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Effect of liquid consortium of *Azotobacter,* phosphate solubilizing bacteria and potassium mobilizing bacteria on soil and plant nutrient status of custard apple (*Annona squamosa* L.) var. Phule Purandar

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Abstract
A field experiment was conducted during *Kharif* Bahar 2024 at the All India Coordinated Research Project on Arid Zone Fruits (Fig and Custard Apple), Jadhavwadi, Pune, with laboratory analyses conducted at the Division of Plant Pathology and Agricultural Microbiology and the Division of Soil Science and Agricultural Chemistry, College of Agriculture, Pune. to study the impact of a liquid consortium containing *Azotobacter*, Phosphate Solubilizing Bacteria (PSB), and Potassium Mobilizing Bacteria (KMB), integrated with varying levels of recommended fertilizer dose (RDF), on the soil and nutrient uptake parameters of custard apple. The experiment was laid out in Randomized Block Design (RBD) with ten treatments and three replications. Treatments included different combinations of RDF (100%, 75%, 50%) with or without the liquid consortium, alongside biofertilizer-only and control plots. The soil application of treatment T_5 (100 % RDF + Liquid consortium of *Azotobacter* PSB and KMB @20 ml each per L water per plant) recorded maximum available soil nitrogen (250.87 kg/ha), phosphorus (54.48 kg/ha), and potassium (509.95 kg/ha) along with highest nutrient uptake (N: 88.20 kg/ha, P: 14.15 kg/ha, K: 76.45 kg/ha). Treatment T_6 i.e.75 % RDF + Liquid cons. of Azotobacter+ PSB + KMB @ 20 ml each per L water per plant followed closely with statistically comparable nutrient uptake values.

Keywords: Azotobacter, phosphate solubilizing bacteria, potash mobilizing bacteria, soil nutrient availability, nutrient uptake

Introduction
Custard apple (*Annona squamosa* L.) is a delectable and significant minor fruit crop well-suited to tropical and subtropical climates. Belonging to the Annonaceae family, this fruit is originally from the West Indies but has been cultivated across Central America to Southern Mexico since ancient times. In India, custard apple is cultivated on approximately 45,000 hectares of land, with a production of 3,90,000 metric tons (Annon, 2021) [1]. The primary states for its cultivation are Maharashtra, Gujarat, Andhra Pradesh, Madhya Pradesh, Karnataka, Tamilnadu, Bihar, Orrisa and Assam. In Maharashtra alone, over 7,000 hectares of land produced 1,20,880 tonnes of custard apples. In Maharashtra, custard apple is mainly cultivated in Pune, Solapur, Dhule, Ahilyanagar, Chhatrapati Sambhajinagar, Nashik, Satara and Beed districts.

Biofertilizer is increasingly important due to its environmental safety, non-toxic nature, and potential to reduce soil and water pollution. It plays a key role in promoting organic and sustainable agriculture, offering small and marginal farmers an eco-friendly means to enhance crop yields (Moorthy and Malliga, 2012) [12]. The application of biofertilizer involves the inoculation of microorganisms that convert non-usable nutrient elements into a usable form through biological processes (Bandara *et al*., 2019) [2].

Microbial inoculants, notably *Azotobacter* (nitrogen-fixing bacteria), PSB (phosphate solubilizing bacteria), and KMB (potash mobilizing bacteria), play pivotal roles in transforming soil nutrients from insoluble or unavailable forms into bioavailable ones for plants. The combined application of these beneficial microbes, known as a liquid consortium, has the capacity to significantly improve soil fertility, nutrient uptake, and crop performance, particularly in custard apple cultivation. Using biofertilizers along with chemical fertilizers in custard apple farming ensures a synergistic effect-boosting productivity, preserving soil health, and promoting sustainability. This integrated nutrient management approach is especially valuable in the long-term cultivation of perennial fruit crops like custard apple. Thus the present studies were carried out to evaluate the effect of liquid consortium of *Azotobacter*, PSB, and KMB on soil nutrient availability and the uptake efficiency in custard apple, contributing to the broader goals of sustainable fruit production.

Materials and Methods

The details of the material used and methods adopted during the course of the present investigation are described under.

