SMART-DOSE MICROBOOST: MICRONUTRIENT IN ORDER TO ENHANCE CHILI GROWTH AND YIELD IN TROPICAL FARMING SYSTEMS

SMART-DOSE MICROBOOST: MIKRONUTRIEN UNTUK MENINGKATKAN PERTUMBUHAN DAN HASIL CABAI PADA SISTEM PERTANIAN TROPIS

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ABSTRACT

Despite the fact that micronutrients are crucial for the growth, metabolism, and crop yield of plants, they are required in relatively small proportions. The recent advancements in agriculture have resulted in the development of biostimulant products that are abundant in micronutrients which is advantageous. The objective of this investigation was to evaluate the potential of micronutrient-enriched biostimulants (MB) to enhance the quality characteristics of chili fruits. This study was conducted at Jatinangor, West Java. The experimental plots were laid out in a Randomized Block Design (RBD) with seven treatments and repeated four times, so the total number of treatments was 28 units. The treatments consist of farmer practice and doses of 0.75; 1.0; 1.5; 2.0; 2.5 and 3.0 L ha^{-1} MB. The results of this experiment indicated that the treatments with doses of 2.0–3.0 L ha^{-1} were consistently preferable in terms of fruit quality, yield, and growth. Plants that were more productive, capable of grading fruit, and had a slightly extended shelf life after harvest were the final result of the biostimulant product, which contained micronutrients. The farmer's practice consistently failed to meet the standards of all the treated sites. The combination of biostimulants and micronutrients significantly enhanced the physiological and reproductive functions of chilies.

Key words: Biostimulant, Chili, Sustainability, Productivity

ABSTRAK

Mikronutrien, meskipun dibutuhkan dalam jumlah yang kecil daripada makronutrien, penting untuk perkembangan tanaman, fungsi metabolisme, dan produktivitas tanaman. Perkembangan terkini dalam bidang pertanian telah menghasilkan produk biostimulan yang kaya akan mikronutrien yang sangat penting. Tujuan dari penelitian ini adalah untuk menilai potensi biostimulan yang diperkaya mikronutrien (MB) dalam meningkatkan kualitas buah cabai. Panelitian ini dilakukan di Jatinangor Sumedang, Jawa Barat. Plot percobaan disusun dalam

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Rancangan Acak kelompok (RAK) dengan tujuh perlakuan dan diulang empat kali, sehingga total perlakuan adalah 28 unit. Perlakuan tersebut terdiri dari metode konvensional; dosis biostimulan yang diperkaya mikronutrien (0,75; 1,0; 1.5; 2,0; 2,5 and 3,0 L ha^{-1} MB). Hasil percobaan ini menunjukkan bahwa perlakuan dengan dosis 2,0–3,0 L ha^{-1} adalah yang paling konsisten unggul di seluruh parameter pertumbuhan, hasil dan kualitas buah. Produk biostimulan dengan tambahan mikronutrien membuat tanaman lebih kuat, lebih produktif, lebih baik dalam kualitas buah, dan memperpanjang masa simpan setelah panen. Dibandingkan dengan semua yang diberi perlakuan pupuk mikronutrien dan biostimulan, perlakuan konvensional memberikan respon yang paling kecil. Secara umum, penambahan mikronutrien dan biostimulan secara bersamaan dapat memberikan dampak besar pada peningkatan fungsi fisiologis dan reproduksi tanaman cabai.

Kata kunci: Biostimulan, Cabai, Keberlanjutan, Produktivitas

INTRODUCTION

Chili (*Capsicum spp.*) is one of Indonesia's most important horticulture crops since it is high economic value and widely used in traditional cuisine. Chili is a frequent spice in Indonesian homes because they utilise it in so many different ways. The national demand for chili remains high, in accordance with population expansion. The average annual consumption of chili per capita in Indonesia is 124 kg, with a population of 270 million (Badan Pusat Statistik, 2022). In order to grow more chili in an environmentally friendly manner, it is crucial to investigate methods of enhancing nutrient management, such as the combination of biostimulants and micronutrients. These concepts have the potential to facilitate the utilisation of nutrients by plants by preventing them from detecting hunger. Additionally, they can assist producers in producing more and superior crops in a variety of weather conditions.

