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Comparative study of bacteria and biofertilizer on strawberry fruit quality grown in perlite substrate

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Abstract: Strawberries are widely consumed fruits known for their rich nutritional content and desirable sensory attributes. Enhancing their quality in soilless cultivation systems, such as perlite substrates, is crucial for sustainable and efficient production. This study evaluated the comparative effects of a humic substance-based biofertilizer (Khumic-100) and the plant growth-promoting bacterium Pantoea agglomerans on the growth and fruit quality of strawberries grown in perlite under controlled greenhouse conditions. Treatments included Khumic-100, Pantoea agglomerans (INB-22), and a non-treated control group. Key parameters assessed were plant height, leaf area, flowering and fruiting patterns, and average fruit weight. The Khumic-100 treatment resulted in the highest fruit weight, along with the most vigorous vegetative and reproductive development. The bacterial treatment showed moderate improvements compared to the control. These results suggest that Khumic-100 is more effective in enhancing strawberry plant performance and fruit quality in perlite-based cultivation systems.

Key words: Strawberry, perlite, biofertilizer, pantoea agglomerans, khumic-100.

1. Introduction

Strawberry is a world-wide consumed soft fruit, highly appreciated as a source of bioactive compounds, including vitamins, healthpromoting antioxidants, polyphenolic compounds, flavonoids, anthocyanins, and amino acids, as well for its organoleptic and sensorial quality. (Giampieri et al., 2012) They are a significant crop in the agricultural industry due to their popularity and nutritional value. They are non-climacteric fruits, meaning they do not continue ripening after harvest. This characteristic makes their post-harvest handling and storage particularly challenging. Factors such as water stress, nutrient deficiencies, and improper growing conditions can significantly affect fruit quality, leading to issues like poor size, flavor, and shelf life. These challenges highlight the need for more effective cultivation systems and innovative agricultural practices. (Mahajan and Pongener 2019) Fruit quality is a multifaceted concept that encompasses various physical, chemical, and sensory attributes, such as size, color, firmness, sweetness, and aroma. (Miao et al., 2017) The cultivation system plays a crucial role in determining the quality of strawberry fruits. (Voća et al., 2009) (Taghavi et al., 2019) Traditionally, strawberries have been grown in soil, but the increasing adoption of soilless culture methods, such as perlite substrate, has gained attention due to their potential environmental benefits and the ability to better control growing conditions. (Cecatto et al., 2013) Perlite is a lightweight, volcanic glass that has been heated and expanded to create small, white particles commonly used in gardening and hydroponics. Known for its exceptional drainage capabilities, perlite prevents waterlogging and helps maintain optimal moisture levels in the root zone. (Shylla et al., 2018) Its structure promotes aeration, allowing roots to breathe and preventing diseases associated with stagnant water. While perlite itself is inert and contains no nutrients, it enhances the performance of soil mixes by improving aeration and drainage. (Stirling 1997) This makes it particularly useful in hydroponic systems and as a soil amendment for potted plants. Due to its lightweight nature, perlite is easy to handle and transport, making it a favorite among gardeners. (Bamforth 2006)

One approach to improving strawberry fruit quality is the use of biofertilizers, which are natural, environmentally-friendly alternatives to chemical fertilizers. Biofertilizers can enhance the availability of essential nutrients, improve soil structure, and promote the growth and development of beneficial microorganisms, thereby potentially improving the nutritional and antioxidant properties of the fruits. (Rahman et al., 2019) Additionally, the use of biofertilizers can help reduce the reliance on synthetic chemicals, contributing to more sustainable agricultural practices. Studies have shown that arbuscular mycorrhizal fungi (AMF) and plant growth-promoting rhizobacteria (PGPR) can enhance various aspects of strawberry production when used as biofertilizers. (García-López et al., 2023; Nardi et al., 2024)

In this study, we aim to investigate the comparative effects of bacteria and biofertilizer on the quality of strawberry fruits grown in a perlite substrate. We hypothesize that strawberries treated with biofertilizers will exhibit superior fruit quality compared to those treated with bacteria.

2. Materials and Methods

2.1. Plant Material and Experimental Design

Strawberries were planted a perlite substrate under controlled greenhouse conditions at the Institute of Fundamental Applied Research, under the Tashkent Institute of Irrigation and Agricultural Mechanization Engineers (TIIAME). The Korean strawberry cultivar was selected for its high yield potential. Plants were maintained under optimal conditions, with a temperature range of 22–25°C, humidity of 60–70%, and light intensity of 16 hours/day, to ensure consistent growth and fruit development.

2.2. Bacteria Inoculation and Biofertilizer Application

In this study, three treatments were applied to evaluate their effects on strawberry fruit quality grown in perlite substrate: Khumic-100 (biofertilizer), Pantoea agglomerans (bacteria), and a control (perlite only). The experimental design was a randomized complete block design with three treatments and three replications. Each block contained 10 strawberry plants, and each treatment was applied according to the standard protocols for biofertilizers and bacterial inoculants.

