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Impact of Biofertilizers and Micronutrients in Combination with NPK on Yield and Quality of Bottle Gourd (*Lagenaria siceraria*)

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ABSTRACT

This study was conducted at the experimental and production station of the National Research Centre in the El-Noubaria region of Beheira Governorate during the 2023 and 2024 growing seasons. The study examined the impact of biofertilizers and micronutrients on the yield and its attributes of bottle gourd plants. Three types of biofertilizers (nitrobin, microbin, and rizobactrin at a rate of 400g per feddan as soil dressing) and micronutrients (micromix) at two different rates (0.84 and 1.64 kg/fed. as foliar application with control) were used in the experiment. microbin, nitrobin, and rizobactrin are commonly used in Egypt as commercial bio-inoculants that aim to enhance soil fertility while reducing the environmental and financial costs associated with synthetic chemical fertilizers. The results indicated that using microbin biofertilizers significantly improved fruit length, fruit diameter, average fruit weight, and overall yield. The micromix application at a rate of 1.64 kg/fed. achieved the highest yield in both seasons. Additionally, the combined application of microbin and micromix at a rate of 1.64 kg/fed. resulted in the highest yield and fruit quality of bottle gourd. The application of biofertilizers and micronutrients enhanced the uptake of mineral fertilizers (N, P, K) and improved the quality of bottle gourd fruits by increasing total soluble solid, vitamin C, total carotenoid content and antioxidants.

Keywords: Bottle gourd, *Lagenaria siceraria*, biofertilizers, micronutrients, yield components, fruit quality, antioxidants, vitamin C.

1. Introduction

Bottle gourd (*Lagenaria siceraria*), a member of the Cucurbitaceae family, is an economically important vegetable crop widely cultivated in tropical and subtropical regions and originated from Africa (Chakravarty, 1982; Malathy *et al.,* 2025). Ghafoor *et al.* (2000) stated that the bottle gourd is a vigorous annual climbing vine widely cultivated in tropical and subtropical countries including India, Egypt, Japan, Thailand, and many others. According to Nagar *et al.* (2017) said that the fruit of bottle gourd is among the cheapest sources of nutrients and a potential source of natural antioxidants. It is consumed as a fresh vegetable in immature form and is used in the preparation of pickles, desserts, and other food products. Whereas Saeed *et al.* (2022) emphasized that the fruit is characterized by a high water content and low calorie value, making it a preferred choice for both culinary and medicinal applications. Nutritionally, bottle gourd is a good source of vitamin B complex and choline, along with fair amounts of vitamin C, minerals, proteins, sterols, flavonoids, and cucurbitacins (Tyagi *et al*., 2017; Mahapatra *et al*., 2023).

Naafe *et al.* (2022) and Hassan *et al.* (2008) found that a 100 g of bottle gourd fruit may contain traces of the following minerals: calcium (20 mg), iron (0.7 mg), and phosphorus (10 mg), as well as protein (2000 mg) and carbohydrates (2500 mg). Their seeds contain a great source of vitamins, sterols, antioxidants, important fatty acids, and vitamins A, C, and E. Ghule *et al.* (2007) mentioned that beyond its food value, the crop has long been an important component of indigenous herbal medicine, particularly in Asia, where it has been employed for its cardioprotective, cardiotonic, diuretic,

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hepatoprotective, antihypertensive, and analgesic properties. Additionally, bottle gourd serves as a valuable rootstock for watermelon grafting and its dried shells are fashioned into musical instruments and household utensils (Aasfar *et al*., 2021).

Biofertilizer such as microbin and nitrobin containing nitrogen-fixing bacteria (e.g., Rhizobium, Azotobacter, Azospirillum), phosphate-solubilizing bacteria (PSB; e.g., Bacillus, Pseudomonas), and potassium-mobilizing bacteria (e.g., *Bacillus mucilaginosus*), among others (Figie *et al*., 2025).

