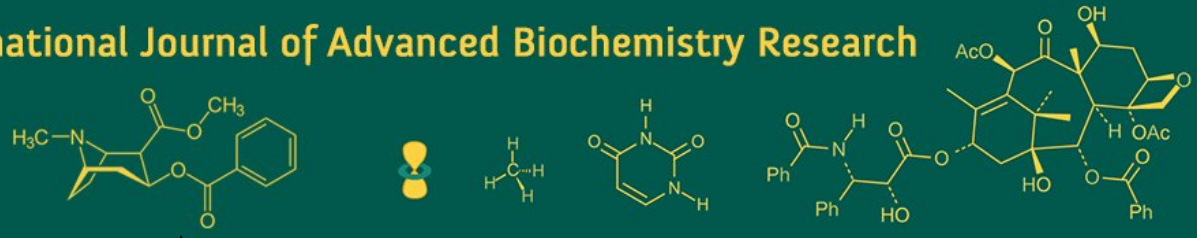
International Journal of Advanced Biochemistry Research



ISSN Print: 2617-4693
ISSN Online: 2617-4707
IJABR 2024; 8(2): 552-556
www.biochemjournal.com
Received: 08-12-2023
Accepted: 14-01-2023

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Effect of micronutrients and bio - capsule on quality of Capsicum (*Capsicum annuum* L.) under protected conditions

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DOI: https://doi.org/10.33545/26174693.2024.v8.i2g.627

Abstract
An experiment investigating the impact of micronutrients and bio-capsules on the quality of capsicum in protected conditions was conducted during the rabi seasons of 2022-23 and 2023-24 at the Horticulture Research Field, SHUATS, Naini, Prayagraj, U.P., within a Completely Randomized Design comprising 15 treatments with 3 replications. The results indicated that the treatment T_{14} (consisting of a mixture of all micronutrients with bio-capsule) significantly improved various quality attributes, including total soluble solids (7.94 °Brix), ascorbic acid content (147.82 mg $100g^{-1}$), and acidity (4.89%). Treatment T_{14} emerged as the most effective, possibly due to the combined application of bio-capsules and micronutrients balancing the C:N ratio, resulting in enhanced nutrient availability and increased plant metabolism. This, in turn, led to greater carbohydrate accumulation in the fruit, consequently increasing total soluble solids and ascorbic acid levels. Treatment T_7 also showed promising results. Conversely, the control treatment (T_0) yielded the lowest values. The findings suggest that farmers can benefit from using a mixture of all micronutrients along with bio-capsules to enhance capsicum quality in protected conditions.

Keywords: Capsicum, bio- capsule, micronutrient, TSS, acidity, ascorbic acid

1. Introduction
Bell pepper, scientifically known as *Capsicum annuum* L. var. grossum Sendt, is a popular and profitable annual herbaceous vegetable crop, especially suitable for protected cultivation. It belongs to the solanaceae family and is extensively grown in various regions of India including Andhra Pradesh, Karnataka, Maharashtra, Tamilnadu, Himachal Pradesh, and hilly areas of Uttar Pradesh. Greenhouse cultivation significantly enhances the quality of bell peppers in terms of fruit size, TSS content, ascorbic acid content, and pH levels. Compared to open-field cultivation, protected structures like polyhouses provide substantial economic returns, improved crop quality, reduced pesticide residues, and higher yields. The adoption of protected cultivation methods is increasingly favored among Indian farmers, particularly those with limited land holdings. Different types of protected structures such as greenhouses, polyhouses, shade net houses, and low tunnels are commonly used in India.
The presence of micronutrients such as calcium, magnesium, boron, and iron plays a crucial role in enhancing the growth, yield, and quality of bell peppers. Studies have shown that the application of these micronutrients, including calcium, sulfur, boron, and iron, effectively improves growth, yield, and seed production. Even though micronutrients are required in small quantities, they are essential for plant growth. The application of micronutrients enhances various metabolic activities, such as photosynthesis, leading to increased production of plant metabolites responsible for cell division and elongation, resulting in increased yields at intervals of 15 days.
Recently, scientists from IISR-ICAR have developed a groundbreaking technology for encapsulating bio-fertilizers. Plant growth-promoting rhizobacteria (PGPR) have been widely utilized in agriculture to enhance yield and suppress diseases. The encapsulation of PGPR represents a significant advancement in the biofertilizer industry. Research indicates that PGPR not only benefit crops but also improve the efficiency of fertilizer and manure utilization, thereby allowing reduced application rates.

