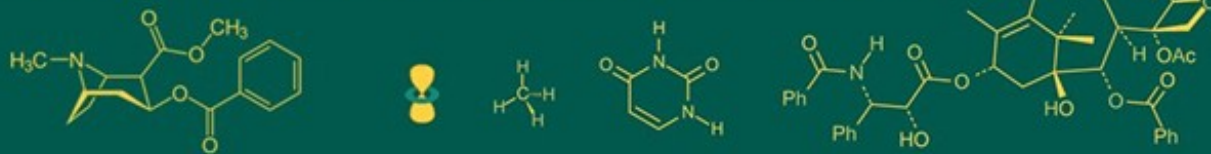


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Influence of phosphorus and potassium solubilizing novel yeast consortia on growth and yield of tomato (*Solanum lycopersicum* L.)

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ABSTRACT

Tomato is a fascinating vegetable crop whose productivity and fruit quality depends on adequate and balanced nutrient availability. The increasing dependence on chemical fertilizers has created emphasis on beneficial microorganisms as complementary inputs for sustainable nutrient management. The present attempt was made to develop liquid formulation of efficient plant growth promoting yeast consortia comprising *Saccharomyces boulardii*, *S. cerevisiae*, *S. mikatae* and *S. paradoxus*. Further, the efficacy of yeast consortia was evaluated on tomato cv. F1 Hybrid LHT - Nandi under pot culture using ten nutrient management treatments in a completely randomized design with three repetitions. Out of ten treatments imposed the treatment T₆, receiving 100 % N and K + 75 % P as Single Super Phosphate (SSP) + EYC recorded the seedling growth of 100.30, 119.30, 129.80 cm at 60, 90 and 120 days after transplanting respectively. With reference to number of leaves the same treatment recorded 520.00, 611.00 and 704.33 leaves plant⁻¹. Similarly, with respect to fruit yield, the maximum fruit yield of 3.94 kg plant⁻¹ and 52.00 t ha⁻¹ was observed in the treatment receiving 100 % N and K + 75 % P as Single Super Phosphate (SSP) + EYC indicating the EYC can improve tomato productivity, fruit quality and may support a 25 % reduction in phosphorus or potassium fertilizer under the tested pot culture conditions. Scale up study is required to further evaluate the developed consortia on different agricultural and horticultural crops for sustainable production.

Keywords: Plant growth-promoting yeast, Efficient Yeast Consortium, Tomato, Sustainable agriculture, Phosphorous and potassium solubilization

1. Introduction

Tomato (*Solanum lycopersicum* L.) is one of the most important vegetable crops cultivated for fresh consumption and processing. The crop has considerable nutritional and economic importance and is valued for its vitamins, minerals and antioxidant compounds, particularly lycopene. Successful tomato production requires adequate and balanced availability of essential nutrients throughout vegetative growth, flowering, fruit development and maturation. Among the major nutrients, nitrogen, phosphorus and potassium play important roles in plant growth, reproductive development, fruit formation and quality.

Conventional tomato production depends considerably on chemical fertilizers to maintain productivity. However, indiscriminate or imbalanced fertilizer application may contribute to nutrient-use inefficiency and deterioration of soil biological properties. Consequently, microbial approaches that complement mineral nutrition have gained increasing attention. Incorporation of beneficial soil microorganisms, including yeasts, into agricultural systems has gained importance for improving nutrient use efficiency and strengthening plant defense responses (Sarabia *et al.*, 2018) [1]. Beneficial microorganisms can contribute to nutrient mobilization, plant growth promotion and maintenance of biologically active rhizosphere environments. Yeasts are increasingly recognized as agriculturally useful microorganisms since they occur naturally in soil and plant-associated habitats and possess several plant-beneficial functions (Fu *et al.*, 2016) [2].

