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Effect of microbial consortia on yield and quality of pomegranate cv. Bhagwa

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Abstract
A field experiment was conducted on "Effect of microbial consortia on plant growth, yield, and fruit quality of *pomegranate* (*Punica granatum* L.) cv. Bhagwa" at farmer's field near University of Horticultural sciences, Bagalkot during 2022-23. Yield and fruit quality parameters were markedly influenced by microbial inoculation. The highest fruit set (78.88%), fruit number (84.67 fruits/plant), fruit weight (302.47 g), and marketable yield (25.63 kg/plant; 21.32 t/ha) were obtained in T_5. Microbial treatments also enhanced aril weight (208.73 g), aril-to-peel ratio (2.23), and fruit firmness (14.68 N), with favourable TSS (16.40 °Brix), juice content (52.67%), and reduced acidity (0.40-0.42%). Fruit micronutrient content (Fe 231.10 mg L^{-1}; Zn 72.01 mg L^{-1}), red pigmentation (high a* values) and total phenols (163.24 mg QE/100 g) were significantly improved under microbial consortia. Overall, the integration of microbial consortia with RDF, particularly in T_5, T_6 and T_8 enhanced yield, and fruit quality of *pomegranate* cv. Bhagwa.

Keywords: Pomegranate, microbial consortia

Introduction
Pomegranate (*Punica granatum* L.), a culturally significant and ancient fruit native to the Middle East, is valued for its nutrient-rich arils and wide range of bioactive phytochemicals found in its seeds, rind, leaves, and juice. A member of the small Lythraceae family, it is consumed fresh or processed into products such as juices, fresh arils, seed oil, jams, syrups, teas, wines, and various confectionaries and oral-care items. The crop is cultivated extensively across many countries, with India being the largest producer especially in Maharashtra, Karnataka, Gujarat, and Andhra Pradesh supported by over 2.82 lakh hectares under cultivation. The fruit is also recognized for its cultural symbolism of abundance and fertility, and has been highlighted in major horticultural events. Its hardy nature allows it to grow well in semi-arid and tropical regions, making it popular among farmers. Increasing global demand for health-promoting foods has further elevated its economic importance in both domestic and export markets.

Optimal nutrient management is crucial for high yield and quality in pomegranate cultivation. Reliance solely on chemical fertilizers can harm soil health, making integrated nutrient management essential. Organic amendments like compost and vermicompost, along with micronutrients and biofertilizers, improve soil fertility, fruit quality, and plant resilience. Beneficial microbes including *Azospirillum*, *Trichoderma harzianum*, *Pseudomonas fluorescens*, and phosphorus-solubilizing organisms enhance nutrient availability, stimulate root growth, suppress pathogens, and boost tolerance to stresses, making microbial consortia more effective than single strains.

Materials and Methods
The experiment was carried out to examine "The effect of microbial consortia on growth, yield and quality of pomegranate cv. Bhagwa" at Hiresamsi village of Bagalkot district, Karnataka, during 2022-23. The location comes under northern dry zone of Karnataka and situated at 16. 22' N latitude and 75°.52' E longitude at an altitude of 542 m above Mean Sea Level (MSL).

Number of treatments: 08
Number of replications: 03
Design: RCBD (Randomized Complete Block Design)
Crop Season: Hasta bahar
Crop Spacing: 12 X 10 feet

Treatment	Treatment details
T_1	75% RDF-UHSB
T_2	100% RDF-UHSB (400:200:200 g NPK/plant) control
T_3	125% RDF-UHSB
T_4	75% RDF+ Microbial consortia
T_5	100% RDF+ Microbial consortia
T_6	125% RDF+ Microbial consortia
T_7	NRCP-RDF (650:250:250 g NPK/plant)
T_8	NRCP-RDF + Microbial consortia

RDF-Recommended dose of fertilizer; NRCP-National Research Centre for Pomegranate; UHSB-University of Horticultural Sciences, Bagalkot

A microbial consortium consisting of *Azotobacter* (15 g), PSB (15 g), KMB (15 g), *Trichoderma* (20 g), *Pseudomonas* (15 g), and VAM (20 g) was applied at 100 g per plant, 15 days before the bahar treatment. Neem cake was also applied at 1 kg per plant to all treatments except the control at the same time. In addition, FYM at 20 kg per plant was given uniformly to all treatments 30 days before the bahar treatment. Micronutrients including $ZnSO_4$, $FeSO_4$, $MnSO_4$ at 25 g per plant each, and boron at 10 g per plant were also applied to support balanced plant nutrition. The full dose of phosphorus, along with 50% of nitrogen and 50% of potassium, was applied 15 days before the bahar treatment. The remaining 50% nitrogen was supplied at the flowering stage, while the remaining 50% potassium was applied after fruit set to support crop growth and development.