The primary focus of our research was to investigate the combined effects of micronutrient concentration and bio-capsules on enhancing the quality of bell peppers under protected conditions.

2. Materials and Methods

The experiment was conducted during in winter (rabi season) during the year 2022 -23 and 2023 - 24 on NVPH at Horticulture Research Field, Sam Higginbottom University of agriculture, Technology and sciences, Naini, Prayagraj, (U.P). The experiment comprised of 15 treatments combinations and replicated thrice i.e. Each treatment received a unique combination of micronutrients and bio - capsule (PGPR). T_0, (Control), T_1, Boric acid 100 ppm (0.571 g/l), T_2, Zinc sulphate 100 ppm (0.246g/l), T_3, Ammonium Molybdate 50 ppm (0.644g/l), T_4, Copper sulphate100 ppm (0.52 g/l), T_5, Ferrous sulphate 100 ppm (0.515 g/l), T_6, Manganese sulphate 100 ppm (0.32 g /l), T_7, Mixture of all micronutrients (T_1+ T_2+T_3+T_4+T_5+T_6), T_8, Boric acid 100 ppm (0.571 g/l) with bio - capsule, T_9, Zinc sulphate 100 ppm (0.246g/l) with bio - capsule, T_{10}, Ammonium Molybdate 50 ppm (0.644g/l) with bio - capsule, T_{11}, Copper sulphate100 ppm (0.52 g/l) with bio - capsule, T_{12}, Ferrous sulphate 100 ppm (0.515 g/l) with bio - capsule, T_{13}, Manganese sulphate 100 ppm (0.32 g /l) with bio - capsule, T_{14}, Mixture of all micronutrient with bio - capsule were arranged in completely randomized design.

10gm seedlings are sufficient for experiment field. 25- 30-day old seedlings at the 3-4 leaf stage were transplanted in the month of November at a spacing of 60 cm x 45 cm during both the years of experimentation. Total 360 seedlings are planted in Raised beds are formed after bringing soil to fine tilth. Total Crop duration is 90-150 days in protected condition. The experimental net cultivated area is 56.7 cm^2 and Gross cultivated area 76.95 cm^2. The crop was harvested during the third week of March during both years 2022-23 and 2023-24.

The responses of capsicum to various treatments were measured in terms of quality *i.e.*, Total soluble solids (°Brix), Ascorbic acid (mg $100g^{-1}$), Acidity (%).

The data obtained were analyzed statistically by adopting CRD using R-Software (v4.3.0) and SPSS 20. The differences among means were tested for significance using critical difference tests (CD) and the results obtained from the analysis are presented in pictorial form.