Biofertilizer is typically applied directly to seeds (seed inoculation) before sowing or applied directly to the soil to improve root zone microbial activity and stimulates growth by making more primary nutrients available to the host plant. The use of bio-fertilizer alone or combined with mineral fertilizers is one of the essential requirements for increasing the yield of vegetable crops (Mandloi *et al.,* 2022 and Rabari *et al.,* 2019). Rizobactrin is a biofertilizer formulation containing active Rhizobium bacteria, designed to enhance crop growth and yield through nitrogen fixation, particularly in leguminous crops. It acts as a soil inoculant to improve soil fertility sustainably, often reducing reliance on synthetic fertilizers. On the other hand, rizobactrin is a commercial biofertilizer formulation widely used in agricultural practices, particularly in Egypt, designed to enhance crop growth, nutrient uptake, and yield. It typically contains active strains of Rhizobium (for leguminous crops) or azotobacter/azospirillum (for non-leguminous crops), acting as nitrogen-fixing bacteria and plant growth-promoting rhizobacteria (PGPR). Recently, free-living bacteria (azotobacter and azospirillum), symbiotic (Rhizobium), and phosphate solubilizers (*Bacillus megaterium*, *B. polymyxa,* and *P. striata*) have become more popular as biofertilizers. Because of its inherent capacity to fix atmospheric nitrogen, azotobacter has gained acceptance as a viable substitute for chemical fertilizers (Bageshwar *et al*., 2017 and Subedi *et al*., 2019). Increasing yield and crop productivity have been achieved by dressing the soil and inoculating of seed with azotobacter through providing extra nitrogen to the crops (Arjun *et al*., 2015). The use of commercial biofertilizer products has expanded in recent years owing to their proven efficiency in boosting nutrient uptake and metabolic activity in various horticultural crops (Borah *et al.,* 2024). Previous studies on cucurbits have shown that microbial inoculation can markedly enhance vegetative vigor, flowering potential, and yield components, suggesting its potential as a promising alternative or supplement to mineral fertilizers (Sireesha and Singh, 2022). Biofertilizers also play an indirect role in improving micronutrient availability by maintaining soil pH in an optimal range and stimulating microbial processes that mobilize bound micronutrients (Khan *et al*., 2022).

Micronutrients, though required in relatively small quantities, are indispensable for numerous physiological and biochemical processes in plants. Zinc (Zn), boron (B), manganese (Mn), iron (Fe), copper (Cu), and molybdenum (Mo) are among the 17 essential plant nutrients, and their deficiency can impose significant limitations on crop growth and productivity (Hänsch and Mendel, 2009).

Micromix is a micronutrient containing Zinc (Zn), Manganese (Mn), Iron (Fe), and Copper (Cu). The use of leaves of zinc and boron has a beneficial role in improving the production and quality of plants due to their involvement as a stimulant of various enzymes and other active physical molecules (Alloway, 2018). Foliar application of micronutrients has been shown to significantly improve growth, yield, and quality attributes of vegetable crops. Zinc is a critical cofactor for many enzymes involved in carbohydrate metabolism, protein synthesis, and auxin production, and its deficiency is one of the most widespread micronutrient problems globally, affecting approximately 50% of the world's cereal soils (Ahmed *et al*., 2024). Boron is essential for cell wall formation, pollen viability, sugar transport, and fruit development, while its deficiency leads to impaired reproductive development and reduced fruit set (Brdar-Jokanović, 2020). Singh *et al*. (2025) demonstrates that the foliar application of micronutrients significantly influences the growth and yield attributes of bottle gourd. Kumar *et al*. (2024) stated that the foliar application of micronutrient formulations (including Zn, Fe, B, Cu, Mn, and Mo) significantly enhances the growth, yield, and quality of crops like cabbage, potato, and fruits by passing soil limitations, increasing nutrient uptake, and boosting physiological processes like photosynthesis.

Previous studies have shown that the application of micronutrient fertilizers enhances both the yield and quality of the produce (Shoormij *et al*., 2022). Although there are numerous methods for applying micronutrients in crop production, such as soil application, seed priming, foliar application, and side dressing, foliar application is the cheapest and fastest method (Shahzad *et al*., 2022). Studies have demonstrated that each crop has specific micronutrient requirements, which depend on various factors such as metabolic activities, root growth, and the presence of root-associated microorganisms (Graham, 2002).