Chili (*Capsicum spp.*) is a substantial horticultural product for the economy and culture of Indonesia, as it is a fixture of Indonesian cuisine. Despite the year-round high demand for their product, chili growers struggle to produce it (Badan Pusat Statistik, 2022). Low yields, poor fruit quality, pests and diseases, declining soil productivity, and fluctuating weather are just a few of the issues facing Indonesia's chili crops (Sudarma et al., 2024). Conventional farming frequently employs a lot of macronutrient fertilizer (NPK), but it rarely uses or gives adequate consideration to micronutrients (Chávez-mejía et al., 2019). Lack of certain micronutrients, particularly zinc (Zn), boron (B), molybdenum (Mo) and iron (Fe), has been linked to poorer growth in plants, flowers, and fruits (Hamzah Saleem et al., 2022). Based on the results of the study, the application of B and Mg at 100 ppm was effective in improving the product yield and plant growth of chili (Harris et al., 2018)

The conditions of the soil and environment make it difficult for plants to obtain the nutrients they require. In the field, some techniques that only employ one or a small number of micronutrient treatments have been successful, but not always. Many studies have been conducted on how to add specific micronutrients or enhance general fertilizer (Kumar et al., 2024). Few significant field studies have examined simultaneous handling of micronutrients and biostimulant approaches (Halpern et al., 2015). Additionally, the majority of solutions are ineffective in enhancing both growth and quality postharvest in the actual tropical agricultural environment (Khaitov et al., 2019). This study illustrates an approach for enhancing the quality, productivity, and growth of chili fruit. By employing a biostimulant that contains additional micronutrients, it achieves this. It combines compounds that aid in the development of plants with critical micronutrients that aid in the absorption of nutrients and the management of stress. In the past, these topics were not sufficiently addressed. The objective of this investigation was to determine whether micronutrient-enriched biostimulants could enhance the quality of chili fruits and provide a beneficial mechanism for plant growth.

MATERIALS AND METHODS

This research was conducted from may to October 2023 in an open field in Jatinangor, Sumedang, West Java. There were seven treatments applied in the experimental plots, and each one was replicated four times, resulting in a total of 28 experimental units. The treatments consisted of MB doses of 0.75; 1.0; 1.5; 2.0; 2.5 and 3.0 L ha^{-1}, as well as farmer practice. All the treatments combined with the application anorganic fertilizers based on local farmer practice for tomato cultivation (20 t ha^{-1} organic fertilizer; Urea 150 kg ha^{-1}; ZA 300 kg ha^{-1}; TSP 200 kg ha^{-1} and KCl 200 kg ha^{-1}). The parameters observed were productivity and yield (number of flowers per plant, number of fruits developed per plant, early harvested fruits per plant, number of harvested fruits per plant, weight of harvested fruits per plant, yield (total weight of harvested fruits per plot), number/frequency of harvest (Mahmud et al., 2020; Rahman et al., 2020). Observations on plant vigor and some production and yield parameters were carried out at 10-day intervals. The sample for analysis consisted of five plants per plot experiments that were observed and analyzed periodically. All data of yield was subjected to analysis of variance at $p \leq 0.05$ to determine the significance of treatment effect on parameters. If the analysis of variance had a significant effect on parameter, then the Duncan's Multiple Range Test (DMRT) at $p \leq 0.05$ was performed. Data processing was performed by using SPSS 17.0 software.

