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Evaluation of banana peel extract as a natural biofertilizer for enhancing germination and early growth in cucumber (*Cucumis sativus*) and tomato (*Solanum lycopersicum*)

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Abstract

Banana peel is an underutilized agricultural by-product rich in nutrients and secondary metabolites that may serve as a natural plant growth promoter. This study evaluated the influence of banana peel extract on the germination and early vegetative growth of cucumber (*Cucumis sativus*) and tomato (*Solanum lycopersicum*) seedlings. Seeds were treated with varying concentrations of banana peel extract (1%, 3%, and 5%) and compared with a tap-water control. Growth experiments were conducted using 20 mL, 40 mL, and 60 mL extract volumes applied to seedlings for 30 days. Phytochemical screening of aqueous and ethanolic extracts was performed to identify major metabolites. Results showed that cucumber seeds treated with 3% and 5% extract exhibited 100% germination, compared with 40% in the control. Tomato seeds displayed maximum germination (100%) at 3% extract. Cucumber seedlings receiving 60 mL extract demonstrated the greatest shoot length (14.9 cm) and biomass (1.5458 g), whereas tomato seedlings responded most positively to moderate extract volumes (20 – 40 mL). Phytochemical analysis revealed the presence of tannins, flavonoids, alkaloids, saponins, and triterpenoids. The findings indicate that banana peel extract enhances seed germination and early seedling development, highlighting its potential use as a sustainable biofertilizer.

Keywords: *Cucumis sativus*, *Solanum lycopersicum*, banana peel, biofertilizer

Introduction

The increasing global demand for food production has accelerated the use of chemical fertilizers, which cause significant threats to soil quality, water resources, and ecological sustainability. As a result, the focus has increasingly shifted towards organic and plant-based fertilizers as environment-friendly alternatives [1]. Agricultural waste materials, such as fruit peels, have gained prominence for their ability to supply nutrients and stimulate plant growth without causing environmental damage. The banana (*Musa* spp.) peel, often discarded as waste, accounts for approximately one-third of the mass of the fruit and is rich in potassium, nitrogen, phosphorus, calcium, and a variety of bioactive phytochemicals [2]. Previous studies have reported its potential for composting, soil enrichment, and extract-based fertilization due to its antioxidant and nutrient rich properties [3; 4]. The weight of a banana peel is approximately 30 – 40 g per 100 g of the total weight, which is classified as an industrial by-product [5]. The natural bioactive compounds present in banana peels, including polyphenols, carotenoids, and dietary fiber, offer health benefits such as the prevention of cardiovascular diseases, cancer, and other degenerative conditions [6]. Banana peel flour contains 32.3 mg of ascorbic acid per 100 g, while the fruit and pulp provide 7.18 mg and 4.97 mg of vitamin C, respectively [7]. The flour derived from banana peels appears to have potential as a health and beauty product, including applications such as facial masks, reduction of skin oil, and scar fading due to its high content of vitamin C and minerals [8]. Vitamin C, or ascorbic acid, has numerous benefits, including boosting immunity, improving skin health, and protecting cells from cancer. Banana peels have remarkable scientific properties and have been utilized to address intestinal sores, constipation, diarrhea, ulcerative colitis, nephritis, gout, coronary heart disease, high blood pressure, and diabetes [9]. The fiber content in banana peels is high, constituting about 50% on a dry matter basis, while the protein content includes 7% essential amino acids. Additionally, they are rich in potassium and polyunsaturated



Figure 1. Germination of cucumber seeds under different treatments of banana peel: (A) control, (B) 1% banana peel, (C) 3% banana peel, and (D) 5% banana peel.

fatty acids [10]. Furthermore, banana peels help replenish soil nutrients, as they have traditionally been used as fertilizer through natural decomposition. However, with advancements in biotechnology and a growing demand for organic fertilizers, banana peels have been repurposed to produce various types of organic fertilizers [11].