The combined application of biofertilizers and micronutrients alongside recommended doses of NPK fertilizers represents a promising and scientifically sound approach to enhancing cucurbit crop productivity. Such integration is expected to improve nutrient use efficiency, reduce chemical fertilizer dependence, enhance soil biological activity, and boost both the yield and nutritional quality of fruits.

Research on related cucurbit and vegetable crops demonstrates consistent improvements in marketable yield, total soluble solids (TSS), dry matter content, protein concentration, and other quality parameters when biofertilizers are used in combination with reduced or full NPK doses compared to exclusive inorganic fertilization (Patel *et al*., 2021; Rathod *et al*., 2018). Besides, its leaves and seeds offer significant health benefits owing to their rich content of antioxidants, minerals, and bioactive compounds (Zahoor *et al*., 2021).

In light of the above considerations, the present study was undertaken to evaluate the effect of the application of biofertilizers and micronutrients (micromix) in combination with NPK fertilizers on fruit yield, and quality attributes of bottle gourd.

2. Materials and Methods

2.1. Location

Two field experiments were conducted during two consecutive summer seasons 2023 and 2024 at the Experimental and Production Station of National Research Centre, Beheira Governorate to study the effect of biofertelizers, micronutrients and their interaction with NPK on yield, quality and chemical composition of bottle gourd fruits grown in sandy soil under Egyptian conditions. Physical and chemical properties of the experimental soil were presented in Table (1).

Table 1: Chemical properties of the experimental soil

Samples (cm)	Chemical analysis						
	pH 1:2.5	EC dSm^{-1}	$CaCO^3$ %	CEC cmol Kg^{-1}			O.M %
0-15	7.65	1.15	3.20	5.12			0.05
15-30	7.42	1.12	2.81	4.53			0.03
Samples (cm)	**Macronutrients (%)**			**Micronutrients (ppm)**			
	N %	**P %**	**K %**	**Fe**	**Zn**	**Mn**	**Cu**
0-15	2.21	0.53	1.31	234	150	341	83
15-30	2.26	0.61	1.72	343	173	297	67

2.2. Plant materials and fertilization

Seeds local cultivar of bottle gourd were sown on the first of April during two growing seasons. The cultivation occurred with a distance of 1 meter between rows and 75cm between plants. The drip irrigation system was used. The commercial biofertilizers Microbin, Nitrobin, and Rizobactrin were produced by the General Authority of the Agricultural Budget Fund, which operates under the Ministry of Agriculture and Reclaimed Lands in Egypt. The bio-fertilizers Microbin, Nitrobin, and Rhizobacterin were applied as soil dressing at a rate of 400 grams per feddan. The first application was added after emergence and second application two weeks after the first.

The composition of Micromix, utilized as a source of micronutrients in this experiment, was as follows: Zinc (Zn) 5%, Manganese (Mn) 3%, Iron (Fe) 10%, and Copper (Cu) 3%. The Micromix was applied as a foliar treatment at rates of 0.84 and 1.68 kg/fed on the leaves, three times in total, beginning approximately two weeks after germination and continuing every two weeks thereafter.

Nitrogen was applied in the form of ammonium nitrate (33.5%) at a rate of 300 kg, potassium sulfate (48% K_2O) at a rate of 150 kg, and calcium superphosphate (15% P_2O_5) at a rate of 300 kg per fed. Calcium superphosphate was applied during soil preparation, while nitrogen and potassium were applied three times during growing season. The other agricultural practices were done according to the recommendation of Egyptian Ministry of Agriculture and Land Reclamation.

2.3. Treatments and experimental design:

The experimental design was split plot design with three replications. Biofertilizers were allocated randomly in the main plots and micronutrients foliar spraying treatments were allocated in the sup- plot. The size of each plot was 21m^2 3m long and 7m wide. Each experiment included 12 treatments which were the combination among four biofertilizers and four foliar spraying fertilizer treatments.