RESULTS AND DISCUSSION

Plant Growth Parameters

Based on Table 1, plant height at all observation dates 35 to 65 Day After Treatment (DAT) was significantly impacted by the use of biostimulants with additional micronutrients. Particularly at 65 DAT, the tallest plants were those that received 2.5 L ha^{-1}. Compared to other dosages and the farmer's methods, this was higher. According to (Tanveer et al., 2023), biostimulants containing micronutrients like zinc and iron cause cells to lengthen and photosynthesis to occur more quickly, which results in taller plants. According to research by (Cardarelli et al., 2023), the use of biostimulants also increases auxin synthesis, which lengthens the shoots of chili plants. All treatments showed an increase in canopy diameter (Table 2) over time, but the 2.0–2.5 L ha^{-1} treatments showed the largest expansion. More space for photosynthesis and general plant health are indicated by a wider canopy. Optimal canopy growth is essential to ensure efficient light capture by plants, thereby supporting the photosynthesis process. According to (Noli et al., 2023), biostimulants containing micronutrients aid in the production of more chlorophyll and the enlargement of leaves.

Micronutrients such as magnesium and manganese are crucial cofactors in the synthesis of chlorophyll and contribute to the improved appearance of the canopy (Cakmak et al., 2023).

Compared to the control and lower dosages, the 2.5 and 3.0 L ha^{-1} treatments had significantly more branches at 65 DAT (Table 3). Because more branches typically equate to more space for flowers and fruit to grow, this factor is crucial. Branching frequently occurs as a result of increased cytokinin activity and nutrition availability. Biostimulants enhance signalling from the roots to the shoots, promoting branching and bud growth (Ogunsanya et al., 2022). According to a study by Halpern (et al., 2015) biostimulants containing micronutrients increase biomass and branching in vegetable crops by facilitating nutrient uptake and maintaining hormone balance. The micronutrients also give the same effect on vegetables plant such as chili (Harris et al., 2018).

All three graphs demonstrate that biostimulants containing micronutrients significantly enhance the growth of chili plants, particularly at 2.5 L ha^{-1}. The plants grew taller as a result of hormonal and nutritional stimulation. More open canopy design to promote more photosynthesis more branches could result in increased output (Amanah et al., 2022). These findings are consistent with other research showing that biostimulants cooperate to increase the efficiency of nutrients and promote vegetative growth. This implies that they can be applied as a long-term strategy to enhance chili crop performance.

Table 1. The Effect of Micronutrients-Enriched Biostimulants on Plant Heigh

Plant Heigh (cm)				
Treatments	35 DAT	45 DAT	55 DAT	65 DAT
Farmer Practices	34.67 a	44.75 a	55.71 a	58.75 a
0.75 L ha^{-1}	36.23 a	49.85 a	60.33 ab	61.40 a
1.0 L ha^{-1}	32.52 a	43.90 a	57.40 ab	57.51 a
1.5 L ha^{-1}	35.48 a	45.96 a	60.96 ab	61.97 a
2.0 L ha^{-1}	34.67 a	49.68 a	61.98 b	61.55 a
2.5 L ha^{-1}	34.71 a	48.63 a	61.71 b	63.80 a
3.0 L ha^{-1}	35.79 a	49.85 a	59.21 ab	61.95 a

Explanation: Numbers followed by the same small letters on the same line and capital letters in the same column show no real difference based on DMRT of 5%.

Table 2. The Effect of Micronutrients-Enriched Biostimulants on Canopy Appreance

Canopy Appreance (cm)				
Treatments	35 DAT	45 DAT	55 DAT	65 DAT
Farmer Practices	22.73 a	30.11 a	34.43 a	38.93 a
0.75 L ha^{-1}	25.29 a	32.23 a	35.34 a	44.64 b
1.0 L ha^{-1}	23.15 a	28.67 a	33.21 a	42.97 ab
1.5 L ha^{-1}	22.04 a	30.24 a	32.98 a	41.16 ab
2.0 L ha^{-1}	25.28 a	31.47 a	34.97 a	42.76 ab
2.5 L ha^{-1}	21.90 a	29.63 a	33.63 a	43.04 ab
3.0 L ha^{-1}	24.23 a	31.15 a	34.79 a	42.18 ab

Explanation: Numbers followed by the same small letters on the same line and capital letters in the same column show no real difference based on DMRT of 5%.

