formulated the ideas of the research, monitored the conduct of the experiment and fine-tuned the writings. All authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interests to declare.

Ethical issues: None

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work the authors used the Grammarly tool in order to improve language and readability of the content.

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