The experimental treatments can be described as follows:

A. Biofetilizers (soil dressing):
1: Control (recommended dose NPK)
2: Recommended dose NPK plus Nitrobin
3: Recommended dose NPK plus Microbin
4: Recommended dose NPK plus Rizobactrin

B. Micro Mix treatments (foliar spraying):
1: Control (without spraying)
2: 0.84 kg/ feddan
3: 1.64 kg/feddan

2.4. Measured characteristics
2.4.1. Fruit yield and quality

At harvest stage 10 fruits of bottle gourd were collected and the following data were recorded: average fruit weight (g), fruit length (cm), fruit diameter (cm) and total yield (ton/fed.) from each plot.

Nitrogen was determined using the micro-Kjeldahl method according to Jones and Benton (1991). Phosphorus was measured colorimetrically following the procedure outlined by Jackson (1973). Potassium was estimated using a flame photometer, as described by Brown and Lilleland (1964).

A random sample of 5 fruits were taken and the following data were recorded: A total soluble solids (TSS) in the fresh fruits sap was done using a hand refract meter (Cox and Pearson, 1962). Ascorbic acid (A.O.A.C., 1990), antioxidant activity (%) by Chance and Maehly (1955). Vitamin C contents (mg/100 gm f.w) and carotenoids (mg/100g) were determined in heads (fresh weigh basis) according to A.O.A.C. (1990).

2.5. Statistical analysis:

Statistical analysis was performed according to procedure outlined by Gomez and Gomez (1984). Treatment means were compared by L.S.D. test at 5% level.

3. Results and Discussion
3.1. Effect of Bioifertilizer

In Table 2, the addition of biofertilizers increased the length, diameter and weight of the fruit, as well as the total yield of bottle gourds in both seasons. The application of microbin was more effective than the control and other treatments in both seasons. This may be because the biofertilizer strains secrete substances that promote plant growth, particularly auxins (IAA), gibberellins and cytokinins. Biofertilizers also establish living microbial colonies in the rhizosphere that continuously fix atmospheric nitrogen, solubilise bound soil phosphorus and mobilise potassium. Furthermore, the enhanced phosphorus supply via biofertiliser inoculation enhances energy transfer, promoting abundant flowering, successful pollination and higher fruit retention rates per plant. This directly increases the total number of fruits and the overall yield.

In addition, rhizobacteria promote the growth of extensive lateral roots and root hairs. This expanded root architecture enables vines to draw higher volumes of water and macronutrients from deeper soil layers. This provides the necessary hydraulic pressure to maximise fresh weight and volume. These findings are consistent with the results of Shukla, and Prabhakar, (1987); Kumar *et al*. (2021); Chaudhary *et al*., (2022); Aljubouri and Aziz, (2024); Mehara *et al.* (2025); Tomar *et al.* (2024); Kavin *et al.* (2024); Figiel *et al*. (2025); Gahory *et al.* (2025).

Table 2: Effect of biofertilizers and micronutrient on yield and its attributes of bottle gourd plants during 2023and 2024 seasons.

Treatments		2023 Fruit length (cm)	2023 Fruit diameter (cm)	2023 Aver. Fruit weight (g)	2023 Total Yield (ton/Fed.)	2024 Fruit length (cm)	2024 Fruit diameter (cm)	2024 Aver. Fruit weight (g)	2024 Total Yield (ton/Fed.)
Bio fertilizers									
Control (NPK)		20.50	6.20	467	4.88	20.91	6.23	453	4.86
Nitrobin		25.77	6.86	539	5.32	27.30	7.17	536	5.33
Microbin		34.87	8.29	673	7.04	35.23	8.56	708	7.14
Rizobactrin		31.43	8.19	665	6.92	32.64	8.41	682	6.84
LSD at 5%		4.63	NS	46	0.22	3.57	NS	23	0.27
Micromix									
Control		25.73	6.91	532	5.37	26.49	6.95	541	5.52
0.84 kg/ feddan		28.45	7.39	598	6.14	29.65	7.58	613	6.16
1.64 kg/feddan		30.25	7.86	629	6.61	30.91	8.25	631	6.45
LSD at 5%		1.63	NS	27	0.41	NS	NS	12	0.19
Bio fertilizers X Micromix									
Control (NPK)	**Control**	17.52	5.50	411	4.03	17.69	5.30	407	3.96
	0.84 kg/ fed.	21.33	6.22	473	4.98	21.51	6.40	482	5.11
	1.64 kg/fed.	22.64	6.87	517	5.65	23.52	6.99	469	5.51
Nitrobin	**Control**	22.86	6.47	454	4.69	23.86	6.78	473	4.97
	0.84 kg/ fed.	26.12	6.99	570	5.48	28.84	7.17	550	5.35
	1.64 kg/fed.	28.32	7.12	592	5.80	29.21	7.57	584	5.67
Microbin	**Control**	33.09	7.85	632	6.41	33.51	7.89	645	6.61
	0.84 kg/ fed.	34.98	8.26	683	7.19	35.40	8.52	723	7.30
	1.64 kg/fed.	36.53	8.75	705	7.53	36.77	9.27	757	7.52
Rizobactrin	**Control**	29.44	7.81	629	6.36	30.92	7.83	640	6.53
	0.84 kg/ fed.	31.35	8.07	665	6.91	32.85	8.23	695	6.87
	1.64 kg/fed.	33.51	8.69	702	7.48	34.15	9.18	712	7.11
LSD at 5%		3.37	NS	38	0.53	2.71	1.12	26	0.55