Fruit number: The number of fruits per plant was counted and recorded.

Fruit set %

$$\text{Fruit set (\%)} = \frac{\text{No.of developing fruitlets}}{\text{No.of hermaphrodite flowers at full bloom}} \text{X } 100$$

Fruit weight: Fruit weight was determined by weighing five randomly selected fruits from each of the three grades and expressing the average in grams.

Fruit length: Fruit length and diameter were measured using Vernier callipers.

Aril weight (g), Peel weight (g), Aril to peel ratio (aril/peel)

Aril weight and peel weight (including lamella) were measured from five fruits, and their averages were expressed in grams, while the aril-to-peel ratio was obtained by dividing aril weight by peel weight.

Yield

Yield per plant (kg/plant) was determined by pooling the total fruit weight harvested from each plant and yield per hectare (t/ha) was calculated using the plant population of 741 plants per hectare at a spacing of 4.5 m × 3.0 m, multiplying yield per plant by 741 and expressing the result in metric tonnes.

TSS (^{0}Brix)

The total soluble solids (TSS) were measured from extracted juice using a Zeiss digital refractometer at room temperature and expressed in °Brix.

Juice (%)

Juice percentage was assessed by crushing 30 g of arils with a mortar and pestle and measuring the extracted juice using a measuring cylinder.

Titratable acidity (%)

Titratable acidity (%) was estimated by titrating 1 mL of juice against 0.01 N NaOH using phenolphthalein indicator, and the value was expressed as percent citric acid equivalent using the formula:

(Titrate volume × Normality of NaOH × Eq. wt. of citric acid × 100)/(Volume of juice sample × 1000).

TSS to acid ratio: The TSS: acid ratio was calculated by dividing TSS by titratable acidity.

Nutrients (Zn and Fe)

For nutrient analysis (Zn and Fe), 15 ml of pomegranate juice was digested with concentrated nitric acid overnight, followed by digestion with a nitric perchloric acid mixture (9:4) on a sand bath, and the final digest was analyzed for Fe and Zn using standard leaf mineral analysis procedures.

Results and Discussion

The yield parameters of pomegranate cv. Bhagwa were significantly influenced by the combined application of microbial consortia with recommended doses of fertilizers. Integration of biofertilizers such as *Azotobacter*, PSB, K-solubilizers, and VAM fungi along with inorganic nutrients resulted in enhanced fruit set and yield attributes compared to sole application of RDF.

The maximum number of fruits per plant was observed in T_5 (84.67) and T_8 (84.33), with significantly higher fruit set (78.88% and 77.13%, respectively), compared to T_1 (63.33 fruits with 68.59% fruit set). Improved fruit set under microbial consortia is attributed to enhanced availability of nutrients, improved pollen viability and reduced flower drop due to balanced hormonal regulation by microbial inoculants (Akash *et al.*, 2013; Solanki *et al.*, 2020) [1, 2, 10]. Maximum fruit weight was recorded in T_5 (302.47 g) and T_6 (302.23 g), followed closely by T_8 (301.94 g), which were significantly superior to the control T_2 (271.02 g). Similarly, fruit length and diameter were highest in T_8 (90.10 mm and 88.97 mm), indicating better cell division and enlargement due to improved potassium and calcium uptake (Yadav *et al.*, 2011) [12]. The maximum aril weight was obtained in T_5 (208.73 g), whereas peel weight was highest in T_1 (107.08 g) and lowest in T_5 (93.74 g). Consequently, the aril-to-peel ratio was highest in T_5 (2.23), indicating better edible portion development and consumer preference. This may be attributed to improved nutrient partitioning and better source sink relationships facilitated by microbial inoculants (Sharma *et al.*, 2013). The yield per plant was highest in T_5 (25.63 kg/plant) and T_8 (24.77 kg/plant), translating to 21.32 and 20.38 t/ha, respectively, compared to 16.73 t/ha in the control (T_2). The substantial increase in yield under integrated treatments demonstrates the positive synergistic effect of RDF and microbial inoculants on nutrient uptake, fruit development, and overall productivity (Dheware *et al.*, 2020) [4].