1. Preparation of bacterial suspension: Inoculate the perlite substrate with a plant growth-promoting bacterium, such as Pantoea agglomera, promoting even application for all plants in this treatment group.

3. Control: This treatment consisted of strawberry plants grown in perlite substrate without any biofertilizer or bacterial inoculants. This treatment was used as a baseline to evaluate the effects of the biofertilizer and bacterial treatments on strawberry fruit quality, including fruit weight and aroma profile. The control treatment followed the same conditions as the other treatments, ensuring consistency across all replicates.

2.3. Data Collection**:**

After harvesting the ripe strawberry fruits from each treatment group, the fruit weight was measured to assess the impact of the different cultivation methods on strawberry size, with the average weight recorded (in grams per fruit) for each treatment. To further evaluate the quality and flavor profile, the fruits were washed and homogenized to obtain a uniform sample. Volatile compounds were then extracted using headspace solid-phase microextraction (HS-SPME). In this method, the homogenized fruit sample was placed in a sealed vial and exposed to a fiber coated with a sorbent material that adsorbed the volatile compounds. The extracted volatiles were analyzed using gas chromatography-mass spectrometry (GC-MS). The SPME fiber was injected into the GC system, where the volatile compounds were separated based on their chemical properties. The separated compounds were identified and quantified using mass spectrometry. This analysis provided valuable insights into the aroma profile and volatile composition of the strawberries, allowing for a comprehensive evaluation of how biofertilizer and bacterial inoculation influenced the chemical composition and overall quality of the fruit.

2.4. Statistical Analysis**:**

Data were analyzed using analysis of variance (ANOVA), and statistical differences were determined using a **p-value < 0.05** to compare treatment effects.

3. Results

The comparative effects of biofertilizer (Khumic-100), bacterial inoculation (Pantoea agglomerans), and the control (perlite substrate without additives) on strawberry plant growth and fruit quality were assessed through various agronomic and biochemical parameters.

3.1. Fruit Weight

As shown in **Table 1**, the highest average fruit weight was observed in the Khumic-100 treatment group (3.9 g), followed by the control group (2.8 g), while the lowest fruit weight was recorded in the Pantoea agglomerans treatment (2.3 g). These findings indicate that Khumic-100 significantly enhanced fruit biomass compared to both bacterial inoculation and the untreated control.

Table 1. The average fruit weight of strawberries from the different treatments.

Treatment	Fruit Weight (g)
Khumic-100 perlite	3.9
Pantoea agglomerans perlite	2.3
Control perlite	2.8

3.2. Plant Growth Parameters

Data recorded at 30, 60, and 90 days showed consistent improvements in plant height and leaf area in the Khumic-100 group, with intermediate values for the bacterial treatment, and the lowest values in the control group. For example, by day 90, plants treated with Khumic-100 reached an average height of approximately 35.6 cm across blocks, compared to 33.8 cm for Pantoea agglomerans and 31.1 cm for the control. A similar trend was observed for leaf area measurements, with the Khumic-100 group consistently exhibiting the highest values.

Table 2. Effect of different treatments on plant height and leaf area over time.

Block	Treatment	Day 30 Plant Height (cm)	Day 60 Plant Height (cm)	Day 90 Plant Height (cm)	Day 30 Leaf Area (cm²)	Day 60 Leaf Area (cm²)	Day 90 Leaf Area (cm²)
1	Khumic-100	15.2	25.1	35.0	25.0	45.0	65.0
1	Pantoea agglomerans	14.8	24.5	33.5	24.0	43.5	63.0
1	Control	14.0	22.5	30.0	23.5	42.0	60.0
2	Khumic-100	15.5	26.0	36.2	26.0	46.5	66.0

2	Pantoea agglomerans	15.0	25.0	34.0	25.5	44.0	64.0
2	Control	14.2	23.0	31.5	24.2	41.5	59.5
3	Khumic-100	15.3	25.5	35.5	25.2	44.5	64.5
3	Pantoea agglomerans	14.5	24.8	33.8	24.8	43.0	63.5
3	Control	14.3	23.3	31.8	24.3	42.5	61.0

3.3. Flowering and Fruiting

The progression of flowering and fruiting over the course of the study is shown in **Table 3**. By day 90, Khumic-100-treated plants exhibited the highest reproductive activity with 5 plants flowering and 4 fruiting out of every 10 observed. The bacterial treatment followed closely (4 flowering, 3 fruiting), whereas the control showed the lowest reproductive response (3 flowering, 2 fruiting).

Table 3. Effect of different treatments on flowering and fruiting of plants over time (per 10 plants).