3.2. Effect of Micronutrients

In the present investigation, applying micronutrients via foliar application at a rate of 1.64 kg per feddan significantly affected yield and its attributes, such as fruit length, diameter, and average weight. Similarly, increasing the concentration of micromix led to a significant increase in the average weight of the fruit and total yield. The treatment involving 1.64 kg per feddan produced the best results in both seasons. This may be due to the invigorating effect of individual micronutrients at different stages of physiological and biochemical processes. A similar trend was also observed by Shukla, and Prabhakar, (1987); Devi *et al*. (1999). Sarap *et al*. (2024); Mehara *et al*. (2025); Kavin *et al*. (2024); Soltan *et al*. (2025); Singh *et al*. (2025);

3.3. Effect of interaction

Table 2 showed that the adding biofertilizers and micromix greatly increased the yield and yield parameters of bottle gourd. As can be seen in Table 2, the most effective treatment was the use of microbin alongside high rates of micromix. The interaction between the biofertiliser and micronutrient produced the highest fruit weight and yield during the two growing seasons. Applying micromix at high rates with biofertiliser significantly improved the yield parameters of bottle gourd. These improvements may be due to enhanced enzymatic activity, a hormonal balance induced by micronutrients, and superior root function. These factors contribute to increased fruit development and biomass accumulation. This is in accordance with the findings of Shukla, and Prabhakar, (1987); Najafi *et al*. (2021); Aloo *et al*.

(2022); Sarap *et al*. (2024); Mehara *et al*. (2025); Kavin *et al*. (2024) Soltan *et al*. (2025); Singh *et al*. (2025);

3.2. Fruit Mineral Content (N, P and K)

3.2.1. Effect of Bioifertilizer

Application of biofertiliser as a soil dressing increases the nitrogen (N), phosphorus (P) and potassium(K) content of bottle gourd (*Lagenaria siceraria*) fruit (Table 3). The highest values were recorded with microbin application, followed by nitrobin, in both seasons. This may be due to the direct chemical conversion of soil nutrients, increased root system growth, and improved source-to-sink transport. Furthermore, biofertilizers such as nitrobin, microbin, and rizobactrin contain plant growth-promoting substances (such as auxins and gibberellins) that improve soil structure and aeration. This stimulates more extensive and finer root development, thereby increasing the root surface area available for absorbing water and dissolved nutrients (N, P and K) from the soil. Along with biofertilizers also boost overall microbial activity in the soil, aiding the decomposition of organic matter and the release of additional nutrients through natural mineralisation. This further enriches the pool of available nitrogen (N), phosphorus (P) and potassium (K). As these minerals become more soluble, available and accessible through increased nutrient release and improved root systems, the bottle gourd plant absorbs greater quantities of them through its roots and transports them to the growing fruit. This results in a higher mineral content in the harvested produce. This is in conformity with findings of Shukla, and Prabhakar, (1987); Chaudhary *et al*., (2022); Aljubouri and Aziz, (2024); Tomar *et al*. (2024); Kavin *et al*. (2024); Mehara *et al*. (2025); Gahory *et al*. (2025); Figiel *et al*. (2025); Kumar *et al*. (2021).

