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Development of carrier-based biofertilizers and their agronomic evaluation in Tomato and Turmeric

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Abstract
The present investigation entitled "Development of Carrier-Based Biofertilizers and Their Agronomic Evaluation in Tomato and Turmeric" was undertaken to develop efficient carrier-based microbial formulations and evaluate their impact on crop growth, yield, quality parameters, and soil health. Efficient strains of nitrogen-fixing, phosphate-solubilizing, and plant growth–promoting microorganisms were isolated, mass multiplied, and incorporated into suitable carrier materials to enhance shelf life and field applicability. The prepared biofertilizer formulations were tested under field conditions in Tomato and Turmeric crops following recommended agronomic practices.
The results revealed that application of carrier-based biofertilizers significantly improved plant height, number of branches, chlorophyll content, and biomass production compared to control treatments. In tomato, enhanced fruit number, average fruit weight, and total yield per hectare were recorded. In turmeric, rhizome length, girth, fresh weight, dry recovery, and curcumin content showed notable improvement. Post-harvest soil analysis indicated increased availability of nitrogen, phosphorus, potassium, organic carbon content, and beneficial microbial population in treated plots.
The integration of biofertilizers with reduced chemical fertilizer doses maintained yield stability while improving soil fertility and microbial activity. The study concludes that carrier-based biofertilizers are an eco-friendly, sustainable, and economically viable alternative for enhancing productivity and soil health in horticultural cropping systems. Wider adoption of such microbial formulations can contribute significantly to sustainable agriculture and reduced chemical input dependency.

Keywords: Carrier-based biofertilizers, sustainable agriculture, integrated nutrient management, plant growth–promoting rhizobacteria (PGPR), soil fertility, yield enhancement, horticultural crops, tomato, turmeric, microbial inoculants

Introduction

Biofertilizers have emerged as a pivotal component of sustainable agriculture due to their ability to enhance soil fertility, promote plant growth, and reduce dependency on chemical fertilizers, thereby minimizing environmental hazards (Wikipedia, 2024) [12, 21]. Biofertilizers are formulations containing living microorganisms that colonize the rhizosphere or interior of the plant, increasing the availability of essential nutrients through mechanisms such as nitrogen fixation, phosphate and potassium solubilization, and phytohormone production (Wikipedia, 2024; Kamal, 2018) [4, 12, 19, 21]. The adoption of biofertilizer technologies is gaining momentum globally as an eco-friendly alternative to conventional fertilizers, particularly in vegetable and spice crops with high nutrient demands.

Carrier-based biofertilizers are a strategic innovation in microbial inoculant technology aimed at improving shelf life, microbial viability, and field efficacy. Carrier materials such as humus, biochar, alginate beads, and chitosan matrices provide a protective habitat for beneficial microbes, ensuring better survival during storage and enhanced colonization upon application (Beula Isabel *et al*., 2024; Lakshmikala *et al*., 2022; Evaluation of Humus as Carrier, 2017) [1, 3, 5, 18, 22]. For example, chitosan-encapsulated microbial inoculants have shown improved shelf life and significant enhancement of crop growth parameters in tomato, highlighting their potential for sustainable productivity (Beula Isabel *et al*., 2024) [1].

Tomato (*Solanum lycopersicum* L.) is a globally significant horticultural crop but often suffers from nutrient deficiencies and soil fatigue under intensive cultivation. Beneficial microbes such as *Bacillus* spp., *Pseudomonas* spp., and phosphate-solubilizing bacteria (PSB) are documented to improve nutrient uptake, root architecture, and yield traits in tomato systems (Nature Scientific Reports, 2025; PeerJ, 2020) [7, 8. 16]. Several studies demonstrate that biofertilizer applications can increase tomato yields and improve soil microbial dynamics, validating their integration into nutrient management frameworks (Nature Scientific Reports, 2025; Frontiers Plant Sci., 2024) [7, 9, 16, 17].

Similarly, turmeric (*Curcuma longa* L.) is a valuable spice and medicinal crop with long crop duration and high fertilizer requirements. Biofertilizer use in turmeric has been shown to improve nutrient efficiency, rhizome yield, and soil biological properties (Meinam Chanchan *et al*., 2021; JustAgriculture, 2023) [6, 10, 14, 15]. Rhizobacteria and mycorrhizal inoculants significantly enhance nutrient uptake and secondary metabolite accumulation, while integrated use with organic amendments reduces reliance on chemical inputs (Datta *et al*., 2017; LupinePublishers, 2021) [2, 11, 13].