Table 1: Effect of application of microbial consortia on yield parameters in pomegranate cv. Bhagwa

Treatment	Number of fruits per plant	Fruit set (%)	Fruit weight (g)	Fruit length (mm)	Fruit diameter (mm)	Aril weight/fruit (g)	Peel weight (g)	Aril to peel ratio	Yield (kg/plant)	Yield (t/ha)
T_1	63.33	68.59	263.71	76.60	77.13	156.63	107.08	1.46	18.72	15.44
T_2	69.67	76.55	271.02	77.30	78.90	170.13	100.89	1.69	20.15	16.73
T_3	70.00	76.64	273.32	80.23	80.27	173.68	99.63	1.74	21.06	17.39
T_4	83.67	77.70	294.96	81.80	80.29	198.10	96.86	2.04	24.48	20.18
T_5	84.67	78.88	302.47	82.63	88.17	208.73	93.74	2.23	25.63	21.32
T_6	81.00	73.63	302.23	86.47	86.43	204.37	97.86	2.09	24.65	20.39
T_7	78.33	72.30	297.10	81.97	80.87	196.92	100.19	1.97	23.31	19.43
T_8	84.33	77.13	301.94	90.10	88.97	203.63	98.31	2.07	24.77	20.38
SEm ±	2.70	1.07	5.71	2.02	2.16	5.14	1.86	0.06	0.80	0.71
CD (p = 0.05)	8.19	3.26	17.33	6.13	6.57	15.60	5.65	0.18	2.41	2.15

The fruit quality parameters of pomegranate cv. Bhagwa were significantly influenced by the application of microbial consortia in combination with recommended fertilizers. Treatments T_5 (100% RDF + microbial consortia) and T_6 (125% RDF + microbial consortia) recorded maximum improvements in most quality traits, highlighting the synergistic role of microbial inoculants in nutrient mobilization, physiological processes, and quality enhancement.

Total soluble solids (TSS) were significantly higher in T6 (16.40 °Brix) compared to the control T_2 (15.30 °Brix). The improvement in TSS may be attributed to enhanced photosynthetic efficiency, increased assimilate production, and greater translocation of sugars to the fruit under the influence of *Azotobacter*, PSB, and K-solubilizing bacteria in the consortia (Osman & El-Rhman, 2010). The number of arils per fruit showed a significant increase, with T_5 (660.07) and T_6 (669.71) outperforming the control (559.84). This could be due to the better nutrient supply, especially nitrogen and potassium, which promote cell division and fruit development (Varghese *et al.*, 2023) [11].

Fruit firmness was highest in T_5 (14.68 N) and T_6 (14.31 N) compared to the control T_2 (12.10 N). Increased firmness may be associated with improved uptake of calcium and potassium, which play a role in cell wall integrity and strengthening of middle lamella (Dheware *et al.*, 2020) [4]. Fruit juice percentage was also enhanced under microbial consortia treatments, with T_6 recording 52.67% compared to 50.83% in T_2. The increase in juice content may be linked with improved water and nutrient relations in the plant, facilitated by VAM fungi, which enhance root absorption efficiency (Hari *et al.*, 2021) [6]. Reported similar results in papaya, where integrated nutrient management improved fruit juice recovery and pulp quality. Titrable acidity decreased under microbial consortia treatments, with the lowest acidity (0.40%) recorded in T_8. A reduction in acidity is often associated with better sugar-acid balance, thereby improving palatability (Akash *et al.*, 2013) [1, 2]. The TSS: acid ratio was highest in T_8 (39.75), followed by T_2 (35.61), indicating a significant improvement in overall sweetness and flavour profile under integrated nutrient management. A higher TSS: acid ratio is a key indicator of consumer preference and market acceptance. Rind thickness varied significantly across treatments, with the highest value in T_5 (3.98 mm), which is associated with improved calcium and potassium assimilation. A balanced rind thickness is essential for fruit transportability and shelf life. Similar observations were reported by Yadav *et al.* (2011) [12] in mango cv. Amrapali, where microbial inoculants increased rind thickness and fruit weight.