Table 3: Effect of biofertilizers and micronutrient on, N, P and K in fruits of bottle gourd plants during 2023and 2024 seasons.

Treatments		2023			2024		
		N%	P%	K%	N%	P%	K%
		Bio fertilizers					
Control (NPK)		1.67	0.34	2.75	1.65	0.31	2.45
Nitrobin		1.98	0.36	2.99	1.97	0.34	2.90
Microbin		2.11	0.39	3.13	2.04	0.37	3.12
Rizobactrin		1.64	0.34	2.70	1.63	0.33	2.51
LSD at 5%		0.11	NS	0.09	0.06	NS	0.15
		Micromix					
Control		1.74	0.34	2.77	1.68	0.32	2.61
0.84 kg/ fed.		1.85	0.36	2.89	1.84	0.33	2.75
1.64 kg/fed.		1.97	0.37	3.01	1.94	0.35	2.94
LSD at 5%		0.09	NS	0.10	0.09	NS	0.13
		Bio fertilizers X Micromix					
Nitrobin	**Control**	1.56	0.31	2.53	1.52	0.3	2.35
	0.84 kg/ fed.	1.59	0.32	2.69	1.56	0.31	2.45
	1.64 kg/fed.	1.62	0.34	2.71	1.61	0.33	2.48
Microbin	**Control**	1.68	0.34	2.75	1.7	0.3	2.54
	0.84 kg/ fed.	1.73	0.35	2.81	1.68	0.32	2.63
	1.64 kg/fed.	1.75	0.35	2.95	1.97	0.32	2.84
Rizobactrin	**Control**	1.83	0.36	2.85	1.78	0.35	2.69
	0.84 kg/ fed.	1.94	0.36	3.02	1.82	0.33	2.95
	1.64 kg/fed.	1.97	0.37	2.85	1.8	0.35	2.69
Nitrobin	**Control**	2.15	0.37	3.17	2.13	0.35	3.18
	0.84 kg/ fed.	2.17	0.39	3.15	2.1	0.38	3.15
	1.64 kg/fed.	2.21	0.41	3.22	2.19	0.41	3.26
LSD at 5%		0.06	1.56	0.31	2.53	1.52	0.3

3.2.2. Effect of Micronutrients

In Table 3, increasing the micromix rate from 0.84 kg to 1.64 kg/feddan has a positive effect on the uptake of nitrogen (N), phosphorus (P) and potassium (K) in bottle gourd leaves. This may be because micronutrients act as enzyme cofactors and metabolic switches that ensure the machinery responsible for absorbing, assimilating and utilising N, P and K functions properly. These findings are consistent with the results of Marschner (2012); Mohamed *et al*. (2016); Cakmak (2008); Römheld & Marschner (1986); and Goldbach & Wimmer (2007). On the other hand, foliar-applied nutrients are absorbed directly through leaf tissue, and the combination of zinc and boron is an efficient way to quickly correct deficiencies. Boron applied alongside the recommended dose of NPK has also been shown to increase the yield of field crops. Together with zinc and boron is also involved in supporting nitrogen fixation, assimilation and utilisation, making these micronutrients important for overall nitrogen use efficiency. (Shukla, and Prabhakar, 1987; Chaudhary *et al*., 2019; Kavin *et al*., 2024; Mehara *et al*., 2025; Soltan *et al*., 2025; Wadiwa *et al*., 2025; Singh *et al*., 2025; Sarap *et al*., 2024)

3.2.3. Effect of interaction

The present investigation found that the combination of biofertilizers and micronutrients positively impacted the percentage uptake of nitrogen (N), phosphorus (P) and potassium (K) in bottle gourd fruits (Table 3). Adding biofertilizers and foliar spraying micronutrients increased the absorption of macronutrients, such as nitrogen, phosphorus and potassium. Data confirmed that combining biofertilizers with a high micronutrient rate increased nutrient uptake in bottle gourd fruit. This may be attributed to the presence of beneficial microorganisms in biofertilizers, including azotobacter, azospirillum, rhizobium, and mycorrhizae, which are capable of solubilising insoluble nutrients within the rhizosphere. Consequently, biofertilizers enhance soil microbial activity and increase the root absorption capacity. Additionally, the foliar spray delivers essential elements directly to the leaves, thereby creating a synergistic effect between root and foliar absorption. The findings are in agreement with the results Shukla, and Prabhakar, (1987); Chaudhary *et al*. (2019); Kavin *et al*. (2024); Mehara *et al*. (2025); Soltan *et al*. (2025); Wadiwa *et al.* (2025); Singh *et al*. (2025).