These components can increase enzymatic activity, stimulate hormone production, and improve overall plant potency. Cucumber and tomato are widely grown vegetable crops whose productivity largely depends on seed germination and seedling establishment. Enhancing these early developmental stages through inexpensive, natural methods could greatly benefit sustainable agricultural practices. The present study investigates the effects of banana peel extract on germination and early seedling development of cucumber and tomato. By examining morphological parameters and performing phytochemical analyses, the study aims to elucidate the potential of the extract as an effective biofertilizer.

Materials and Methods

Preparation of banana peel extract

Fresh banana peels were washed thoroughly, cut into small pieces, and dried in a hot air oven, followed by grinding. The banana peel powder was used to prepare 1%, 3%, and 5% (w/v) extracts. The mixture was filtered, and the extracts were stored at 4 °C prior to use.

Selection of seeds and inoculation

Two types of seeds (*Cucumis sativus* and *Solanum lycopersicum*) were selected for this study. The seeds were surface-sterilized with mercuric chloride, followed by inoculation in different concentrations of banana peel extract prepared in Petri plates from the previous steps. After 5 hours, the seeds were transferred onto filter paper, and the germination percentage was recorded after 7 days of incubation.

Seed germination test

Cucumber and tomato seeds were surface-sterilized and placed in identical germination trays lined with moist cotton. Four treatments were applied: T1 (control, tap water), T2 (1% banana peel extract), T3 (3% banana peel extract), and T4 (5% banana peel extract). Germination percentage was recorded after 7 days. The concentrations (1%, 3%, and 5%) were selected based on preliminary trials and previously reported studies to evaluate

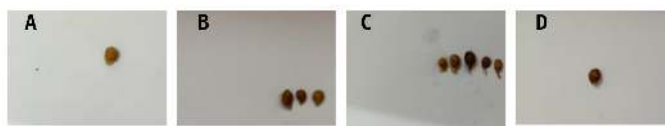


Figure 2. Germination of tomato seeds under different treatments of banana peel: (A) control, (B) 1% banana peel, (C) 3% banana peel, and (D) 5% banana peel.

dose-dependent effects and to avoid phytotoxicity at higher concentrations.

Collection of soil samples

Soil samples were collected from a naturally vegetated site located at Manasapata, Odisha, India (Latitude: 21.554489° North; Longitude: 86.778737° East). Soil was collected from the upper layer (0 – 15 cm), where nutrient availability and microbial activity are typically highest. The soil was transported to the laboratory in airtight, labeled bags and stored at room temperature for further physicochemical analysis and experimental use. The physicochemical parameters of the soil were estimated to evaluate the soil characteristics [12].

Table 1. Germination percentage of cucumber seeds under different treatment condition

Treatment (cucumber)	No. of seeds inoculated	No. of seeds germinated	Germination percentage
Cont (Tap Water)	5	2	40%
1% Banana peel solution	5	3	60%
3% Banana peel solution	5	5	100%
5% Banana peel solution	5	5	100%

Seedling growth experiment

Seedlings were transplanted into pots containing 30 g of homogenized soil for each treatment. Four treatment groups were maintained over an experimental period of 30 days: T1 (control) received only tap water, while T2, T3, and T4 received 20 mL, 40 mL, and 60 mL of banana peel extract, respectively. Each treatment was applied evenly to ensure consistent nutrient availability and moisture conditions. Seedling growth was monitored at regular intervals, and key morphological parameters, including seedling length, root length, number of leaves, and fresh biomass, were recorded at 7, 14, and 21 days. This approach allowed a comparative evaluation of the dose-dependent effects of banana peel extracts on early plant growth.

Phytochemical screening

Banana peel was shade-dried, powdered, and subjected to Soxhlet extraction using ethanol and aqueous solvents. The extract was concentrated using a rotary evaporator, re-dissolved in the respective solvents, and stored for further use in allelochemical screening and chromatographic analysis. Standard qualitative



Figure 3. Sample collection site

Table 2. Germination percentage of tomato seeds under different treatment

Treatment (tomato)	No. of seeds inoculated	No. of seeds germinated	Germination percentage
Cont (Tap Water)	5	1	20%
1% Banana peel solution	5	1	20%
3% Banana peel solution	5	5	100%
5% Banana peel solution	5	3	60%

assay methods were performed to detect the presence of various phytochemicals, including tannins, saponins, flavonoids, alkaloids, glycosides, terpenoids, and steroids in the culture broth under axenic and co-culture conditions [13].