Although, yeasts are traditionally associated with food fermentation and industrial applications, several studies have reported their beneficial effects on plant growth and soil health. Soil yeasts are capable of exhibiting various plant growth promoting activities such as phosphate solubilization, nitrogen and sulphur transformation, siderophore production, stimulation of mycorrhizal root colonization, production of extracellular enzymes and biological control of plant pathogens (Cloete *et al.*, 2009) [3]. A wide diversity of yeast species has been investigated for their potential use as bio fertilizers and plant growth promoting microorganisms (Eman *et al.*, 2008) [4]. Some yeast are also capable of producing Indole Acetic Acid (IAA), gibberellins and other metabolites that positively influence plant growth and root development (Sharma *et al.*, 2026) [5]. In addition, several yeast species act as effective biocontrol agents against plant pathogens and some yeasts also contribute to soil aggregation and maintenance of soil structure through production of extracellular

polymeric substances that help bind soil particles together (Botha, 2006) [6]. Their multifunctional nature makes them potential components of microbial inoculants for sustainable crop production. The use of microbial consortia may provide an additional advantage because compatible microorganisms possessing complementary functional characteristics can be combined into a single inoculant. In tomato, such an approach may improve nutrient acquisition and plant growth while permitting partial optimization of chemical fertilizer inputs. Therefore, the present study was undertaken to develop and evaluate a compatible Efficient Yeast Consortium (EYC) in combination with different nutrient management regimes and to determine its influence on growth and yield of tomato under pot culture conditions.

2. Materials and Methods

2.1 Experimental site

The study was conducted during 2024–2026 at the Department of Microbiology, College of Agriculture, Shivamogga, Keladi Shivappa Nayaka University of Agricultural and Horticultural Sciences, Shivamogga, Karnataka, India. The study includes the development of efficient yeast consortium to evaluate on tomato under pot culture conditions.

2.2 Collection of efficient yeast isolates

Four efficient plant growth promoting yeast isolates *ie.*, *Saccharomyces boulardii*, *S. cerevisiae*, *S. mikatae* and *S. paradoxus* were collected from Department of Microbiology, College of Agriculture, Shivamogga, Keladi Shivappa Nayaka University of Agricultural and Horticultural Sciences, Shivamogga, Karnataka,

2.3 Compatibility testing and formulation of EYC

Compatibility among the four efficient yeast isolates was assessed by the cross-streak method on Yeast Extract Peptone Dextrose Agar (YEPDA) media. The isolates were streaked on the medium and incubated at $28 \pm 2^\circ\text{C}$ for 48 h. Isolates showing uninterrupted or overlapping growth without an inhibition zone were considered compatible.

Since, all four isolates were compatible and were used for development of the Efficient Yeast Consortium (EYC). The pure cultures of the four isolates were inoculated into fresh medium containing glycerol and polyvinylpyrrolidone at 0.5 % and incubated for seven days to attain the population density of approximately 1×10^9 CFU ml⁻¹ and the whole liquid formulation was used for the pot culture experiment.

2.4 Pot culture experiment

The liquid formulation of EYC was evaluated on tomato cv. F1 Hybrid LHT-Nandi (Plate 1). The experiment consisted of ten nutrient-management treatments (Table 1) with three repetitions in a Completely Randomized Design (CRD).

Experimental details:

Location : College of Agriculture, Shivamogga

Crop : Tomato

Variety : F1 Hybrid LHT- Nandi

Number of repetitions (replications) : 3

Number of treatments : 10

Experimental design : Completely Randomized Design (CRD)

NPK : 250:250:250 kg/ha

Farmyard manure (FYM) : 25 t ha⁻¹ (Common to all treatments)

Liquid EYC : @ 625 ml ha⁻¹.

Table 1. Nutrient management treatment details imposed on tomato under pot culture

Treatments	Nutrient-management treatments
T ₁	100% NPK
T ₂	100% NPK + EYC
T ₃	100% N & K
T ₄	100% N & K + EYC
T ₅	100% N & K + 75% P as SSP
T ₆	100% N & K + 75% P as SSP + EYC
T ₇	100% N & P
T ₈	100% N & P + EYC
T ₉	100% N & P + 75% K as MOP
T ₁₀	100% N & P + 75% K as MOP + EYC

Note: EYC: Efficient yeast consortium; SSP: Single super phosphate; MOP: Muriate of potash.

