International Journal Of Public Mental Health And Neurosciences
ISSN: 2394-4668
(An Official publication of Sarvasumana Association)

Utilizing Biodegradable Fruit Waste for Biofertilizer Production: A Sustainable Approach to Increase Crop Growth and Soil Fertility

Omkar Agale*, Gajanan Agale, Jayesh Chaudhari, Om Joshi,
Akash Choudhari, Ronit Savale, and Himanshu Patil
Department of Biotechnology, Institute of Biosciences and Technology
MGM University
Chatrapati Sambhaji Nagar, India
*Corresponding Author Email: Oagale2@gmail.com

***Abstract*— Agriculture is a cornerstone of India's economy, but its sustainability faces challenges such as soil fertility depletion, dependence on chemical fertilizers, and environmental degradation. This study explores the development and application of biofertilizers derived from biodegradable fruit waste, particularly papaya and watermelon peels, using Solid State Fermentation (SSF). Microbial strains were isolated and characterized through techniques such as Gram staining and indole tests, revealing a diversity of beneficial microorganisms like Escherichia coli. The biofertilizer's efficacy was tested on fenugreek plants (*Trigonella foenum-graecum*), showing significant improvements in growth parameters such as plant height, leaf count, and overall plant health compared to a control group. These findings highlight the potential of fruit waste-derived biofertilizers as a sustainable and eco-friendly alternative to chemical fertilizers, contributing to improved soil health and agricultural productivity.**

***Index Terms*— Biofertilizer, Biodegradable Waste, Solid State Fermentation, Microbial Isolation, Plant Growth, Soil Health, Fenugreek, Sustainable Agriculture.**

I. Introduction

Agriculture is one of the largest sectors of India's economy, contributing significantly to the Gross Domestic Product (GDP) alongside fisheries and forestry (1). However, issues such as soil fertility depletion, inefficient crop harvesting and storage practices, and dependence on chemical fertilizers present challenges to sustainable agricultural productivity (2). The intensive use of inorganic fertilizers, though essential for crop yield, has been linked to environmental degradation, causing pollution of air, soil, and water ecosystems (3). To mitigate these adverse effects, researchers are exploring sustainable alternatives, including biofertilizers, which harness the power of microorganisms to enhance soil fertility and promote plant growth (4).

Biofertilizers are natural fertilizers that improve soil health by supplying essential nutrients, enhancing organic content, and reducing nitrogen depletion (5). Produced from organic waste, they offer a sustainable solution to chemical fertilizers, especially when produced from biodegradable waste materials like fruit residues. The use of fruit waste in biofertilizer production (6), not only reduces environmental waste but also provides a nutrient-rich substrate for beneficial microbial growth through processes like Solid State Fermentation (SSF).
Fruit waste serves as a valuable raw material in producing nitrogen-fixing, phosphorus-solubilizing, and plant growth-promoting biofertilizers. Microorganisms such as Rhizobium, Azotobacter, Bacillus, and Pseudomonas play vital roles in biofertilizer production, enhancing plant nutrient absorption and stimulating growth (7). This review focuses on methodologies for isolating microbial strains from fruit waste, characterizing their biochemical properties, and evaluating biofertilizer efficacy on fenugreek plants.

II. METHODOLOGY

The objective of this paper is to formulate a sustainable biofertilizer from biodegradable organic fruit wastes, peels of papaya and watermelon as substrates. Using the nutrient-rich composition of organic wastes, optimizing the growth of efficacious microorganisms like *Rhizobium*, *Azotobacter*, *Bacillus, and Pseudomonas*.

In this study, isolation and characterization of such strains have been done to utilize their nitrogen-fixing properties, phosphorus-solubilizing, and plant growth-promoting properties. The production of biofertilizers was done under optimized conditions by using SSF (Solid State Fermentation) techniques. This improves soil health and enhances the growth of fenugreek plants in an eco-friendly approach.

A. Collection and Preparation of Fruit Waste:

Fruit waste, primarily papaya, was collected from local markets as described [8]. It was stored in sterile, ventilated containers at 25–30°C for one week to enable spoilage and microbial colonization, fostering nitrogen-fixing and phosphorus-solubilizing bacteria essential for biofertilizer production (9). The decomposed waste was homogenized before microbial isolation.