Results

The experimental results from all figures and tables collectively demonstrate significant effects of banana peel extract on germination, soil-based seedling growth, and physiological performance in both cucumber and tomato. **Figure 1**, along with **Table 1**, clearly depicts the germination response of cucumber seeds to different concentrations of banana peel extract. A progressive increase in germination was observed, from 40% in the control to 60% at 1% extract, and finally reaching 100% at both 3% and 5% treatments, indicating a strong concentration-dependent stimulatory effect. As shown in **Figure 2** and **Table 2**, similar trends were observed in tomato seeds, where germination remained low in the control and 1% treatments (20%), but increased rapidly to 100% at 3% extract, before decreasing slightly to 60% at 5%. This suggests that tomato is more sensitive to higher extract concentrations than cucumber. **Figure 3** provides an overview of the soil collection site.

Further analysis of the soil indicated that the experimental soil had a loamy sand texture and was classified as red soil, suggesting good drainage but relatively low nutrient retention capacity. The pH level of the soil was strongly acidic (4.38), a

Table 3. Soil profiling analysis

Parameter	Value	Status / Interpretation
Soil texture	Loamy sand	Well-drained
Soil type	Red soil	Typical of tropical regions
pH	4.38	Strongly acidic
Electrical conductivity (EC)	0.04 dS m ⁻¹	Non-saline

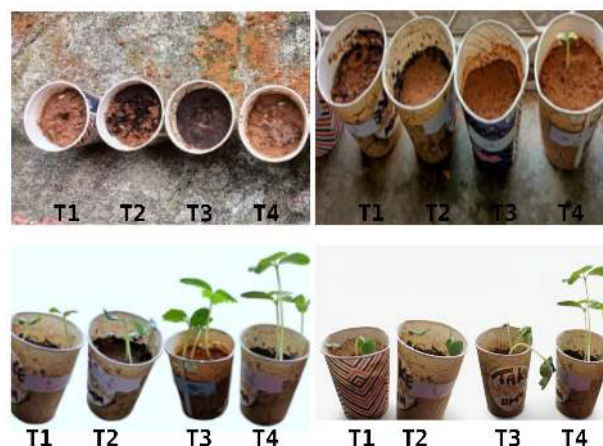


Figure 4. Germination of tomato seeds under different treatments of banana peel: (T1) Control, (T2) 1% banana peel, (T3) 3% banana peel, and (T4) 5% banana peel.

factor known to affect nutrient availability and potentially hinder optimal plant growth. The electrical conductivity, measured at 0.04 dS m⁻¹, indicated non-saline conditions, implying that salinity stress was not a limiting factor for plant development **Table 3**. Nutrient analysis revealed deficiencies in key macronutrients, particularly nitrogen (137 kg ha⁻¹) and potassium (101 kg ha⁻¹), both categorized as low. Since nitrogen is essential for vegetative growth and chlorophyll production, and potassium plays a crucial role in enzyme activation and water regulation, their deficiency likely resulted in a nutrient-limited environment for plant growth. In contrast, phosphorus (36 kg ha⁻¹) was present at a medium level, potentially supporting root development and energy transfer processes. Regarding micronutrients, zinc (0.57 ppm) and copper (0.45 ppm) were identified as deficient, which could adversely impact enzymatic activities, protein synthesis, and overall plant metabolism **Table 4**. On the other hand, iron (9.63 ppm) and manganese (12.63 ppm) were present in sufficient amounts, supporting essential physiological processes such as chlorophyll formation and photosynthesis.