3. Results and Discussion

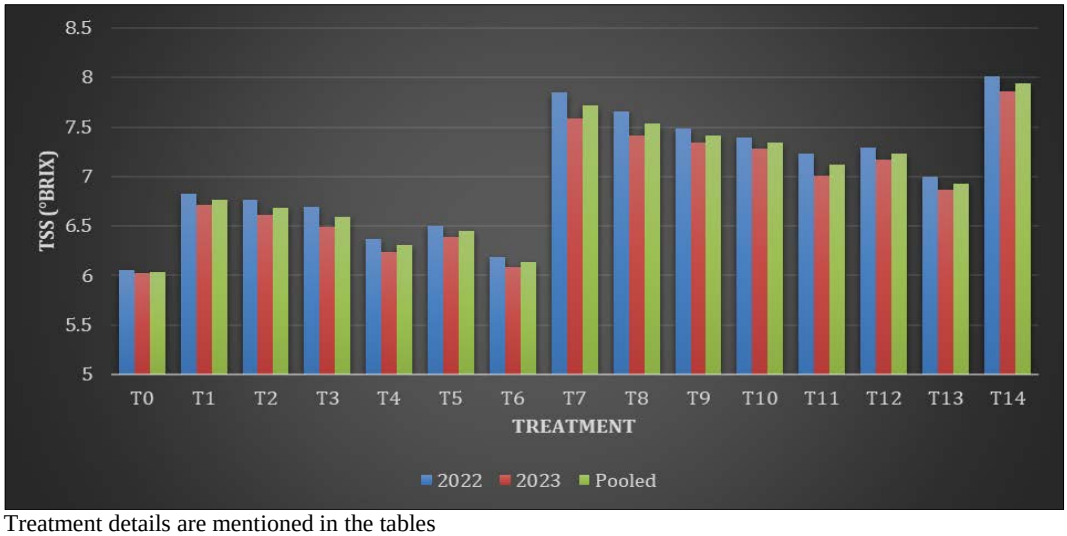
3.1 Quality parameters

According to the pooled analysis data related to total soluble solids shows that the maximum (7.94 °Brix) in the T_{14} treatment which was found at par with treatment T_7 (7.54 °Brix). However, the minimum total soluble solids (6.03 °Brix) were observed in the T_0-Control. While results of ascorbic acid shows that the maximum (147.82 mg $100g^{-1}$) in the T_{14} treatment and at par with treatment T_7 (141.93 mg $100g^{-1}$). While, the minimum ascorbic acid (122.97 mg $100g^{-1}$) was recorded in the T_0-Control. Similarly, the pooled data related to acidity shows that the minimum (4.89%) in the T_{14} treatment and it was found at par with treatment T_7 (5.00%). However, the maximum acidity (6.01%) was observed in the T_0-Control.

The combined application of bio capsule and micronutrients might have led to balance C:N ratio which resulted in satisfactory nutrient availability and increased plant metabolism, which ultimately lead to increased carbohydrate accumulation in fruit as a result TSS and ascorbic acid increased. Bio capsule supplied adequate level of nutrients because of Bio capsule prevent the leaching of nutrient and fixed the nutrient for plant growth. Thus, synthesized carbohydrates translocated to the fruits, which ultimately increased the total soluble solids of the fruit. A similar finding was given by Chiou *et al*., (2014) [14] in capsicum, Gadalla *et al*. (2020) [15] in chilli, Thriveni *et al*., (2015) [16] in bitter gourd and Das *et al*., (2015) [17] in bottle gourd, Jaipaul *et al*., (2011) [5]. Kumar *et al*., (2016) [7], Naik MR (2018) [10].

Table 1: Effect of micronutrients and bio-capsule on TSS (°Brix) of capsicum under protected conditions during 2022-23 and 2023-24 (Pooled Data)

Treatment combination	TSS (°Brix)		
	2022-23	2023-24	Pooled
T_0-Control	6.05	6.02	6.03
T_1-Boric acid 100 ppm (0.571 g/l)	6.83	6.71	6.77
T_2-Zinc sulphate 100 ppm (0.246g/l)	6.76	6.61	6.68
T_3-Ammonium molybdate 50 ppm (0.644g/l)	6.69	6.49	6.59
T_4-Copper sulphate 100 ppm (0.52 g/l)	6.37	6.24	6.31
T_5-Ferrous sulphate 100 ppm (0.515 g/l)	6.50	6.39	6.45
T_6-Manganese sulphate 100 ppm (0.32 g /l)	6.19	6.09	6.14
T_7-Mixture of all	7.85	7.59	7.72
T_8-Boric acid 100 ppm (0.571 g/l) with bio- capsule	7.66	7.41	7.54
T_9-Zinc sulphate 100 ppm (0.246g/l) with bio- capsule	7.48	7.34	7.41
T_{10}-Ammonium molybdate 50 ppm (0.644g/l) with bio- capsule	7.39	7.28	7.34
T_{11}-Copper sulphate 100 ppm (0.52 g/l) with bio- capsule	7.23	7.01	7.12
T_{12}-Ferrous sulphate 100 ppm (0.515 g/l) with bio- capsule	7.29	7.17	7.23
T_{13}-Manganese sulphate 100 ppm (0.32 g /l) with bio- capsule	7.00	6.87	6.93
T_{14}-Mixture of all micronutrient with bio- capsule	8.01	7.86	7.94
F - test	S	S	S
S.Em±	0.18	0.18	0.11
CD at 5%	0.51	0.52	0.33
CV %	4.40	4.56	2.84