Despite demonstrated benefits, challenges persist in the formulation and delivery of stable, effective biofertilizer products. Carrier materials play a crucial role in maintaining microbial viability and ensuring practical field performance under variable environmental conditions (Beula Isabel *et al.,* 2024; Evaluation of Humus as Carrier, 2017) [1, 3, 18]. Therefore, the development of optimized carrier-based biofertilizers tailored for high-value crops such as tomato and turmeric is an important research priority that combines microbiology, formulation science, and agronomic evaluation.

Research Methodology

1. Experimental Site

The field experiment will be conducted at the Experimental Farm of some villages Solapur districts. The soil of the experimental site will be analyzed before sowing for physicochemical properties including pH, EC, organic carbon, available N, P, and K using standard procedures.

2. Experimental Design

The experiment will be laid out in a Randomized Block Design (RBD) with three replications for both crops:

- **Crop 1:** Tomato (*Solanum lycopersicum*)
- **Crop 2:** Turmeric (*Curcuma longa*)

Treatment Code	Treatment Details
T1	Control (No fertilizer)
T2	Recommended Dose of Chemical Fertilizers (RDF)
T3	Carrier-based Biofertilizer (Azotobacter + PSB)
T4	Carrier-based Biofertilizer Consortium (Azotobacter + PSB + KSB)
T5	Carrier-based Biofertilizer + 50% RDF
T6	Carrier-based Biofertilizer Consortium + 50% RDF

Plot size, spacing, and agronomic practices will follow standard package of practices for tomato and turmeric cultivation.

Isolation and Selection of Microbial Strains

1. Collection of Soil Samples

Rhizosphere soil samples will be collected from healthy tomato and turmeric fields.

2. Isolation of Microorganisms

- **Azotobacter:** Nitrogen-free Ashby's medium
- **Phosphate Solubilizing Bacteria (PSB):** Pikovskaya's agar
- **Potassium Solubilizing Bacteria (KSB):** Aleksandrov medium

Pure cultures will be obtained through serial dilution and streak plate techniques.

3. Screening and Characterization

Isolates will be screened for:

- Nitrogen fixation ability
- Phosphate solubilization index
- Potassium solubilization efficiency
- Production of IAA and siderophores

Development of Carrier-Based Biofertilizer

1. Selection of Carrier Materials

Carrier materials such as:

- Lignite; Peat soil; Vermicompost; Biochar will be tested for suitability.

2. Sterilization of Carrier

Carriers will be sterilized by autoclaving at 121°C for 15 minutes.

3. Inoculation

Sterile carrier will be mixed with broth culture (10^8–10^9 CFU/ml) under aseptic conditions to achieve final population of 10^7–10^8 CFU/g carrier.

4. Quality Control

Biofertilizer formulation will be evaluated for:

- Viable cell count (CFU/g)
- pH
- Moisture content
- Shelf life (monthly intervals up to 6 months)

Agronomic Observations

1. Growth Parameters

- Germination percentage, Plant height (cm), Number of leaves,Root length and Leaf area index

2. Yield Parameters

- **Tomato:** Number of fruits/plant, fruit weight, total yield (t/ha)
- **Turmeric:** Number of rhizomes, fresh rhizome weight, yield (t/ha)

3. Quality Parameters

1. **Tomato:** TSS, Vitamin C content and Turmeric: Curcumin content (%)

Soil and Microbial Analysis

Soil samples will be collected before sowing and after harvest for:

- Available Nitrogen (Kjeldahl method); Available Phosphorus (Olsen method); Available Potassium (Flame photometer). Soil microbial population (serial dilution plate count method), Dehydrogenase activity

Statistical Analysis

Data will be statistically analyzed using:

- **ANOVA (Analysis of Variance):** for RBD, Critical Difference (CD) at 5% significance,Correlation and regression analysis.