The growth pattern of cucumber plants under different extract volumes is clearly illustrated in **Figures 4, 5**, which show a gradual improvement in plant vigor from day 0 to day 30. In **Figure 4**, cucumber plants treated with 60 mL of banana peel extract (T4) exhibited visible shoot emergence earlier than other treatments, as early as the second day, indicating faster establishment. This accelerated initial growth in T4 suggests that the higher ex-

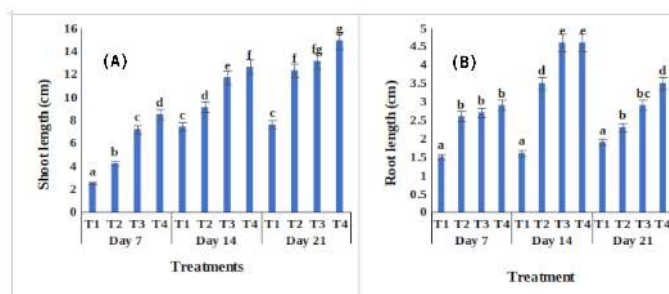
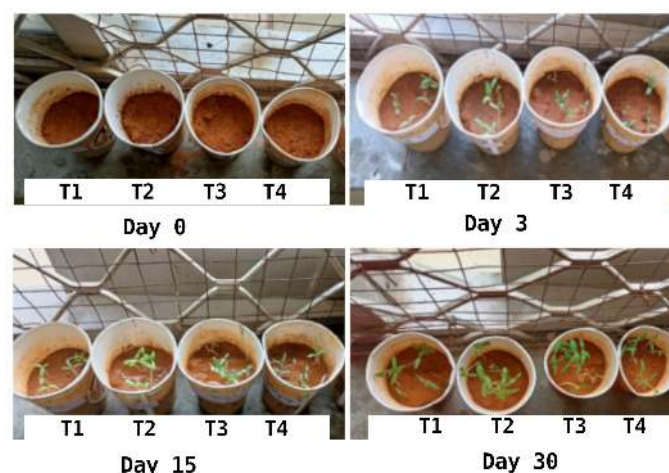
Table 4. Nutrient analysis of soil

Parameter	Value	Interpretation
Available Nitrogen (N)	137 kg ha ⁻¹	Low
Available Phosphorus (P)	36 kg ha ⁻¹	Medium
Available Potassium (K)	101 kg ha ⁻¹	Low
Zinc (Zn)	0.57 ppm	Deficient
Copper (Cu)	0.45 ppm	Deficient
Iron (Fe)	9.63 ppm	Sufficient
Manganese (Mn)	12.63 ppm	Sufficient

**Figure 5.** Plant condition under different treatments (T1 = tap water, T2 = 20 ml banana peel extract, T3 = 40 ml banana peel extract, and T4 = 60 ml banana peel extract).

tract dose enhanced immediate nutrient uptake, leading to rapid physiological activation and seedling emergence. By day 30, cucumber plants treated with 60 mL of extract (T4) not only showed earlier establishment but also maintained an erect, erect posture, whereas plants in all other treatments appeared bent or bent over. This indicates that the higher extract dose contributed to stronger stem development and improved structural strength compared to lower dose treatments. These visual observations are quantitatively supported by **Table 5**, which shows consistent and significant increases in shoot length, root length, number of leaves, and fresh biomass as the extract volume increased from 20 mL (T2) to 60 mL (T4). By day 21, cucumber seedlings under the highest extract dose (T4) displayed the greatest shoot length (14.9 cm), longest root length (3.5 cm), and highest total biomass (1.5458 g), compared to the much lower biomass of the control (0.2754 g). These results indicate that cucumber plants respond strongly to nutrient-rich extracts with enhanced vegetative growth and accelerated biomass accumulation. **Figure 6** further illustrates improvements in shoot and root architecture, emphasizing the dose-responsive increase in morphological traits.