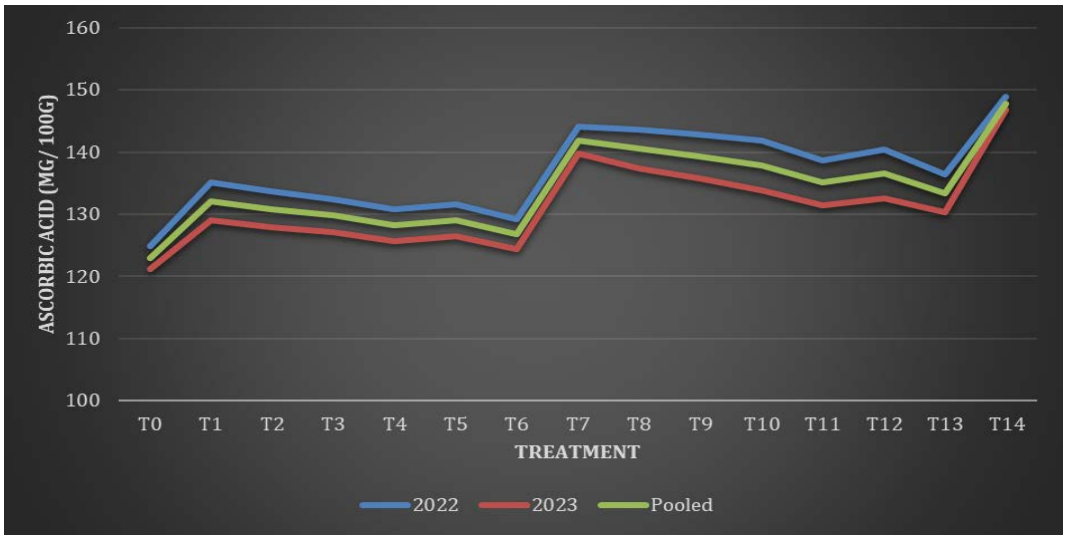


Treatment details are mentioned in the tables

Fig 1: Effect of micro nutrients and bio - capsule on TSS (°Brix) of capsicum under protected conditions during 2022-23 and 2023-24 (Pooled Data)

Table 2: Effect of micro nutrients and bio - capsule on Ascorbic acid (mg/100 g) of capsicum under protected conditions during 2022-23 and 2023-24 (Pooled Data)

Treatment combination	Ascorbic acid (mg/ 100g)		
	2022-23	2023-24	Pooled
T_0-Control	124.83	121.12	122.97
T_1-Boric acid 100 ppm (0.571 g/l)	135.17	129.10	132.13
T_2-Zinc sulphate 100 ppm (0.246g/l)	133.69	127.90	130.80
T_3-Ammonium Molybdate 50 ppm (0.644g/l)	132.42	127.16	129.79
T_4-Copper sulphate100 ppm (0.52 g/l)	130.72	125.67	128.20
T_5-Ferrous sulphate 100 ppm (0.515 g/l)	131.52	126.54	129.03
T_6-Manganese sulphate 100 ppm (0.32 g /l)	129.24	124.34	126.79
T_7-Mixture of all	144.10	139.75	141.93
T_8-Boric acid 100 ppm (0.571 g/l) with bio- capsule	143.66	137.43	140.55
T_9-Zinc sulphate 100 ppm (0.246g/l) with bio- capsule	142.84	135.69	139.27
T_{10}-Ammonium Molybdate 50 ppm (0.644g/l) with bio- capsule	141.81	133.88	137.85
T_{11}-Copper sulphate100 ppm (0.52 g/l) with bio- capsule	138.69	131.45	135.07
T_{12}-Ferrous sulphate 100 ppm (0.515 g/l) with bio- capsule	140.44	132.54	136.49
T_{13}-Manganese sulphate 100 ppm (0.32 g /l) with bio-capsule	136.33	130.30	133.31
T_{14}-Mixture of all with bio-capsule	148.87	146.76	147.82
F - test	S	S	S
S.Em±	2.02	3.78	2.15
CD at 5%	5.84	10.92	6.21
CV %	2.56	4.99	2.78