2.5 Observations recorded

To evaluate the impact of the yeast consortia, growth parameters were systematically recorded for all experimental units at 60, 90, 120 Days After Transplanting (DAT). The specific methodologies and standardized protocols employed for the quantification of these morphological and physiological parameters are detailed in the subsequent sections.

Growth parameters

Plant height (cm)

The plant height was quantified at 60, 90, 120 DAT and is expressed in centimeters (cm). Measurements were taken from the node on soil surface to the apical meristem of the shoot. In indeterminate varieties, the height was recorded along the main axis to the highest growing point. This measurement served to evaluate the biostimulatory effect of the yeast on the vertical vegetative extension of the tomato plants.

Number of leaves

The total number of leaves per plant was recorded at 60, 90, 120 DAT. In the context of the tomato canopy, only fully expanded true leaves were quantified. Cotyledonary leaves and those exhibiting more than 50 % senescence were excluded to accurately reflect the photosynthetic capacity of the plant as influenced by the yeast treatments.

Yield parameters

Number of flowers per plant

The total number of flowers produced per plant was systematically recorded across all inflorescences. This parameter served as a primary indicator of the reproductive vigour induced by the yeast inoculation.

Fruit yield per plant (Kg)

The total fruit mass harvested from each plant across all picking cycles was aggregated to determine the cumulative yield per plant, expressed in kilograms (kg/plant).

Fruit yield per hectare (tonnes)

The total yield per hectare was extrapolated from the cumulative plant yield. The results were standardized and expressed in tonnes per hectare (t/ha) to facilitate a comparative analysis of the yeast's agroeconomic efficacy.

2.6 Statistical analysis

The experiment was conducted in CRD with three replications. The recorded observations were subjected to statistical analysis following the procedures (Panse *et al.*, 1985) [7]. Treatment means were compared using Duncan's Multiple Range Test at the level of significance reported for the respective observations (Steel *et al.*, 1960) [8].

3. Results and Discussion

3.1 Compatibility and development of efficient yeast consortium

The four selected yeast isolates showed compatibility in the cross-streak assay, with no inhibition zones observed between the isolates. This compatibility among the yeast isolates facilitated for development of liquid consortial formulation. The liquid EYC developed containing four compatible yeast isolates and 0.5 % glycerol and polyvinylpyrrolidone with the population density of 1×10^9 CFU ml^{-1} .

The compatibility of component microorganisms is an important consideration in consortium development because antagonistic interactions may interfere with establishment and performance of individual members (Nimsi *et al.*, 2023) [9]. The successful establishment of the four isolates in the formulation provided the basis for evaluating EYC on tomato under pot culture.

Pot culture studies

The efficient yeast consortium was imposed along with the Recommended Dose of Fertilizers (with and without EYC) and 75 % P and K (with and without EYC) to tomato plants grown under pot culture and the effect yeast consortia on tomato growth and development was assessed. The observations recorded on various growth and yield parameters revealed the influence of the yeast consortium on tomato plants.

Influence of plant growth promoting yeast formulation on growth parameters

Plant height

The influence of consortial formulation of Efficient Yeast Consortium (EYC) on the plant height of tomato at 60, 90 and 120 Days After Transplanting (DAT) was assessed.

At 60 DAT, significant differences in plant height were observed among the treatments. Among all the treatments, T₁₀ (100 % N & P + 75 % K as MOP + EYC) recorded the highest plant height of 109.30 cm and was found to be significantly superior to the other treatments. This was followed by T₆ (100 % N & K + 75 % P as SSP + EYC), which recorded a plant height of 100.30 cm.

The similar trend was observed at 90 DAS, wherein T₁₀ recorded the maximum plant height of 122.20 cm and was significantly superior over the remaining treatments and the treatment T₆ (100 % N & K + 75 % P as SSP + EYC) showed 119.30 cm that was found to be statistically on par with T₁₀. In contrast, the minimum plant height was recorded in T₇ (103.50 cm), followed by T₃ (103.70 cm).