For tomato, the sequential growth stages presented in **Figures 7, 8** show noticeable treatment-dependent variation in vigor from day 0 to day 30. The corresponding quantitative data in **Table 6** indicate that tomato plants achieved optimal growth at moderate extract levels, particularly T2 (20 mL), which produced the highest shoot length (4.9 cm), root length (2.4 cm), and biomass (0.0949 g) at day 21. In contrast to cucumber, tomato growth decreased at higher extract volumes (T4), suggesting that excessive nutrient or metabolite concentrations may induce light stress or osmotic imbalance. **Figure 9** clearly highlights this trend, showing improved root and shoot development at lower extract

**Figure 6.** Morphological parameters of cucumber plant under different conditions: (A) Shoot length and (B) Root length.**Figure 7.** Growth of tomato plant under different conditions (T1 = tap water, T2 = 20 ml banana peel extract, T3 = 40 ml banana peel extract, and T4 = 60 ml banana peel extract).

volumes compared to the reduced growth observed at 60 mL.

Table 7 summarizes the phytochemical composition of banana peel extracts, revealing the presence of various bioactive compounds such as tannins, alkaloids, flavonoids, saponins, and triterpenoids. The strong detection of tannins and saponins in the aqueous extract, along with the abundance of alkaloids and flavonoids in the ethanolic extract, indicates that banana peel contains a wide range of plant growth promoting substances, with a total phenolic content of 0.171 mg/mL. These compounds are known to enhance germination, regulate hormone-mediated growth pathways, improve nutrient uptake, and protect young plants from oxidative stress. Integrating the phytochemical profile with germination and growth data supports the conclusion that these metabolites contributed to the improved plant responses observed across all treatments. Overall, the figures and tables provide comprehensive evidence that banana peel extract enhances germination and plant growth in both cucumber and tomato. Cucumber exhibited a strong dose-dependent response, while tomato showed optimal growth at moderate extract levels, highlighting the potential of banana peel as an effective biofertilizer.

Table 5. Study of morphological parameters of cucumber plant under different treatment with banana peel

Day	Treatment	No. of leaves	Shoot length (cm)	Root length (cm)	Root weight (g)	Leaf weight (g)	Total weight (g)
Day 7	T1	2	2.5	1.5	0.002	0.0595	0.0856
	T2	2	4.2	2.6	0.005	0.0879	0.160
	T3	2	7.2	2.7	0.005	0.134	0.217
	T4	3	8.5	2.9	0.008	0.325	0.556
Day 14	T1	2	7.4	1.6	0.0241	0.1236	0.2878
	T2	3	9.1	3.5	0.0625	0.2658	0.3941
	T3	3	11.7	4.6	0.0634	0.2987	0.4553
	T4	4	12.6	4.6	0.0606	0.3207	0.4697
Day 21	T1	2	7.6	1.9	0.0654	0.0537	0.2754
	T2	2	12.3	2.3	0.0319	0.0639	0.4128
	T3	4	13.1	2.9	0.0635	0.0497	0.4789
	T4	5	14.9	3.5	0.0692	0.0834	1.5458

T1 = tap water, T2 = 20 ml banana peel extract, T3 = 40 ml banana peel extract, T4 = 60 ml banana peel extract

Discussion

The findings of this study clearly demonstrate that banana peel extract has significant positive effects on seed germination and early vegetative growth in both cucumber and tomato. The sharp increase in germination percentage in cucumber – from 40% in the control to 100% at both 3% and 5% extract concentrations **Figure 1, Table 1** indicates a strong concentration-dependent stimulatory effect. A similar but more sensitivity-dependent trend was observed in tomato, where germination increased from 20% in the control to a maximum of 100% at 3% extract and decreased to 60% at 5% **Figure 2, Table 2**. This reduction at higher concentrations suggests that tomato seeds may be more sensitive to osmotic or metabolite-induced inhibition, consistent with previous studies reporting that excessive organic solutes can inhibit water uptake [4]. Soil conditions documented at the collection site **Figure 3** and the physicochemical analysis of the soil **Table 3** revealed that the experimental soil was classified as loamy sand with a red soil profile, characterized by high acidity (pH 4.38) and low electrical conductivity (0.04 dS m^{-1}). Such acidic conditions are known to significantly affect nutrient solubility and availability, often resulting in reduced uptake of essential macro- and micronutrients by plants [14]. The insufficient levels of available nitrogen and potassium further indicate a nutrient-deficient environment, which can limit vegetative growth, chlorophyll production, and overall plant productivity as given in **Table 4**. Nitrogen is a fundamental component of amino acids and proteins, while potassium plays a key role in enzyme activation and osmotic regulation [15]. Additionally, deficiencies in micronutrients such as zinc and copper may hinder enzymatic functions and metabolic processes, thereby impacting early seedling development. Zinc is essential for auxin synthesis and growth regulation, whereas copper is involved in redox reactions and electron transport during photosynthesis [16]. In