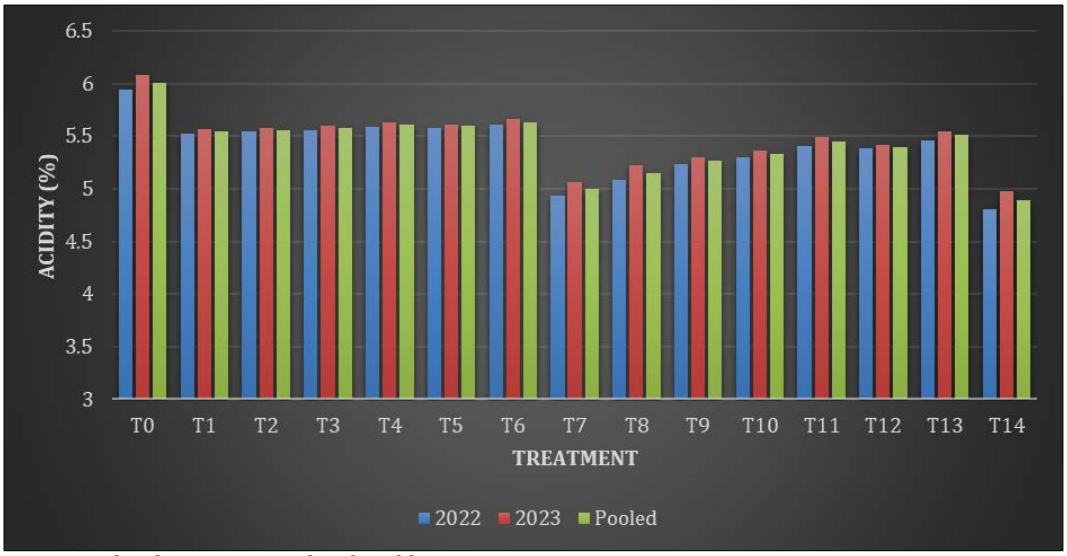


Treatment details are mentioned in the tables

Fig 2: Effect of micro nutrients and bio - capsule on Ascorbic acid (mg/100 g) of capsicum under protected conditions during 2022-23 and 2023-24 (Pooled Data)

Table 3: Effect of micro nutrients and bio - capsule on Acidity (%) of capsicum under protected conditions during 2022-23 and 2023-24 (Pooled Data)

Treatment combination	Acidity (%)		
	2022-23	2023-24	Pooled
T_0-Control	5.94	6.08	6.01
T_1-Boric acid 100 ppm (0.571 g/l)	5.52	5.57	5.54
T_2-Zinc sulphate 100 ppm (0.246g/l)	5.54	5.58	5.56
T_3-Ammonium Molybdate 50 ppm (0.644g/l)	5.56	5.60	5.58
T_4-Copper sulphate100 ppm (0.52 g/l)	5.59	5.63	5.61
T_5-Ferrous sulphate 100 ppm (0.515 g/l)	5.58	5.61	5.60
T_6-Manganese sulphate 100 ppm (0.32 g /l)	5.61	5.66	5.63
T_7-Mixture of all	4.93	5.06	5.00
T_8-Boric acid 100 ppm (0.571 g/l) with bio- capsule	5.08	5.22	5.15
T_9-Zinc sulphate 100 ppm (0.246g/l) with bio- capsule	5.23	5.30	5.27
T_{10}-Ammonium Molybdate 50 ppm (0.644g/l) with bio- capsule	5.30	5.36	5.33
T_{11}-Copper sulphate100 ppm (0.52 g/l) with bio- capsule	5.41	5.49	5.45
T_{12}-Ferrous sulphate 100 ppm (0.515 g/l) with bio- capsule	5.38	5.42	5.40
T_{13}-Manganese sulphate 100 ppm (0.32 g /l) with bio- capsule	5.46	5.55	5.51
T_{14}-Mixture of all with bio- capsule	4.81	4.98	4.89
F - test	S	S	S
S.Em±	0.14	0.11	0.09
CD at 5%	0.41	0.31	0.25
CV %	4.56	3.34	2.73



Treatment details are mentioned in the tables

Fig 3: Effect of micro nutrients and bio - capsule on Acidity (%) of capsicum under protected conditions during 2022-23 and 2023-24 (Pooled Data)

4. Conclusion

The research findings clearly demonstrate that the combination of micronutrients along with bio-capsules resulted in superior quality capsicum under protected conditions. Therefore, we recommend that farmers engaged in protected cultivation opt for this combination for large-scale production.

5. Acknowledgement

The authors express sincere gratitude to the Department of Horticulture at Sam Higginbottom University of Agriculture, Technology & Sciences in Prayagraj (Uttar Pradesh), India, for their invaluable assistance. Special appreciation is extended to both the teaching and non-teaching staff for their support and contributions to this study.

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