At 120 DAT, the treatment T₁₀ continued to record the highest plant height of 132.20 cm, followed by T₆ with 129.80 cm which was statistically on par with T₁₀ followed by the treatments T₂ and T₁ that also showed comparatively higher plant height values of 124.80 cm and 125.66 cm, respectively. The lowest plant height at this stage was observed in T₇ of 113.88 cm (Table 2 and Plate 2).

Overall, the application of efficient yeast consortium in combination with reduced fertilizer treatments positively influenced the plant height of tomato, with T₁₀ emerging as the most effective treatment throughout the crop growth period. The enhanced plant height observed in these treatments may be attributed to the ability of plant growth promoting yeasts to synthesize growth regulating substances such as indole-3-acetic acid, gibberellins and cytokinins, which stimulate cell division, cell elongation and stem growth. Similar findings were reported by Fu *et al.* (2016) [2] and Streletskii *et al.* (2016) [10], who observed significant improvements in vegetative growth of *Drosera spatulata* Lab due to yeast inoculation.

Number of leaves per plant

The data pertaining to the number of leaves per plant at different stages of crop growth as influenced by the application of EYC are presented in Table 2. At 60 DAT, significant differences were observed among the treatments with respect to number of leaves per plant. Among all the treatments, the T₆ receiving 100 % N & K + 75 % P as SSP + EYC recorded the more number of leaves per plant with

520.00 in number and was found to be significantly superior over the other treatments which was followed by T₁₀ with 477.66.

At 90 DAT, the treatment T₆ continued to record the highest number of leaves per plant (611.00), followed by T₁₀ (518.00) and T₂ (516.33). The treatments T₁, T₄, T₇, T₈, T₉ and T₅ showed moderate values ranging from 462.66 to 507.00 leaves per plant. The minimum number of leaves was observed in T₇ (462.66), which were statistically comparable with T₃ (464.33).

Similarly, at 120 DAT, treatment T₆ recorded the maximum number of leaves per plant of 704.33 and was significantly superior to all other treatments. This was followed by T₁₀ (606.00) and T₂ (605.33) that were on par with each other. The lowest number of leaves per plant was observed in T₇ (505.00), while T₃, T₄, T₈ and T₉ recorded intermediate values. (Table 2 and Plate 2)

Overall, the application of efficient yeast consortium along with nutrient management practices significantly influenced the number of leaves per plant, with T₆ emerging as superior throughout the crop growth period. The superiority of T₆ over other treatments suggests that the combination of EYC and balanced nutrient management created favorable conditions for sustained leaf initiation and expansion throughout the crop growth period. The comparatively higher leaf numbers recorded in T₁₀ and T₂ further support the positive role of yeast inoculation in promoting vegetative growth. In contrast, the lower number of leaves observed in T₇ and T₃ may be due to the absence of EYC inoculation, resulting in comparatively reduced growth and canopy development.

The increased leaf production observed in EYC inoculated treatments may be attributed to enhanced vegetative growth and improved canopy development resulting from better nutrient acquisition and physiological activity. Since leaves are the primary photosynthetic organs, greater leaf production reflects plant vigor growth potential under the influence of beneficial yeast inoculation. Similar observations were reported by Fu *et al.* (2016) [2] and Sharma *et al.*, 2026 [5] where they observed increased vegetative growth and foliage development in crops inoculated with plant growth promoting yeasts.

Similarly, several studies have demonstrated that inoculation with beneficial yeasts significantly improves plant growth attributes by promoting root proliferation, increasing nutrient uptake and enhancing physiological activities such as photosynthesis and assimilate production. Yeast mediated improvement in plant growth has been reported in various horticultural crops, where enhanced vegetative growth was associated with increased phytohormone production and improved nutrient use efficiency. Furthermore, yeast inoculation has been shown to improve plant vigor and biomass accumulation through favorable modifications in the rhizosphere environment, ultimately contributing to better crop performance and productivity (Streletskii *et al.*, 2016; Sharma *et al.*, 2026) [10, 5].