Experimental details

Season *Kharif Bahar* 2024
Treatments 10
Replication Three
Design RBD

Treatment Details

T_1	Recommended Dose of Fertilizers (RDF) (250: 125: 125 g NPK per plant)
T_2	100% RDF + Liquid consortium of *Azotobacter* PSB and KMB @ 10ml each per L water per plant
T_3	75 % RDF + Liquid consortium of *Azotobacter* PSB and KMB @10 ml each per L water per plant
T_4	50 % RDF + Liquid consortium of *Azotobacter* PSB and KMB @10 ml each per L water per plant
T_5	100 % RDF + Liquid consortium of *Azotobacter* PSB and KMB @20 ml each per L water per plant
T_6	75 % RDF + Liquid consortium of *Azotobacter* PSB and KMB @20 ml each per L water per plant
T_7	50 % RDF + Liquid consortium of *Azotobacter* PSB and KMB @20 ml each per L water per plant
T_8	Liquid consortium of *Azotobacter* PSB and KMB @10 ml each per L water per plant
T_9	Liquid consortium of *Azotobacter* PSB and KMB @20 ml each per L water per plant
T_{10}	Absolute control

Soil analysis

The representative soil samples were collected at initial and as per treatments at harvest stage and were analysed for chemical properties by using the different standard analytical methods to find out initial and after harvest available Nitrogen. Phosphorous and Potash (kg/ha(in soil as given below.

Available nitrogen (kg/ha)

It was determined with alkaline potassium permagnate method as suggested by Subbiah and Asija (1956) [14].

Available phosphorus (kg/ha)

The available phosphorus was extracted from the soil with 0.5M sodium bicarbonate as an extracting agent and determined by using double beam UV-VIS spectrophotometer with Olsens method as described by Olsen et al., (1954) [13].

Available potassium (kg/ha)

The available potassium in soil was extracted with Neutral Normal Ammonium Acetate as an extractant and the potassium in the extract was determined by using Flame photometer (Jackson, 1973) [8].

Nutrient uptake by Custard apple at harvest

The Custard apple samples were collected from each treatment at harvest stage. The collected plant samples were cleaned and air dried under shade and subsequently kept in hot air oven at 65±2°C till the sample gain constant weight and then ground well to maximum fineness. The processed Custard apple samples were used for fruit analysis as per standard methods as mentioned in table below.

SN	Parameter	Used Method	References
1.	Total N	Modified kjeldahl	Jackson (1967) [7]
2.	Total P	Vanadomolybdate phosphoric yellow colour	Jackson (1973) [8]
3.	Total K	Flame photometric	Chapman & Pratt (1961) [4]

Results and Discussion

1. Effect liquid consortium of *Azotobacter*, PSB and KMB on soil nutrient status

The results of effect of liquid consortia of *Azotobacter*, phosphate solubilizing bacteria and potash mobilizing bacteria on soil nutrient parameters viz., available nitrogen (kg/ha), phosphorus (kg/ha) and potassium (kg/ha) were recorded and is presented in Table 1.

Available Nitrogen

The results revealed that different treatments had a significant effect of soil application of liquid consortium of *Azotobacter*, PSB, and KMB on available nitrogen. Among all the treatments, T_5 (100% RDF + Liquid consortium of *Azotobacter* + PSB + KMB @ 20 ml each per L water per plant) was most effective treatment and which was recorded significantly maximum available nitrogen (250.87 kg/ha). It was statistically at par with T_2 (100% RDF + Liquid consortium of *Azotobacter* + PSB + KMB @ 10 ml each per L water per plant) treatment which recorded 246.70 kg/ha available nitrogen. However, minimum available nitrogen (129.62 kg / ha) was obtained with T_{10} (Absolute control) treatment. Nitrogen increase in soil with soil application of *Azotobacter* along with 100 % RDF and FYM had been reported by Waghamare *et al.,* (2019) [16]. Similarly, Jangid *et al.,* (2022) [9] and Gondaliya *et al.,* (2025) [6] also found increase in available nitrogen in post-harvest soil with application of *Azotobacter* along with inorganic manures.

Available Phosphorus

Among the treatments, T_5 (100% RDF + Liquid consortium of *Azotobacter* + PSB + KMB @ 20 ml each per L water per plant) was the most effective treatment and which was significantly maximum available phosphorus (54.48 kg / ha). It was statistically at par with T_2 (100% RDF + Liquid consortium of *Azotobacter* + PSB + KMB @ 10 ml each per L water per plant), T_6 (75% RDF + Liquid consortium of *Azotobacter* + PSB + KMB @ 20 ml each per L water per plant), T_3 (75% RDF + Liquid consortium of *Azotobacter* + PSB + KMB @ 10 ml each per L water per plant) and T_1 (100 % RDF i.e 250: 125 :125 g NPK per plant) treatment in which 53.82, 52.69, 50.81 and 50.31 kg/ha available phosphorus recorded, respectively. However, minimum available phosphorus (41.03 kg / ha) was obtained with T_{10} (Absolute control) treatment. These results corroborated the findings of Waghmare *et al.,* (2018) [15] who reported increased available phosphorus in soil due application of PSB along with 100% RDF + FYM + Azotobacter in custard apple. Similar trends were observed by Jangid *et at.* (2022) [9] and Gondaliya *et al.* (2025) [6], who emphasized the effectiveness of integrated nutrient management involving biofertilizers in enhancing soil phosphorus availability and crop yield.