B. Isolation of Microorganisms

Serial dilution and spread plate technique was used (10):

For a dilution of 10^ (-1), ten grams of degraded waste were homogenized in 90 milliliters of sterile distilled water which was further diluted to 10^ (-6). Dilutions (10^ (-3)–10^ (-6)) were inoculated onto nutrient agar, spread evenly, and were incubated at 28°C for 24–48 hours. Distinct colonies were isolated and sub-cultured for characterization.

C. Biochemical Characterization:

Gram Staining to classify cell wall properties.
Indole test to assess nutrient cycling and metabolic functions (11).

D. Gram Staining and IMViC Tests:

Gram staining was used to classify isolates as Gram-positive or Gram-negative, aiding in identifying microbial cell wall properties critical for soil and biofertilizer application. Indole Test provided further biochemical characterization by assessing the indole production from tryptophan, highlighting enzymatic and nutrient cycling roles.

Results were compared with known microbial profiles for potential roles in nutrient cycling and plant growth (12).

E. Biofertilizer Evaluation on Fenugreek Plants:

The biofertilizer's efficacy was tested on *Trigonella foenum-graecum* under controlled greenhouse conditions (13):

Experimental Setup: A randomized block design with treated (biofertilizer) and control (no biofertilizer) groups, each with 30 replicates, present in alternating rows.
Application: 10 ml of biofertilizer per plant is applied near the roots during planting.
Growth Metrics: Plant height and leaf numbers are monitored weekly.

III. RESULTS AND DISCUSSIONS

A. Collection and Spoilage of Biodegradable Waste:

Fruit waste, particularly from papayas and watermelon, was collected from a fruit market and allowed to spoil over one week to test its effectiveness as biofertilizer material.

Fig 1: Homogenized spoilage of Papaya and Watermelon.

B. Spread Plate Technique and Colony Analysis:

The spread plate technique, using serial dilution, successfully isolated bacterial colonies. Table 1 summarizes the characteristics of colonies observed at different dilutions.

TABLE I. CHARACTERISTICS OF BACTERIAL COLONIES ISOLATED THROUGH SERIAL DILUTION.

Serial No.	Dilution	No. of Colonies	Color	Elevation	Size	Shape
1	10^ (-1)	30	White	Concave	Small	Irregular
2	10^ (-2)	61	White	Concave	Medium	Irregular
3	10^ (-3)	90	White	Round	Small	Irregular
		20	White	Concave	Big	Sausage
4	10^ (-4)	15	White	Round	Big	Regular
		165	White	Concave	Small	Regular
		25	White	Concave	Very small	Regular

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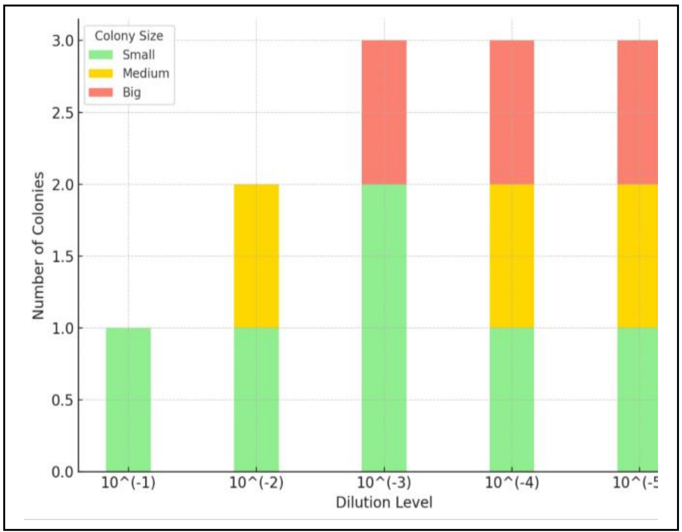
5	10^ (-5)	45	White	Round	Big	Regular
		108	White	Round	Medium	Regular
		147	White	Round	Small	Regular

GRAPH I. COLONY SIZE DISTRIBUTIONS ACROSS THE DILUTIONS.



C. Gram Staining Analysis:

Ten colonies underwent Gram staining, revealing five colonies as Gram-negative (pink) and five as Gram-positive (purple) observed under the microscope. The following table provides the morphological characteristics of these colonies.

TABLE II. GRAM STAINING RESULTS AND MORPHOLOGICAL DETAILS.