Days	Treatment	Flowering (Number of Plants)	Fruiting (Number of Plants)
30	Khumic-100	0 Plant	0 Plants
	Bacteria	0 Plant	0 Plants
	Control	0 Plants	0 Plants
60	Khumic-100	3 Plants	1 Plants
	Bacteria	2 Plants	1 Plant
	Control	1 Plant	0 Plants

90	Khumic-100	5 Plants	4 Plants
	Bacteria	4 Plants	3 Plants
	Control	3 Plants	2 Plant

3.4. Vegetative and Reproductive Development

Detailed monitoring of leaves, stems, flowers, and fruits per plant over time is presented in **Table 4**. Across all observation days, the Khumic-100 treatment consistently outperformed the other two groups. By day 90, plants in the Khumic-100 group had the highest number of leaves (24), stems (9), flowers (6), and fruits (4) per plant, suggesting enhanced vegetative vigor and reproductive capacity. In comparison, the Pantoea agglomerans treatment achieved slightly lower values (22 leaves, 8 stems, 5 flowers, 3 fruits), with the control showing the least development.

Table 4. Number of leaves, stems, flowers, and fruits per plant at different time points.

Days	Treatment	Leaves (per plant)	Stems (per plant)	Flowers (per plant)	Fruits (per plant)
30	Khumic-100	12	4	0	0
	Bacteria	10	3	0	0
	Control	9	3	0	0
50	Khumic-100	16	6	2	0
	Bacteria	14	5	1	0
	Control	12	4	1	0
70	Khumic-100	20	8	4	2
	Bacteria	18	7	3	1
	Control	16	6	2	1

90	Khumic-100	24	9	6	4
	Bacteria	22	8	5	3
	Control	20	8	3	2

4. Discussion

The results of this study demonstrate the potential of bacteria and biofertilizers to enhance the quality of strawberry fruits grown in a perlite substrate. The use of biofertilizers, containing a combination of beneficial microorganisms, also showed promising results in terms of improving the nutritional and sensory properties of the strawberry fruits. (Flores-Félix et al., 2018) These findings are consistent with previous studies that have reported the positive effects of plant growth-promoting rhizobacteria and biofertilizers on the quality of strawberries. (Pırlak and Köse, 2009; Kumar et al., 2019) The mechanisms by which bacteria and biofertilizers enhance fruit quality are multifaceted and may involve various processes, such as the solubilization of nutrients, the production of plant growth-promoting substances, and the suppression of pathogenic microorganisms. (Okur 2018; Mącik et al., 2020) Several studies have demonstrated the positive impacts of these biological agents on various aspects of strawberry cultivation. Research has indicated that the use of plant growth-promoting rhizobacteria (PGPR) and arbuscular mycorrhizal fungi (AMF) as biofertilizers can significantly enhance strawberry plant growth, yield, and fruit quality. (Kilic et al., 2023) For instance, a study on the Monterey strawberry variety found that a combination of organic fertilizers and bacterial biofertilizers containing multiple strains (including Azosprillium brasilense, Azotobacter vinelandii, and Bacillus subtilis) resulted in the highest total yield, largest fruits, and best nutrient content in leaves. (Kilic, 2023) Similarly, vermicompost-based fertilization with PGPR and AMF improved plant growth, yield, and fruit quality in organically grown Monterey strawberries. (Kilic et al., 2023) Interestingly, the application of arbuscular mycorrhizal fungi has been shown to reduce the need for phosphorus fertilization without compromising fruit yield. A study on the Camarosa cultivar demonstrated that AMF inoculation allowed for a 75% reduction in phosphorus supply while maintaining fruit yield and improving phytochemical quality. (Nardi et al., 2024) This highlights the potential of AMF as a sustainable biofertilizer in strawberry production. Gas chromatography has been employed to analyze the impact of fertilization on strawberry fruit quality, particularly in terms of volatile compounds. A study using SPME/GC-MS revealed that nitrogen and calcium fertilization altered the content of volatile compounds in strawberry fruits. Higher doses of nitrogen and calcium increased unpleasant aldehydes, while nano-fertilization with Lithovit enhanced fruity esters. (Weber et al., 2021) These findings underscore the importance of considering the effects of fertilization on fruit aroma and flavor when developing biofertilizer strategies.

5. Conclusion

This study demonstrates that the use of the biofertilizer Khumic-100 significantly enhances strawberry plant growth and fruit quality when grown in a perlite substrate. Plants treated with Khumic-100 exhibited superior performance across all measured parameters, including plant height, leaf area, flower and fruit count, and especially average fruit weight. Although the bacterial treatment with Pantoea agglomerans showed some positive effects, it was less effective than the biofertilizer and only moderately better than the control. These findings support the use of humic substance-based biofertilizers as a sustainable and efficient alternative to conventional inputs for improving strawberry production in soilless systems. Further research could explore combinations of microbial and organic inputs to optimize results.

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