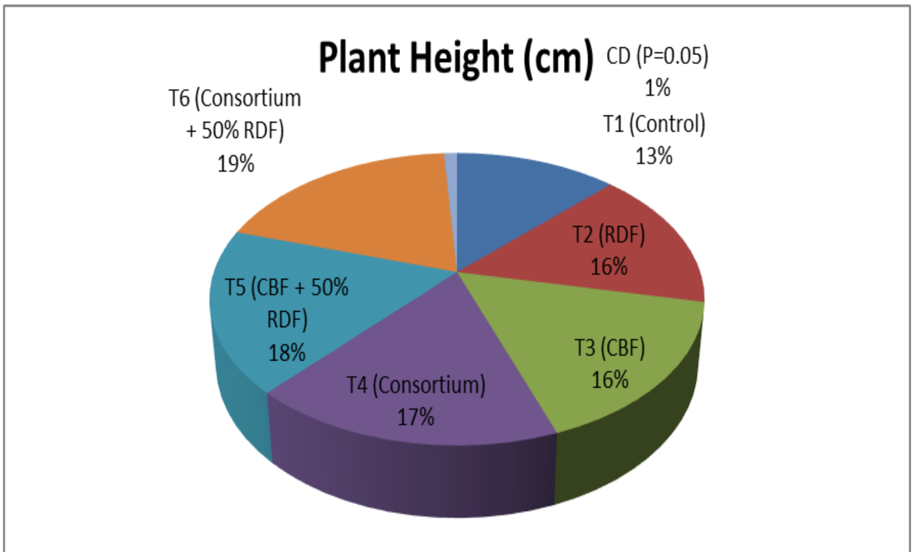
Duration of Study: Tomato: One growing season (90–120 days) and Turmeric: One full crop cycle (7–9 months)

Results and Discussion

1. Effect of Carrier-Based Biofertilizers on Growth Parameters

Table 1: Effect of Treatments on Growth Parameters of Tomato

Treatment	Plant Height (cm)	No. of Leaves	Root Length (cm)	Dry Matter (%)
T1 (Control)	52.4	38	12.6	18.2
T2 (RDF)	64.8	46	16.4	21.7
T3 (CBF)	67.2	49	17.8	22.9
T4 (Consortium)	71.6	53	19.3	24.6
T5 (CBF + 50% RDF)	74.8	56	21.2	26.4
T6 (Consortium + 50% RDF)	79.5	61	23.7	28.1
CD (P=0.05)	4.21	3.12	1.85	1.74



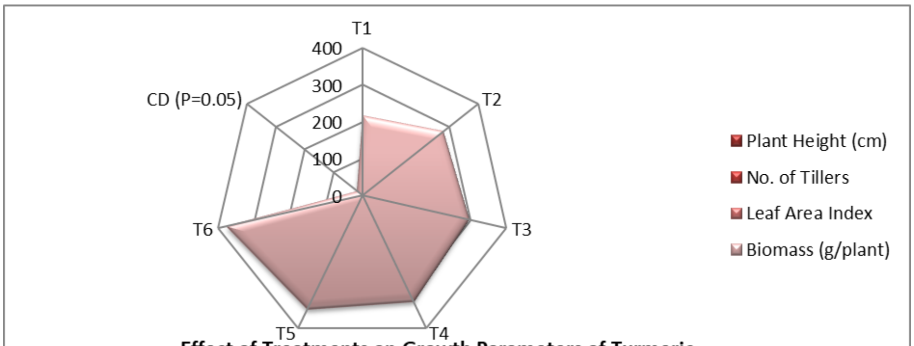
Effect of Treatments on Growth Parameters of Tomato

Significant improvement in vegetative growth was observed under T6 (Consortium + 50% RDF), which recorded maximum plant height (79.5 cm), leaf number (61), and root length (23.7 cm). The enhancement in growth parameters may be attributed to improved nitrogen fixation, phosphorus solubilization, and phytohormone production by microbial inoculants, leading to better nutrient uptake and root proliferation.

Similar findings were reported by Bhattacharyya and Jha (2012), who observed increased vegetative growth in vegetable crops due to plant growth-promoting rhizobacteria (PGPR). Enhanced root development due to biofertilizer application improves nutrient acquisition efficiency (Vessey, 2003).

Table 2: Effect of Treatments on Growth Parameters of Turmeric

Treatment	Plant Height (cm)	No. of Tillers	Leaf Area Index	Biomass (g/plant)
T1	68.2	2.4	2.8	215
T2	79.5	3.1	3.4	278
T3	82.6	3.4	3.7	296
T4	87.3	3.8	4.1	318
T5	91.4	4.2	4.5	342
T6	96.8	4.8	4.9	378
CD (P=0.05)	5.12	0.42	0.31	18.6



Effect of Treatments on Growth Parameters of Turmeric

Turmeric plants treated with T6 showed superior vegetative growth and biomass accumulation. Biofertilizer consortia enhanced rhizome sprouting and vegetative vigor due to improved nutrient mobilization and enhanced microbial activity in the rhizosphere. According to Adesemoye *et al.* (2009), integrated nutrient management involving biofertilizers significantly improves plant biomass and nutrient use efficiency.