Serial No.	**Dilution**	**Gram Positive/Negative**	**Morphology**
1	10^ (-1)	Negative	Rod shape
2	10^ (-2)	Positive	Circular
3	10^ (-3)	Positive	Rod shape
		Positive	Convex
4	10^ (-4)	Negative	Circular
		Positive	Circular
		Negative	Rod shape
5	10^ (-5)	Negative	Rod shape
		Positive	Convex
		Negative	Circular

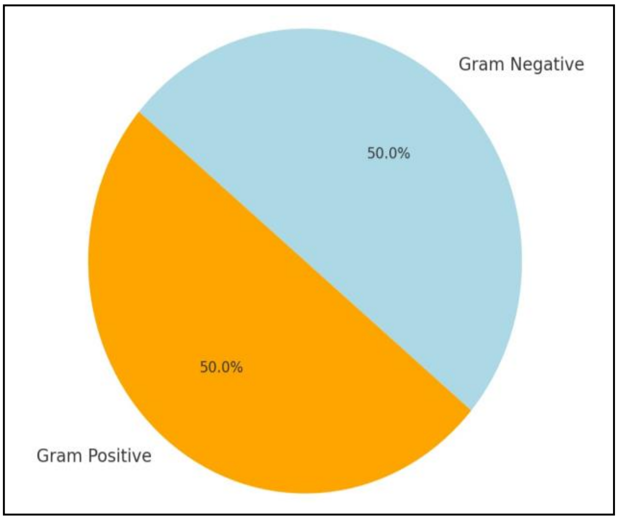


Fig 2: Distribution of gram staining result.

D. Indole Test Results:

Indole tests for all colonies were positive, indicating the presence of *Escherichia coli*, with each colony forming a characteristic cherry red ring.

TABLE III. INDOLE TEST RESULTS.

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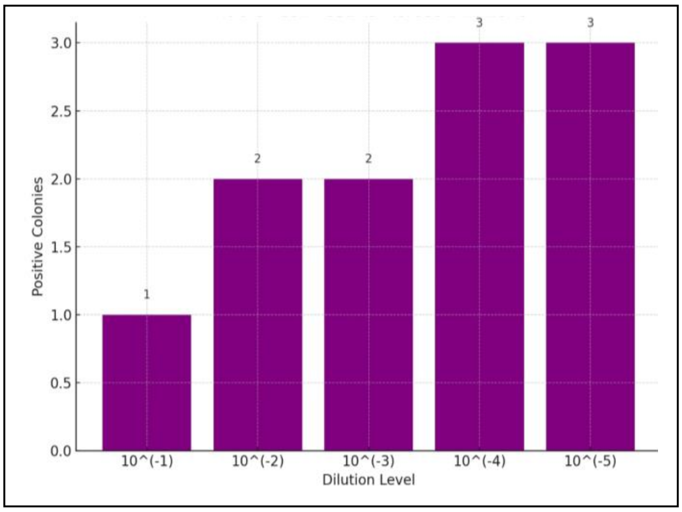
GRAPH II. INDOLE TEST RESULT DISTRIBUTION ACROSS DILUTIONS.



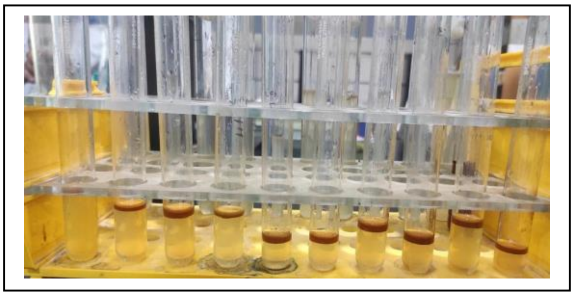


Fig. 5 Indole test result.

E. Effect of Biofertilizer on Plant Growth (Fenugreek):

The study examined the influence of biofertilizer, derived from decomposed fruit waste, on fenugreek plant growth. The effect was measured by observing changes in plant height, leaf count, and overall plant health over a set period, compared to a control group without biofertilizer.

Observations:

Increased Growth Rate: Plants treated with biofertilizer showed a significantly higher growth rate compared to untreated plants. This suggests that the biofertilizer enhanced nutrient availability.

Leaf Development: Treated plants exhibited a greater number of leaves per plant, indicating improved vegetative growth and chlorophyll production due to enriched soil nutrients.