Table 3. The Effect of Micronutrients-Enriched Biostimulants on Number of Branch

	Number of Brunch			
Treatments	35 DAT	45 DAT	55 DAT	65 DAT
Farmer Practices	1.71 a	3.96 a	14.67 a	44.33 a
0.75 L ha^{-1}	1.75 a	4.90 a	16.19 a	45.58 a
1.0 L ha^{-1}	1.63 a	4.04 a	14.58 a	45.21 a
1.5 L ha^{-1}	1.48 a	4.14 a	15.02 a	53.83 ab
2.0 L ha^{-1}	1.75 a	5.42 a	16.15 a	59.17 ab
2.5 L ha^{-1}	1.79 a	4.78 a	14.25 a	63.56 b
3.0 L ha^{-1}	1.81 a	5.38 a	15.75 a	56.44 ab

Explanation: Numbers followed by the same small letters on the same line and capital letters in the same column show no real difference based on DMRT of 5%.

PRODUCTIVITY AND YIELD

The use of biostimulants increased the quantity of flowers as well (Table 5). 2.0 L ha^{-1} produced the most flowers at 65 DAT, followed by 0.75 and 1.5 L ha^{-1}. According to these findings, moderate application rates promote flower growth, most likely as a result of their ability to increase nutrient uptake and improve stress tolerance in plants (Wang et al., 2023). Micronutrients like zinc and boron are well known to be critical for reproductive processes like pollen survival and flower production (Hamzah Saleem et al., 2022).

It took 97 days to reach the first harvest for all treatments except farmer practices, 1.5, and 2.5 L ha^{-1} (Graph 1). Additionally, the frequency of crop harvests increased with higher dosages, peaking at 17 times for 2.0 and 3.0 L ha^{-1}. These findings demonstrate that biostimulants lengthen the fruiting period and accelerate plant growth. According to (Vasanthkumar, 2025) by accelerating the vegetative and reproductive stages of growth, biostimulants with micronutrients, particularly at 2.0 L ha^{-1}, cause chili plants to produce more branches, flowers, and fruits. These enhancements support their potential importance in sustainable chili production by facilitating earlier and more frequent harvests.

The Table 6 illustrates three crucial yield indicators such as the total amount of fruit per plot, the weight of each fruit, and the number of fruits on each plant. The application of biostimulants containing micronutrients at concentrations of 0.75 to 3.0 L ha^{-1} significantly enhanced all yield indicators in comparison to conventional farming practices. At a rate of 3.0 L ha^{-1}, the fruit count per plant increased 14.54%. This suggests that fruit development and flowers were more effective. According to Colla et al. (2017), it was found that biostimulants and micronutrients improve reproduction better by making it easier for nutrients to move around and hormones to stay in check. It was seen that a greater number of assimilations were being transferred to fruit biomass as the weight of fruit per plant increased 14.86%.

According to (Paciolla et al., 2019), the bioavailability of vitamins accelerates fruit growth by enhancing enzyme activity and increasing chlorophyll production.The total yield per plot increased significantly, from 14.7 kg in the farmer practices group to 17.9 kg (Table 6) in the group that received the most effective treatment. This demonstrates that biostimulants function as metabolic enhancers in the field, thereby facilitating the more uniform development of crops. This proves that biostimulants act in the field as metabolic enhancers, which helps crops develop more evenly (du Jardin, 2015). In summary, the application of biostimulants at a rate of 2.0 to 3.0 L ha^{-1} results in a significant increase in the productivity of chili plants with the addition of additional micronutrients. They generate a greater quantity of fruit, which is larger in size, and a greater overall output. By incorporating them into your routine agricultural practices, may be able to produce larger crops in a cost-effective and long-lasting manner.