Table 2: Effect of application of microbial consortia on fruit quality parameters in pomegranate cv. Bhagwa

Treatment	TSS(^{0}Brix)	Aril number/fruit	Firmness of fruit (N)	Fruit juice (%)	Titrable acidity (%)	TSS to acid ratio	Rind thickness (mm)
T_1	13.97	494.95	12.41	49.77	0.49	32.70	2.63
T_2	15.30	559.84	12.10	50.83	0.43	35.61	3.34
T_3	15.90	528.80	12.36	52.00	0.44	36.14	2.14
T_4	14.50	615.00	14.36	51.00	0.46	31.52	3.89
T_5	15.00	660.07	14.68	52.57	0.42	35.72	3.98
T_6	16.40	669.71	14.31	52.67	0.48	34.17	3.06
T_7	15.10	636.49	13.79	50.67	0.45	33.56	2.34
T_8	15.90	648.87	14.32	51.83	0.40	39.75	3.26
SEm ±	0.21	18.32	0.19	0.48	0.01	0.60	0.25
CD (p = 0.05)	0.64	55.57	0.58	1.46	0.02	1.81	0.75

Fruit colour is a important quality trait in pomegranate, influencing both market preference and nutritional value. Among the treatments, The $L*$ (lightness) value was highest in T_1 (44.67) and lowest in T_8 (26.40), whereas the $a*$ value (redness) was highest in T_4 (41.57), followed by T_5 (36.70) and T7 (35.87). Similarly, the b* value (yellowness) was maximum in T_1 (31.67) and lowest in T5 (23.97). These results suggest that microbial consortia, when integrated with RDF, promoted higher redness (a*) values while reducing lightness, which corresponds to the development of deep red aril colour preferred in the Bhagwa cultivar. The enhancement of red pigmentation ($a*$) under treatments involving microbial consortia (T_4, T_5, T_7, T_8) can be attributed to the role of beneficial microbes in improving nutrient availability, particularly potassium and micronutrients, which are crucial for anthocyanin biosynthesis. Potassium application significantly enhances anthocyanin accumulation and improves red pigmentation in pomegranate (Harhash *et al.*, 2019) [5].

Micronutrient content in fruit juice was significantly improved under microbial consortia. The highest Fe (231.10 mg L⁻¹) and Zn (72.01 mg L⁻¹) were recorded in T_5 and T_6, respectively, compared to the control. This improvement is due to microbial activity (siderophore production, organic acid secretion) that enhances Fe and Zn solubility and uptake (Hasan *et al.*, 2013) [7].

Table 3: Effect of Application of microbial consortia on instrumental colour values, micronutrient and phenol content in pomegranate cv. Bhagwa

Treatment	*L**	*a**	*b**	Phenols (mg QE/100g)	Fe content in fruit juice (mg L^{-1})	Zn content in fruit juice (mg L^{-1})
T_1	44.67	32.50	31.67	126.27	198.60	58.90
T_2	38.77	31.97	24.37	138.14	199.60	69.80
T_3	35.87	30.43	26.13	139.82	210.00	65.30
T_4	34.87	41.57	26.63	155.74	213.80	70.02
T_5	29.97	36.70	23.97	163.24	224.80	72.01
T_6	37.27	34.43	26.97	138.35	231.10	70.42
T_7	37.90	35.87	28.03	150.05	210.90	67.45
T_8	26.40	34.70	24.53	143.63	205.00	69.00
SEm ±	1.14	1.89	1.41	2.35	2.68	1.22
CD (p = 0.05)	3.47	5.74	4.28	7.13	8.13	3.69

Conclusion

The study showed that integrating microbial consortia with recommended fertilizer doses significantly improved the yield and quality of pomegranate cv. Bhagwa. Treatments T5, T6 and T8 consistently increased fruit set, fruit weight, aril-to-peel ratio and overall marketable yield. Fruit quality parameters including total soluble solids, juice percentage, firmness, micronutrient content, phenolics and micronutrient content were also markedly enhanced. Overall, microbial consortia effectively boosted both yield and fruit quality by improving nutrient use efficiency.

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