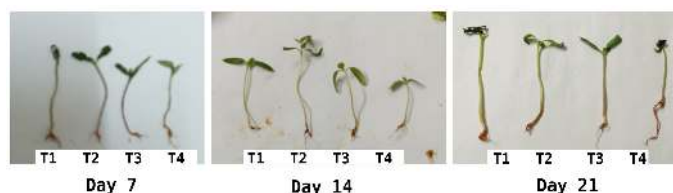


Figure 8. Tomato plant condition under different treatments (T1 = tap water, T2 = 20 ml banana peel extract, T3 = 40 ml banana peel extract, and T4 = 60 ml banana peel extract).

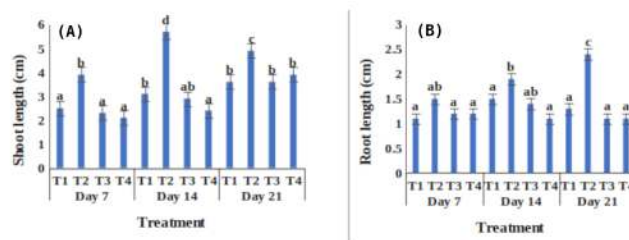


Figure 9. Morphological parameters of tomato under different conditions A) Shoot length B) Root length

contrast, adequate levels of iron and manganese suggest that certain physiological processes, such as chlorophyll synthesis and photosynthesis, may not be adversely affected.

Overall, the soil conditions indicate a nutrient-limited and acidic environment, which is generally unfavorable for crop cultivation. Under such conditions, the application of organic amendments or biofertilizers becomes particularly important, as they can enhance nutrient availability, boost microbial activity, and mitigate soil acidity [10]. Thus, the observed plant growth responses in this study can be interpreted in the context of these soil limitations, where the addition of external nutrients played a cru-

Table 6. Study of morphological parameters of tomato plant under different treatment with banana peel

Day	Treatment	No. of leaves	Shoot length (cm)	Root length (cm)	Root weight (g)	Leaf weight (g)	Total weight (g)
Day 7	T1	3	2.5	1.1	0.0016	0.0301	0.0565
	T2	6	3.9	1.5	0.0069	0.0331	0.0793
	T3	4	2.3	1.2	0.0025	0.0295	0.0552
	T4	3	2.1	1.2	0.0019	0.0227	0.0501
Day 14	T1	3	3.1	1.5	0.0069	0.0583	0.0616
	T2	5	5.7	1.9	0.0194	0.0824	0.09989
	T3	3	2.9	1.4	0.0162	0.0187	0.064
	T4	2	2.4	1.1	0.0069	0.018	0.061
Day 21	T1	3	3.6	1.3	0.0038	0.0551	0.0824
	T2	4	4.9	2.4	0.0039	0.0689	0.0949
	T3	3	3.6	1.1	0.0057	0.0499	0.0744
	T4	3	3.9	1.1	0.0064	0.0429	0.045

T1 = control (tap water), T2 = 20 ml of 3% banana peel extract, T3 = 40 ml, T4 = 60 ml