FRUIT QUALITY

Compared to what the farmer typically does, the data in Table 7 demonstrate that the use of biostimulants with additional micronutrients significantly improves a number of fruit quality characteristics, including the size, length, diameter, and thickness of the pericarp. The best size uniformity was achieved by the 3.0 L ha^{-1} treatment (122.93%), which was significantly better than the control (100%). Improved size homogeneity is crucial for processing and sale. Fruit cell division and expansion can be altered by biostimulants rich in micronutrients, particularly zinc, boron, and iron, which can result in more consistent growth patterns (Ahmed et al., 2024). Additionally, improved nutrient absorption aids in the regulation of hormones such as auxins and cytokinins, promoting balanced fruit growth (Sosnowski et al., 2023). All treatments varied between 13.59 to 14.22 cm, whereas the farmer's approach (11.18 cm) was the least effective. The extended fruit length aligns with prior research indicating that the incorporation of micronutrients improved photosynthesis and nutrient allocation to fruit organs (Ahmed et al., 2024). Fruit set and growth are directly impacted by nutrients like boron, which are known to help pollen survive and cells grow longer (Luxmi et al., 2024). Molybdenum (Mo) also essential for the quality of fruit by affecting numerous aspects of plant physiology and metabolism. The size, sweetness, and overall quality of the fruit are ultimately influenced by the development of essential flavour and aroma compounds, nutrient uptake, and photosynthesis (Cardarelli et al., 2023).

The fruit's size followed the same pattern, increasing 16% after biostimulant treatments. This substantiates the notion that micronutrients enhance vascular function and promote nutrition transport to developing fruits, hence reinforcing sink strength (Ahmed et al., 2024). The fruit's hardness and shelf life are directly correlated with the thickness of the pericarp. This measurement increased 18% after biostimulant treatments. The presence of calcium and boron, which are essential for the development of cell walls and membranes, could be the cause of the thickness increase. Moreover, fruit cultivated with biostimulants abundant in micronutrients exhibits enhanced size uniformity, dimensions, and structural integrity. These findings align with recent research demonstrating the advantageous agronomic impacts of biostimulants, particularly those enriched with micronutrients that enhance crop performance and nutrient efficiency.
(Chávez-mejía et al., 2019).

Graph 2 illustrates the impact of varying quantities of micronutrient-rich biostimulants on the duration of chili damage (perishability) and the latency period before the damage becomes apparent. According to observations, harm commences 2.75 days post-treatment. Treatments with higher concentrations (2.5 and 3.0 L ha^{-1}) postponed obvious damage for as long as 3.5 days. Biostimulants significantly increased the shelf life of the fruit. The 3.0 L ha^{-1} treatment exhibited an extended duration, increasing from 5.0 days under farmer practice to 6.0 days. That is, fruits that contain biostimulants and micronutrients have an extended shelf life after they are harvested. This is likely accomplished by strengthening the cell walls, preventing the fruit from losing water, and inhibiting the proliferation of microbes. These effects are confirmed by research conducted by (Ahmed et al., 2024).

The morphological state of chili fruits is altered as time progresses, as illustrated in Figure 1. The fruits in the upper row deteriorated at an accelerated rate due to their shrivelling, wrinkling, and loss of colour. This is likely due to the fact that the farmers treat them with respect and used lower doses. This is likely due to the high-dose treatments, as the epidermis in the bottom row had firmer, smoother, and shinier epidermis, which suggested that the high-dose treatments helped maintain fruit health for a longer period and slowed down the ageing process.

These visual observations are a strong complement to the quantitative trends in Graph 2, which demonstrate that chili fruits remain fresh for an extended period of time after they are harvested as the dose of micronutrient-enriched biostimulants increases. According to research, biostimulants enhance the antioxidant activity and reinforce the cells of plants after they are harvested, thereby promoting their overall health (Di Sario et al., 2025). Both the graph and the picture indicate that biostimulant treatments, particularly those administered at 2.5–3.0 L ha^{-1}, may delay the onset and progression of harm to chili fruit, thereby increasing their shelf life and market value.