Influence of plant growth promoting yeast formulation on yield parameters

Fruit yield per plant

The influence of efficient yeast consortium on fruit yield per plant is presented in Table 3. Among the treatments, T₆ recorded the highest of 3.94 kg of fruit yield per plant, followed by T₁₀ with 3.64 kg. However, the lower fruit yield was recorded in T₇ (2.04 kg plant⁻¹) and T₃ (2.27 kg plant⁻¹) which might be due to their comparatively lower flower production, fruit set, fruit size and fruit weight, which collectively reduced overall yield. Although, T₁₀ also received EYC inoculation, T₆ produced a higher yield owing to its superior performance in most yield attributes. The comparatively higher yield obtained in T₂ and T₁ further indicate that yeast inoculation, when integrated with appropriate nutrient management, contributes positively to yield improvement in tomato. The study is in line with the findings of Cabrini *et al.* (2019) [11], who observed significant improvements in yield parameters of lettuce where the microbial inoculation was integrated along with varied concentration of nutrients. Similarly, Sharma *et al.* (2026) [5] also concluded the positive influence of the native yeast and yeast like organisms on crop productivity.

Fruit yield per hectare

The effect of efficient yeast consortium on fruit yield per hectare is highlighted in Table 3. The highest fruit yield per hectare was recorded in T₆ with 52.00 tonnes ha⁻¹, followed by T₁₀ with 48.00 tonnes ha⁻¹. The superior yield obtained in T₆ can be attributed to its better performance in major yield contributing traits, including number of fruits per plant, fruit diameter and individual fruit weight. The cumulative improvement in these parameters ultimately translated into higher marketable yield per unit area. Similar increases in crop productivity following inoculation with beneficial yeasts have been reported by Vargas *et al.* (2024) [12], who observed that yeast inoculation enhanced yield performance through improved crop growth and nutrient utilization in lettuce and tomato.

The comparatively lower yields recorded in T₇ and T₃ may be due to their poor performance in yield attributes, resulting in reduced fruit production per plant and consequently lower yield per hectare. Although T₁₀ also recorded a substantially higher yield, the slightly lower productivity compared to T₆ is associated with differences in nutrient management in crop responses. The higher yields obtained in T₁ and T₂ further indicate that the integration of EYC with nutrient

management practices positively influenced tomato productivity. These findings are in agreement with studies of Tapia *et al.*, 2020 [13] who reported plant growth promoting yeasts contribute significantly to enhanced crop yield and overall productivity of tomato under field conditions.

4. Conclusion

The present investigation demonstrated that the efficient yeast consortium developed from four compatible plant growth promoting yeasts improved tomato growth, reproductive development and fruit yield under pot culture conditions. Among the nutrient-management treatments, T₆ comprising 100 % N and K + 75 % P as SSP + EYC recorded the highest fruit yield of 52.00 t ha⁻¹, together with superior fruit quality and N and P uptake. The results indicate that the efficient yeast consortium has potential for improving tomato productivity while permitting a 25 % reduction in phosphorus and potassium fertilizer under the pot conditions. However, the present findings were obtained under pot culture conditions and require validation under field conditions and across different agro-climatic environments before wider recommendation.

Table 2. Effect of efficient yeast consortia on plant height and number of leaves of tomato at different growth stages