Table 7. Qualitative analysis of ethanolic and aqueous extract of banana peel

Metabolite	Ethanolic extract	Aqueous extract
Tannins	+	++
Steroids	-	-
Alkaloids	++	+
Flavonoids	+	-
Saponins	-	+
Triterpenoids	+	+
Glycosides	-	-
Total Phenol	+ (0.171 mg/mL)	+ (0.157 mg/mL)

cial role in improving plant performance. Based on germination performance, the 3% extract concentration was selected for pot culture experiments. Cucumber plants exhibited a strong positive response to increasing extract volumes during the 30-day growth period. Visual observations in **Figures 4, 5** showed consistent improvements in plant vigor, with T4 (60 mL) resulting in earlier seedling emergence (day 2) and stronger plants compared to other treatments. Notably, by day 30, the stem of T4 seedlings remained straight, whereas seedlings in T1T3 appeared bent or bent **Figure 4**, indicating enhanced stem strength and structural integrity at higher extract doses. Quantitative data in **Table 5** support these observations, showing that by day 21, T4 achieved the highest shoot length (14.9 cm), root length (3.5 cm), and total biomass (1.5458 g), all significantly higher than the control (0.2754 g). The dose-dependent improvements in shoot and root parameters are further illustrated in **Figure 6**, highlighting substantial enhancement in morphological parameters with increasing extract application. These findings are consistent with previous studies reporting that potassium- and phenolic-rich amendments stimulate root activity, nutrient assimilation, and shoot elongation [2; 3].

In contrast, tomato exhibited optimal growth at medium extract amounts. As shown in **Figures 7, 8, and 9**, T2 (20 mL)

consistently produced the highest shoot length (4.9 cm), root length (2.4 cm), and biomass (0.0949 g) up to day 21 **Table 6**. Higher extract doses (T4) resulted in reduced growth, suggesting that tomato may experience osmotic stress or metabolite overload at higher doses. This species-specific response aligns with previous reports indicating that high concentrations of tannins, alkaloids, or organic acids can temporarily inhibit root elongation or disturb ion balance in tomato seedlings [5]. The contrasting responses between cucumber and tomato highlight the importance of optimizing dosage before field use. Phytochemical analysis provides insight into the biochemical basis of the observed growth promotion **Table 7**. The presence of tannins, flavonoids, alkaloids, saponins, and triterpenoids in both aqueous and ethanolic extracts is significant, as these metabolites are known to enhance germination physiology, hormonal modulation, improve antioxidant defense, and increase nutrient uptake efficiency [10]. The strong detection of tannins and saponins in aqueous extracts may enhance water absorption and microbial interactions, while flavonoids and alkaloids in ethanolic extracts may support auxin regulation and root initiation. The synergistic interaction of these compounds, along with essential mineral nutrients such as potassium and calcium, explains the increased germination and vegetative responses observed during the treatments. Collectively, the results of this study confirm that banana peel extract effectively enhances seed germination, accelerates early seedling growth, and improves structural strength in vegetable crops. Cucumber benefits most from higher extract levels, whereas tomato performs best at moderate concentrations. These findings highlight the potential of banana peel extract as a cost-effective and eco-friendly biofertilizer, while also emphasizing the need for crop-specific dosage optimization for practical agricultural applications.

Conclusion

The present study demonstrates that banana peel extract is an effective natural biofertilizer capable of enhancing seed germi-

nation and early seedling growth in both cucumber and tomato. Cucumber exhibited a strong dose-dependent response, with the highest extract volume (60 mL) promoting earlier emergence, greater shoot and root development, and significantly higher biomass compared to the control. In contrast, tomato displayed maximum growth at moderate extract levels (20 – 40 mL), indicating species-specific sensitivity to higher metabolite concentrations. The observed improvements are supported by the presence of beneficial phytochemicals – such as tannins, flavonoids, alkaloids, saponins, and triterpenoids – which likely contribute to increased physiological activity, enhanced nutrient uptake, and improved structural strength. Overall, the findings confirm that banana peel extract can serve as a low-cost, sustainable, and environmentally friendly alternative to chemical fertilizers, with its effectiveness depending on crop type and extract dosage. Further field-scale studies are recommended to optimize application rates and to evaluate long-term effects on soil health and plant performance.

Author contributions

KD conceptualized and designed the study. LS, PS, and UM contributed to data acquisition, analysis, and interpretation. All authors participated in manuscript writing and revision.

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