Table 4. The Effect of Micronutrients-Enriched Biostimulants on Fruit Development per Plant

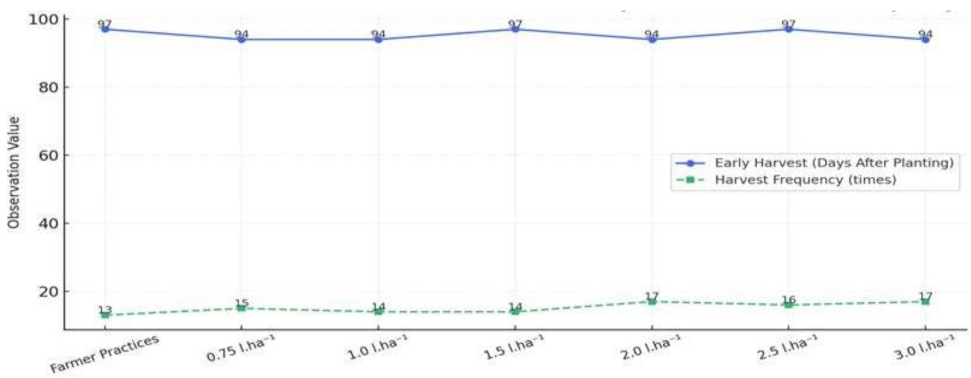
Treatments	Average Number of Fruit Developed per Plant			
	35 DAT	45 DAT	55 DAT	65 DAT
Farmer Practices	0.25 a	2.43 a	8.08 a	11.10 ab
0.75 L ha^{-1}	0.25 a	3.55 a	8.23 a	14.80 ab
1.0 L ha^{-1}	0.25 a	2.06 a	6.95 a	11.91 ab
1.5 L ha^{-1}	0.25 a	2.55 a	6.07 a	14.80 ab
2.0 L ha^{-1}	0.55 a	5.10 a	11.57 a	19.95 b
2.5 L ha^{-1}	0.25 a	2.85 a	8.58 a	12.19 ab
3.0 L ha^{-1}	0.25 a	3.04 a	8.08 a	8.24 a

Explanation: Numbers followed by the same small letters on the same line and capital letters in the same column show no real difference based on DMRT of 5%.

Table 5. The Effect of Micronutrients-Enriched Biostimulants on Number of Flowers

	Number of Flower per Plant			
Treatments	35 DAT	45 DAT	55 DAT	65 DAT
Farmer Practices	2.60 a	4.45 a	7.95 a	6.75 a
0.75 L ha^{-1}	3.05 a	4.90 a	8.20 a	11.60 ab
1.0 L ha^{-1}	1.50 a	2.88 a	5.32 a	6.19 a
1.5 L ha^{-1}	2.25 a	4.14 a	6.95 a	9.95 ab
2.0 L ha^{-1}	2.55 a	6.25 a	10.94 a	12.35 b
2.5 L ha^{-1}	2.63 a	4.70 a	7.35 a	7.48 ab
3.0 L ha^{-1}	3.10 a	4.70 a	8.00 a	6.35 a

Explanation: Numbers followed by the same small letters on the same line and capital letters in the same column show no real difference based on DMRT of 5%.



Graph 1. The Effect of Micronutrients-Enriched Biostimulants on Early harvest and Harvest Frequency