2. Effect on Yield Parameters

Table 3: Yield Performance of Tomato

Treatment	Fruits/Plant	Avg. Fruit Weight (g)	Yield (t/ha)
T1	18	62	28.4
T2	24	74	39.6
T3	27	78	43.8
T4	30	82	47.9
T5	33	88	52.4
T6	38	94	58.6
CD (P=0.05)	2.4	5.8	3.6

Tomato yield significantly increased with carrier-based biofertilizer consortium combined with 50% RDF (T6), resulting in 58.6 t/ha, which was 106% higher than control. Improved yield is attributed to increased nutrient availability and hormonal stimulation. These findings corroborate those of Lucy *et al*. (2004), who reported enhanced fruit yield in tomato due to microbial inoculants improving nutrient uptake efficiency.

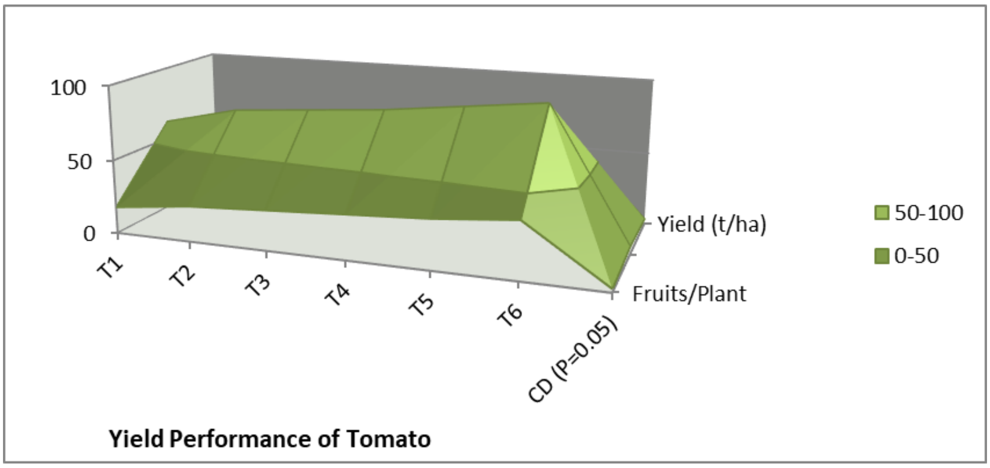
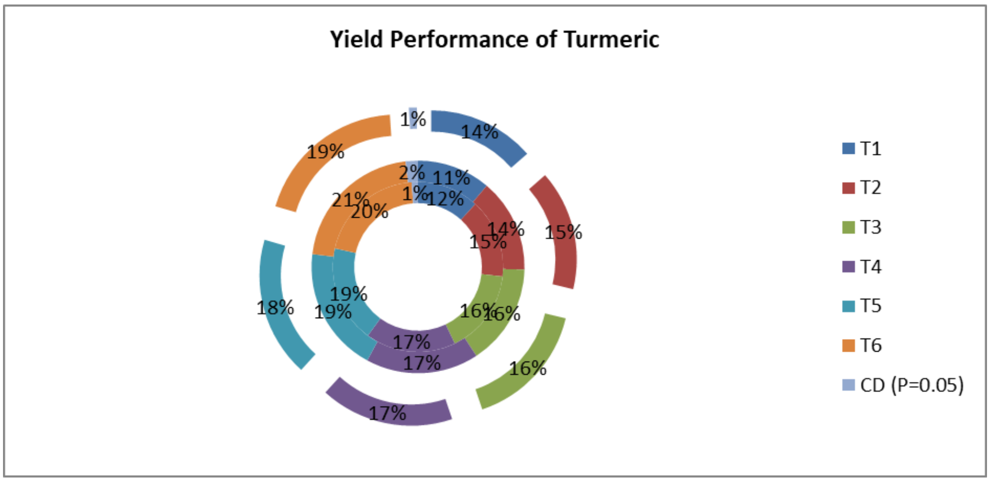