Sl. No.	Treatment	Plant height (cm)			Number of leaves per plant (Number)		
		60 DAT	90 DAT	120 DAT	60 DAT	90 DAT	120 DAT
1	T ₁ - 100 % NPK (Control)	97.40 ^{bc}	114.20 ^{abc}	124.80 ^{abc}	421.66 ^{cd}	507.00 ^{bc}	590.66 ^{bc}
2	T ₂ - 100 % NPK + EYC	98.00 ^{bc}	118.20 ^{ab}	125.66 ^{abc}	431.00 ^c	516.33 ^b	605.33 ^b
3	T ₃ - 100 % N & K	89.98 ^{de}	103.70 ^d	114.07 ^d	315.00 ^f	464.33 ^c	545.33 ^{cd}
4	T ₄ - 100 % N & K + EYC	95.20 ^{bcd}	108.80 ^{cd}	119.79 ^{cd}	372.66 ^e	473.66 ^{bc}	551.66 ^{bcd}
5	T ₅ - 100 % N & K + 75 % P as SSP	97.00 ^{bc}	113.50 ^{bc}	123.20 ^{bc}	410.00 ^{cde}	500.60 ^{bc}	588.33 ^{bc}
6	T ₆ - 100 % N & K + 75 % P as SSP + EYC	100.30 ^b	119.30 ^{ab}	129.80 ^{ab}	520.00 ^a	611.00 ^a	704.33 ^a
7	T ₇ - 100 % N & P	87.95 ^e	103.50 ^d	113.88 ^d	311.66 ^f	462.66 ^c	505.00 ^d
8	T ₈ - 100 % N & P + EYC	92.23 ^{cde}	107.80 ^{cd}	118.58 ^{cd}	372.00 ^e	466.00 ^c	550.33 ^{bcd}
9	T ₉ - 100 % N & P + 75 % K as MOP	96.57 ^{bcd}	112.70 ^{bc}	120.89 ^{cd}	390.33 ^{de}	480.66 ^{bc}	561.33 ^{bc}
10	T ₁₀ - 100 % N & P + 75 % K as MOP + EYC	109.30 ^a	122.20 ^a	132.20 ^a	477.66 ^b	518.00 ^b	606.00 ^b
S.Em. ±		2.103	2.512	2.644	12.63	13.46	16.88
CD (5%)		6.204	7.41	7.8	37.56	39.78	49.79
p		< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
CV (%)		3.74	3.871	3.745	5.43	4.66	5.04

Note:

- 1) Liquid formulation of EYC at 625 ml ha⁻¹
- 2) EYC : Efficient Yeast Consortia
- 3) SSP : Single Super Phosphate
- 4) MOP : Muricate of Potash
- 5) DAT : Days After Transplanting
- 6) Means followed by the same letter do not differ significantly

Table 3. Effect of efficient yeast consortia on yield parameters of tomato

Sl. No.	Treatment	Yield parameters		
		Number of Fruits per plant (Number)	Fruit yield per plant (kg)	Fruit yield per hectare (tonnes)
1	T ₁ - 100 % NPK (Control)	35.00 ^c	3.18 ^c	42.00 ^c
2	T ₂ - 100 % NPK + EYC	36.00 ^c	3.26 ^c	43.00 ^c
3	T ₃ - 100 % N & K	28.00 ^e	2.27 ^f	30.00 ^f
4	T ₄ - 100 % N & K + EYC	30.00 ^{de}	2.50 ^{de}	33.00 ^e
5	T ₅ - 100 % N & K + 75 % P as SSP	31.00 ^d	2.65 ^d	35.00 ^d
6	T ₆ - 100 % N & K + 75 % P as SSP + EYC	46.30 ^a	3.94 ^a	52.00 ^a
7	T ₇ - 100 % N & P	26.00 ^f	2.04 ^h	27.00 ^g
8	T ₈ - 100 % N & P + EYC	30.00 ^{de}	2.42 ^{ef}	32.00 ^e
9	T ₉ - 100 % N & P + 75 % K as MOP	31.00 ^d	2.65 ^d	35.00 ^d
10	T ₁₀ - 100 % N & P + 75 % K as MOP + EYC	41.00 ^b	3.64 ^b	48.00 ^b
	S. Em. ±	0.65	0.71	0.64
	CD (5%)	1.94	0.21	1.9
	<i>p</i>	< 0.01	< 0.01	< 0.01
	CV (%)	3.41	4.33	2.96

Note:

- 1) Liquid formulation of EYC at 625 ml ha⁻¹
- 2) EYC : Efficient Yeast Consortia
- 3) SSP : Single Super Phosphate
- 4) MOP : Muriate of Potash
- 5) DAT : Days After Transplanting
- 6) Means followed by the same letter do not differ significantly

**Plate 1.** General view of the pot culture experiment**Plate 2.** Effect of effective yeast consortia on plant height and number of leaves**Note:**

- 1) T₁ : 100 % NPK (Control)
- 2) T₆ : 100 % N & K + 75 % P as SSP + EYC
- 3) T₁₀ : 100 % N & P + 75 % K as MOP + EYC
- 4) EYC : Efficient Yeast Consortia
- 5) RDF : Recommended Dose of fertilizers

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