Table 6. The effect of micronutrients-enriched biostimulants on Yield Parameters

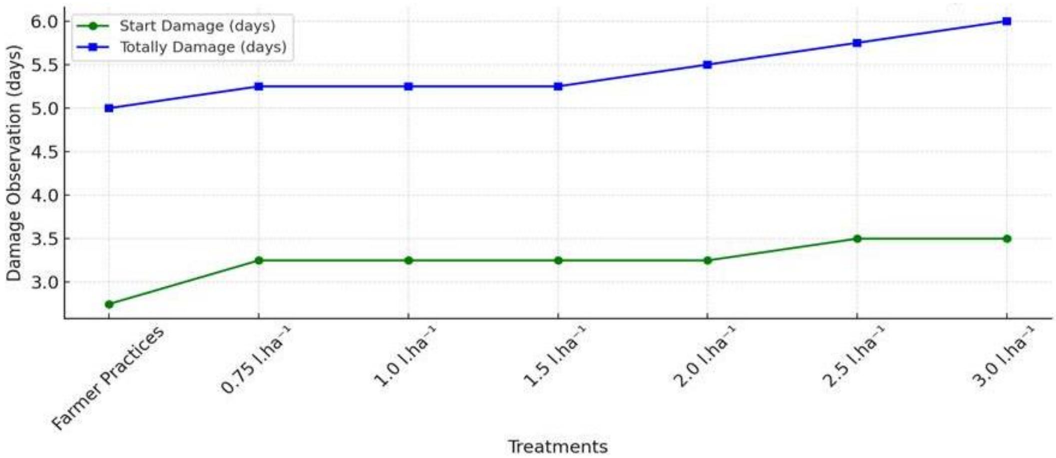
Treatments	Number of Fruit per Plant	Weight of Fruit per Plant (g)	Total Weight of Fruit per Plot) (Kg)
Farmer Practices	55.0375 a	719.90 a	14.70 a
0.75 L ha^{-1}	59.1375 b	783.68 b	15.78 ab
1.0 L ha^{-1}	61.6125 bc	810.30 bc	16.69 ab
1.5 L ha^{-1}	62.0875 c	819.49 bc	16.73 bc
2.0 L ha^{-1}	62.675 c	826.53 c	17.80 c
2.5 L ha^{-1}	62.7375 c	825.18 c	17.88 c
3.0 L ha^{-1}	63.0125 c	826.94 c	17.91 c

Explanation: Numbers followed by the same small letters on the same line and capital letters in the same column show no real difference based on DMRT of 5%.

Table 7. The effect of micronutrients-enriched biostimulants on Fruit Quality

Treatments	Size Unformity (%)	Length (cm)	Diameter (mm)	Thickness (mm)
Farmer Practices	100.00 a	11.18 a	12.33 a	1.70 a
0.75 L ha^{-1}	112.22 b	13.80 b	13.98 b	1.96 b
1.0 L ha^{-1}	113.10 b	13.68 b	13.90 b	1.98 b
1.5 L ha^{-1}	114.52 c	13.59 b	13.94 b	2.00 b
2.0 L ha^{-1}	122.16 d	14.20 b	14.33 b	1.97 b
2.5 L ha^{-1}	122.84 d	14.16 b	14.32 b	1.99 b
3.0 L ha^{-1}	122.93 d	14.22 b	14.35 b	2.02 b

Explanation: Numbers followed by the same small letters on the same line and capital letters in the same column show no real difference based on DMRT of 5%.



Graph 2. The Effect of Micronutrients-Enriched Biostimulants on Damage Observation

Figure 1. Analysis of Perishability

CONCLUSION

1. Micronutrient-enriched biostimulants significantly enhanced chili plant growth, including plant height, canopy appearance, number of branches, and flower development. The most notable improvements were observed at application rates of 2.0–2.5 L ha^{-1}, with earlier flowering and more fruits per plant compared to conventional farmer practices.
2. Fruit yield and quality improved substantially with increasing biostimulant doses. Treatments at 2.5–3.0 L ha^{-1} resulted in the highest number of fruits per plant, greater fruit weight, and good fruit characteristics such as longer length, thicker walls, larger diameter, and better size uniformity.
3. Postharvest performance also improved, with treated fruits showing reduced damage, delayed decay, and extended shelf life. The highest effectiveness in both yield and postharvest resilience was observed at 3.0 L ha^{-1}, indicating this dose as the most beneficial for maximizing productivity and market value.

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