3.3. Fruit quality

3.3.1. Effect of Bioifertilizer

The application of biofertilizer significantly improved the quality of the fruit, including the vitamin C, total soluble solids, total carotenoids and antioxidants of the bottle guard, in both seasons (Table 4). The microbin treatment was more effective than the other treatments and the control treatment. This may be because applying the biofertiliser enhanced nutrient uptake and enzyme synthesis by providing beneficial microorganisms, which directly boosted the key biochemical and physical quality traits of the fruit. Furthermore, biofertilizers enhance photosynthetic efficiency, producing higher amounts of soluble sugars and carbohydrates. These carbohydrates then accumulate in the developing fruit, resulting in a noticeable increase in TSS (°Brix) and a sweeter, richer flavour. In addition, applying biofertilizers improves the concentrations of calcium and potassium in tissue, thereby maintaining the structural integrity of cell walls. This reduces post-harvest moisture loss, softening of the fruit and physiological decay during transport and storage. Biological inputs activate secondary metabolic pathways, increasing the levels of total phenolics, flavonoids and natural antioxidants in the fruit flesh, thereby enhancing its overall nutritional value. These findings are consistent with the results of Shukla, and Prabhakar, (1987); Kumar *et al*. (2021); Chaudhary *et al*., (2022); Tomar *et al*. (2024); Kavin *et al*. (2024); Aljubouri and Aziz, (2024); Figiel *et al*. (2025); Gahory *et al.* (2025); Mehara *et al*. (2025).

3.3.2. Effect of Micronutrients

Foliar application of micro max compound containing iron (Fe), boron (B), and zinc (Zn) significantly enhances the fruit quality, physical attributes, and biochemical composition of bottle gourd (*Lagenaria siceraria*) in both seasons (Table 4). This may be due to the presence of foliar boron facilitates the translocation of photosynthetic sugars (such as sucrose) from mature leaves into developing fruit, thereby increasing their sweetness and soluble solid content. Both zinc and iron serve as vital enzyme cofactors in the synthesis of ascorbic acid precursors. Combined sprays can significantly increase the concentration of vitamin C in fruit pulp. Iron stimulates the production of ferredoxin and chlorophyll, thereby sustaining photosynthetic activity during the fruit-filling stage. Furthermore, boron plays a key role in the growth of pollen tubes and successful fertilisation. It cross-links pectins within cell walls, thereby maintaining structural integrity. Sprays containing a combination of zinc and boron reduce post-harvest physiological weight loss, maintain tissue turgor and extend fruit shelf life during handling and transport. A similar trend was also observed by Shukla, and Prabhakar, (1987); Upaganlawar and Balaraman, (2009); Kavin *et al*. (2024); Sarap *et al*. (2024); Soltan *et al*. (2025); Singh *et al*. (2025).

Table 4: Effect of biofertilizers and micromix on vitamin C, total soluble solid, total carotenoid content and antioxidant in fruits of bottle gourd plants during 2023and 2024 seasons.