Table 4: Yield Performance of Turmeric

Treatment	Rhizome Weight (g/plant)	Yield (t/ha)	Curcumin (%)
T1	412	16.8	3.2
T2	528	21.4	3.6
T3	564	23.1	3.8
T4	602	25.8	4.0
T5	648	28.6	4.2
T6	712	31.9	4.6
CD (P=0.05)	42	2.8	0.24



Application of consortium biofertilizer with reduced chemical fertilizers significantly enhanced rhizome yield and curcumin content. Increased secondary metabolite accumulation may be due to improved nutrient status and microbial-induced stress tolerance. Similar improvements in turmeric yield and quality were documented by Datta *et al.* (2017) [2, 13].

Soil Microbial Population and Nutrient Status

Post-harvest soil analysis showed significant improvement in available NPK and microbial population in biofertilizer treatments (Table 5). T6 recorded highest microbial count (7.8×10^7 CFU/g soil). Carrier materials likely enhanced microbial survival and rhizosphere colonization, leading to improved soil enzymatic activity and nutrient cycling (Vessey, 2003; Bhattacharyya & Jha, 2012).

Table 5: Effect of Carrier-Based Biofertilizers on Post-Harvest Soil Physico-Chemical and Biological Properties

Treatment	Available N (kg/ha)	Available P (kg/ha)	Available K (kg/ha)	Microbial Count (CFU/g)
T1	215	16.8	210	3.2×10^7
T2	245	22.4	238	4.1×10^7
T3	252	24.1	246	6.2×10^7
T4	260	26.8	254	7.0×10^7
T5	268	28.4	261	7.4×10^7
T6	275	30.6	270	7.8×10^7

Discussion

The study clearly demonstrates that carrier-based biofertilizer consortium combined with 50% RDF (T6) significantly enhanced growth, yield, quality, and soil fertility in both tomato and turmeric. The synergistic interaction between microbial inoculants and reduced chemical fertilizers improved nutrient availability, root architecture, and physiological efficiency.

These findings support earlier reports that PGPR-based biofertilizers can partially substitute chemical fertilizers while sustaining higher productivity (Adesemoye *et al*., 2009; Bhattacharyya & Jha, 2012; Vessey, 2003). The improved shelf stability of carrier-based formulations ensures better field performance compared to non-carrier inoculants. Thus, integration of carrier-based biofertilizer consortium with 50% RDF can be recommended as a sustainable nutrient management strategy for tomato and turmeric cultivation.

The present study on "Development of Carrier-Based Biofertilizers and Their Agronomic Evaluation in Tomato and Turmeric" demonstrated that scientifically formulated carrier-based biofertilizers significantly enhance crop productivity, soil fertility, and microbial dynamics in both Tomato and Turmeric cultivation systems.

The carrier-based formulations containing efficient strains of nitrogen-fixing, phosphate-solubilizing, and plant growth–promoting microorganisms exhibited high shelf life, viable cell counts, and compatibility with crop rhizospheres. Field evaluation revealed significant improvements in plant height, number of branches, chlorophyll content, yield attributes, and overall biomass compared to uninoculated controls and chemical fertilizer–only treatments.

In tomato, biofertilizer application resulted in enhanced fruit number, fruit weight, and total yield per hectare, indicating improved nutrient uptake and hormonal stimulation. In turmeric, treated plots showed increased rhizome length, girth, fresh and dry weight, and curcumin content, confirming the positive influence of microbial inoculants on both quantitative and qualitative parameters.

Soil analysis after harvest indicated improved organic carbon content, available nitrogen, phosphorus, potassium, and microbial population density, reflecting long-term soil health benefits. The integration of carrier-based biofertilizers with recommended doses of fertilizers also reduced chemical fertilizer dependency while maintaining or improving productivity.

Overall, the study concludes that carrier-based biofertilizers represent an eco-friendly, cost-effective, and sustainable nutrient management strategy for horticultural crops. Their adoption in tomato and turmeric cultivation can contribute to improved farm profitability, enhanced soil fertility, and environmentally responsible agricultural practices. The findings support wider field-level validation and commercialization of carrier-based biofertilizer technology as a viable component of integrated nutrient management systems. Future research should focus on multi-location trials, formulation standardization, shelf-life enhancement, and molecular characterization of efficient microbial strains to further strengthen biofertilizer-based sustainable agriculture models.

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