Table 1: Effect of liquid consortium of *Azotobacter*, PSB and KMB on initial and after harvest available NPK in orchard of custard apple (*Annona Squamosa L.*) cv. Phule Purandar

SN	Treatments	Initial (kg /ha)	After harvest (Kg/ha)		
			Available N	Available P	Available K
1	RDF (250: 125 :125 g NPK per plant)	N- 213.20 P- 42.04 K-388.15	196.52	50.31	399.95
2	100 % RDF + Liquid cons. *Azotobactor,* + PSB + KMB @ 10 ml each per L water per plant		246.70	53.82	505.08
3	75 % RDF + Liquid cons. of *Azotobactor*,+ PSB + KMB @ 10 ml each per L water per plant		209.06	50.81	462.17
4	50 % RDF + Liquid cons. of *Azotobactor*,+ PSB + KMB @ 10 ml each per L water per plant		175.63	47.69	406.19
5	100 % RDF + Liquid cons. of *Azotobactor*,+ PSB + KMB @ 20 ml each per L water per plant		250.87	54.48	509.95
6	75 % RDF + Liquid cons. of *Azotobactor*,+ PSB + KMB @ 20 ml each per L water per plant		217.42	52.69	495.83
7	50 % RDF + Liquid cons. of *Azotobactor*,+ PSB + KMB @ 20 ml each per L water per plant		192.34	49.68	397.77
8	Liquid cons. of *Azotobactor*,+ PSB + KMB @ 10 ml each per L water per plant		158.89	45.04	383.27
9	Liquid cons. of *Azotobactor*,+ PSB + KMB @ 20 ml each per L water per plant		171.43	47.10	395.01
10	Absolute control		129.62	41.03	346.14
	SE(m)±		7.76	1.43	30.98
	CD (0.05)		23.24	4.27	92.76
	CV (%)		6.90	5.01	12.48

Available Potash: The result indicated significant effect of soil application of liquid consortium of *Azotobacter*, PSB, and KMB on available potassium (kg/ha). Among the treatments T_5 (100% RDF + Liquid consortium of *Azotobacter* + PSB + KMB @ 20 ml each per L water per plant) was the most effective treatment and which was obtained significantly maximum available potassium (509.95 kg/ha). It was statistically at par with T_2 (100% RDF + Liquid consortium of *Azotobacter* + PSB + KMB @ 10 ml each per L water per plant), T_6 (75% RDF + Liquid consortium of *Azotobacter* + PSB + KMB @ 20 ml each per L water per plant) and T_3 (75% RDF + Liquid consortium of *Azotobacter* + PSB + KMB @ 10 ml each per L water per plant) treatment wherein 505.08, 495.83 and 462.17 kg/ha available potassium observed, respectively. However, minimum available potassium (346.14 kg/ha) was found with T10 (Absolute control) treatment. These observations are in line with the findings of Waghmare *et al.,* (2018) [15], Jangid *et at.* (2022) [9] and Gondaliya *et al.* (2025) [6].

2. Effect liquid consortium of *Azotobacter*, PSB and KMB on plant nutrient status (Nutrient uptake)

The results of application of liquid consortium of *Azotobacter*, PSB and KMB along with inorganic fertilizers on plant nutrient status (Nutrient uptake) i.e. nitrogen uptake (kg/ha), Phosphorous uptake (kg/ha) and potash uptake (kg/ha) at harvest were recorded and presented in table 2.

Nitrogen Uptake (kg/ha)

The result indicated significant effect of soil application of liquid consortium of *Azotobacter*, PSB, and KMB on nitrogen uptake (kg/ha). Among all the treatments, T_5 (100% RDF + Liquid consortium of *Azotobacter* + PSB + KMB @ 20 ml each per L water per plant) was most effective treatment and which was recorded significantly maximum nitrogen uptake (88.20 kg/ha). However, it was statistically at par with T_6 (75% RDF + Liquid cons. of *Azotobactor*,+ PSB + KMB @ 20 ml each per L water per plant) and T_2 (100% RDF + Liquid cons. of *Azotobactor*,+ PSB + KMB @10 ml each per L water per plant) treatment which recorded 83.97 and 77.09 kg/ha nitrogen uptake, respectively. However, minimum nitrogen uptake (19.75 kg / ha) was obtained with T_{10} (Absolute control) treatment. Similar results regarding increase in nitrogen uptake were noticed by Gaikwad and Wani (2001) [5], Mishra (2020) [11] and Biswas and Shivaprakash (2022) [3].