Treatments		2023				2024			
		Vitamin C (mg/100g)	TSS %	TCC (mg/100g)	AOX (mg/g)	VC (mg/100g)	TSS %	TCC (mg/100g)	AOX (mg/g)
Bio fertilizers									
Control (NPK)		86.06	6.29	4.55	149.41	85.55	6.13	4.44	142.81
Nitrobin		86.19	6.36	4.64	161.84	85.75	6.24	4.57	151.83
Microbin		87.08	6.95	5.18	176.94	87.11	6.88	5.11	171.60
Rizobactrin		86.98	6.82	5.05	177.64	86.96	6.69	4.90	172.66
LSD at 5%		0.12	0.07	0.09	7.35	0.15	0.10	0.12	6.43
Micromix									
Control		86.34	6.47	4.74	162.65	85.98	6.28	4.57	154.73
0.84 kg/ fed.		86.54	6.59	4.85	163.45	86.28	6.46	4.75	155.96
1.64 kg/fed.		86.85	6.76	4.98	173.28	86.76	6.72	4.95	168.49
LSD at 5%		0.18	0.11	0.10	5.48	0.27	0.15	0.13	1.19
Bio fertilizers X Micromix									
Control	Control	85.74	6.13	4.37	142.97	85.06	5.89	4.17	139.62
	0.84 kg/ fed.	85.97	6.25	4.56	173.86	85.41	6.07	4.46	166.89
	1.64 kg/fed.	86.08	6.33	4.58	150.62	85.58	6.19	4.49	141.33
Nitro-bin	Control	86.12	6.39	4.64	152.9	85.64	6.29	4.58	144.82
	0.84 kg/ fed.	86.35	6.41	4.69	154.65	86.00	6.32	4.66	147.49
	1.64 kg/fed.	86.48	6.44	4.71	158.77	86.19	6.36	4.69	143.8
Micro-bin	Control	86.74	6.59	4.89	165.49	86.59	6.33	4.66	154.08
	0.84 kg/ fed.	86.92	6.91	5.12	168.28	86.87	6.82	5.01	158.35
	1.64 kg/fed.	86.96	6.76	5.02	174.88	86.93	6.59	4.86	168.45
Rizo-bactrin	Control	86.98	6.88	5.15	175.39	86.96	6.78	5.06	169.23
	0.84 kg/ fed.	87.25	7.12	5.23	192.54	87.37	7.14	5.18	195.47
	1.64 kg/fed.	87.33	7.05	5.28	187.15	87.49	7.04	5.26	187.22
LSD at 5%		0.18	0.08	0.11	6.13	0.22	0.13	0.16	9.55

TSS: Total soluble solid, **TCC:** Total Carotenoid Content, **AOX:** Antioxidants

3.3.3. Effect of interaction

In the present investigation, the applying biofertilizer to soil and micronutrients to the leaves at a high rate improved the quality of the bottle guard in terms of Vitamin C, total soluble solids, total carotenoids and antioxidants in two growing seasons compared to the control (Table 4). This may be attributed to the dual action of biofertilizers that encourage the growth of a healthy root system, along with the high dosage of foliar micronutrients, which directly stimulate canopy metabolism and create a continuous 'source-to-sink' flow of nutrients. (Dumas et al., 2003; Lee and Kader, 2000). Furthermore, soil-applied microbes colonise the rhizosphere and continuously release bound macronutrients (nitrogen, phosphorus, and potassium), along with plant hormones that promote synthesis (such as auxins and cytokinins), directly to the roots. Whereas the application of micronutrients, such as iron, zinc, and boron, through foliar methods stimulates leaf enzymes and enhances metabolic activity. Iron and zinc facilitate optimal chlorophyll production and improve photosynthetic efficiency. The findings are agreement with results of Shukla, and Prabhakar, (1987); Upaganlawar and Balaraman, (2009); Kavin *et al*. (2024); Tomar *et al*. (2024); Sarap *et al*. (2024); Mehara *et al*. (2025); Soltan *et al*. (2025); Singh *et al*. (2025);

4. Conclusions

The results indicate that the use of biofertilizers effectively enhances the yield and its components of bottle gourd across both seasons. The application of micromix at a rate of 1.64 kg per fed increased the fruit length, fruit diameter, and average fruit weight (in grams) of bottle gourd during both seasons. Furthermore, combining biofertilizers and micronutrients with the recommended dosage of NPK improved fruit quality, as reflected in increased levels of vitamin C, carotenoids, and antioxidant activity.

5. Recommendation

To increase productivity and improve the quality of bottle gourd fruit, it is recommended that biofertiliser is used as a soil dressing at a rate of 1.64 kg/fed., alongside a foliar application of the recommended dose of NPK fertiliser.

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