Serial No.	Dilution	Indole Positive/Negative
1	10^ (-1)	Positive
2	10^ (-2)	Positive
5	10^ (-5)	Positive
		Positive
		Positive

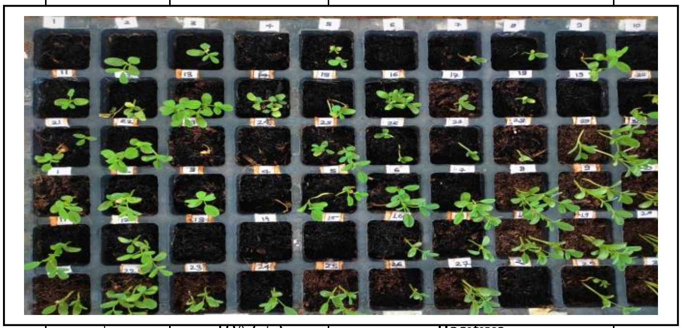


Fig. 6 Effects of biofertilizer on plant growth.

Overall Plant Health: Treated plants were visibly healthier, with darker green leaves and stronger stems, compared to the control group. This could be attributed to the beneficial microbes and organic matter provided by the biofertilizer, which improved soil structure and nutrient retention.

TABLE IV. COMPARISON OF GROWTH PARAMETERS BETWEEN TREATED (WITH BIOFERTILIZER) AND UNTREATED (CONTROL) FENUGREEK PLANTS.

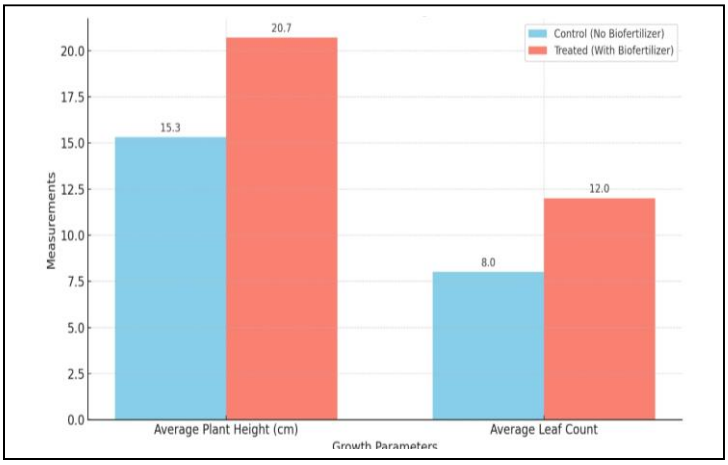


Fig 7. Effect of biofertilizer on plant growth parameters.

Parameter	Control (No Biofertilizer)	Treated (With Biofertilizer)
Average Plant Height (cm)	15.3 ± 0.5	20.7 ± 0.8
Average Leaf Count	8 ± 1	12 ± 1
Leaf Colour	Light Green	Darkish Green
Stem Strength	Moderate	Strong

The findings show that biofertilizers made from biodegradable fruit waste have the potential to increase plant growth. Increased plant height, more leaves, and better plant health were among the improved growth characteristics shown by treated fenugreek plants. These enhancements are attributable to the biofertilizer's organic matter and advantageous microbes, which probably enhanced the soil's nutritional profile and structural integrity. This emphasizes how crucial it is to use biodegradable waste as an efficient agricultural input in addition to for sustainable waste management.

The existence of beneficial bacteria like Escherichia coli, which are known to increase nitrogen availability in soil, is further confirmed by the continuously positive indole test findings. Gram staining was used to characterize the colony and showed that there was an equal distribution of both Gram-positive and Gram-negative bacteria, demonstrating microbiological diversity. By promoting nutrient cycling and inhibiting dangerous pathogens, this diversity significantly contributes to the improvement of soil health. A strong bacterial growth pattern is also shown by the colony size distribution across dilutions, indicating that the microbial population was flourishing in the enriched environment. These results confirm how biofertilizers help to create a microbial environment that promotes sustainable farming.

IV. CONCLUSION

The study effectively illustrated how biofertilizers made from biodegradable waste improve soil health and plant growth. Microbial activity and organic matter work together to create an environmentally responsible and reasonably priced substitute for chemical fertilizers. Future studies into maximizing the use of biodegradable waste and broadening its use across various crops and agricultural systems are made possible by these discoveries.

ACKNOWLEDGMENT

The success of any project depends largely on the team work and also encouragement and guidelines of many others. We take this opportunity to express our gratitude to the people who have been instrumental in the successful completion of this research.

Foremost, we would like to express our sincere gratitude towards Mahatma Gandhi Mission Universities' Institute of Biosciences and Technology for granting us the opportunity to work in the laboratories of the institute.

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