Phosphorus Uptake (kg/ha)

The result indicated significant effect of soil application of liquid consortium of *Azotobacter*, PSB, and KMB on phosphorus uptake (kg/ha). The maximum phosphorus uptake was recorded in T_5 treatment (100% RDF + Liquid cons. of *Azotobactor*, + PSB + KMB @ 20 ml each per L water per plant) (14.15 kg /ha). However, it is at par with T_6 (75% RDF + Liquid cons. of *Azotobactor*, + PSB + KMB @ 20 ml each per L water per plant) (11.72 kg/ha) and T_2 (100% RDF + Liquid cons. of *Azotobactor*, + PSB + KMB @ 10 ml each per L water per plant) (11.32 kg/ha). The lowest total phosphorus uptake (2.11 kg/ha) was noted in T_{10} (Absolute control). These results were in accordance with the rsults obtained by Kundu and Mishra (2018) [10], Mishra (2020) [11] and Biswas and Shivaprakash (2022) [3].

Table 2: Effect of liquid consortium of *Azotobacter*, PSB and KMB on NPK uptake by custard apple (*Annona Squamosa L.*) cv. Phule Purandar at harvest

S. N.	Treatments	Nutrient uptake (kg/ha)		
		N	P	K
1	RDF (250 : 125 :125 g NPK per plant)	58.95	8.21	51.78
2	100 % RDF + Liquid cons. *Azotobactor,* + PSB + KMB @ 10 ml each per L water per plant	77.09	11.32	67.19
3	75 % RDF + Liquid cons. of *Azotobactor*,+ PSB + KMB @ 10 ml each per L water per plant	63.90	9.74	60.86
4	50 % RDF + Liquid cons. of *Azotobactor*,+ PSB + KMB @ 10 ml each per L water per plant	47.67	5.19	42.90
5	100 % RDF + Liquid cons. of *Azotobactor*,+ PSB + KMB @ 20 ml each per L water per plant	88.20	14.15	76.45
6	75 % RDF + Liquid cons. of *Azotobactor*,+ PSB + KMB @ 20 ml each per L water per plant	83.97	11.72	72.70
7	50 % RDF + Liquid cons. of *Azotobactor*,+ PSB + KMB @ 20 ml each per L water per plant	50.21	7.05	47.04
8	Liquid cons. of *Azotobactor*,+ PSB + KMB @ 10 ml each per L water per plant	34.92	3.70	27.91
9	Liquid cons. of *Azotobactor*,+ PSB + KMB @ 20 ml each per L water per plant	35.33	4.15	29.69
10	Absolute control	19.75	2.11	19.51
	SE(m)±	6.40	1.07	4.10
	CD (0.05)	19.17	3.20	12.29
	CV (%)	19.80	23.90	14.33

Potassium Uptake (kg/ha)

The result indicated significant effect of soil application of liquid consortium of *Azotobacter*, PSB, and KMB on potash uptake (kg/ha). Among all the treatments, T_5 (100% RDF + Liquid consortium of *Azotobacter* + PSB + KMB 20 ml each per L water per plant) was the most effective treatment and which was recorded significantly maximum potash uptake (76.45 kg/ha). However, it was statistically at par with T_6 (75% RDF + Liquid cons. of *Azotobactor*, + PSB + KMB 20 ml each per L water per plant) and T_2 (100% RDF + Liquid cons. of *Azotobactor*,+ PSB + KMKMB0 ml each per L water per plant) treatment which recorded 72.70 and 67.19 kg/ha nitrogen uptake, respectively. However, minimum nitrogen uptake (19.1 kg / ha) was obtained with T_{10} (Absolute control) treatment. These results are in accordance with the findings of Kundu and Mishra (2018) [10], Mishra (2020) [11] and Biswas and Shivaprakash (2022) [3].

Conclusion

The study demonstrates that the integrated application of a liquid consortium of *Azotobacter*, phosphate solubilizing bacteria (PSB), and potassium mobilizing bacteria (KMB) with the recommended dose of fertilizers (100% RDF) substantially enhances soil nutrient availability and nutrient uptake in custard apple (*Annona squamosa* L.) cv. Phule Purandar compared to control and other treatment combinations. The highest levels of available nitrogen (250.87 kg/ha), phosphorus (54.48 kg/ha), and potassium (509.95 kg/ha) were achieved with the treatment T_5 (100 % RDF + Liquid cons. of *Azotobactor*,+ PSB + KMB @ 20 ml each per L water per plant), which also resulted in the most significant uptake of nitrogen (88.20 kg/ha), phosphorus (14.15 kg/ha), and potassium (76.45 kg/ha) by the plants. Treatments using 75% RDF with the consortium also provided comparable benefits, indicating potential for fertilizer savings alongside improved soil health. Overall, combining biofertilizers and chemical fertilizers supports sustainable productivity in custard apple cultivation, increases nutrient efficiency, and contributes to long-term soil fertility management in arid zone fruit orchards.

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