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Lactic Acid Bacteria Serum as a Natural Farming Input: Effects on Vegetative Growth, Biomass Accumulation, and Reproductive Onset of Tomato (*Solanum lycopersicum* L.) under Pot Culture

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Abstract:

Natural farming systems in India increasingly rely on farm-made microbial inputs, yet few controlled studies have quantified how such preparations influence crop growth across a full cropping cycle. This study evaluated a lactic acid bacteria (LAB) serum, prepared from fermented rice-wash water and cow milk and stabilised with jaggery, as a soil-applied biostimulant for tomato (*Solanum lycopersicum* L.). A pot experiment was conducted in 50 grow bags divided equally between an untreated control and a LAB treatment irrigated with a 1:1000 dilution. Plant height, root and shoot length, leaf number, leaf area, fresh and dry weight, and flower and fruit counts were recorded at 15-day intervals from 15 to 105 days after sowing (DAS). The establishment lag in LAB-treated plants was observed at 15 DAS, but from 30 DAS, the LAB-treated plants started to outperform the control plants, and LAB plants were favored in 31 of 36 vegetative comparisons from 30 to 105 DAS. The highest responses were at 60 DAS, with fresh weight, number of leaves, and plant height showing 158%, 94%, and 33%, respectively, more than the controls. The treated plants also bloomed approximately 15 days earlier, set more fruits, and had fewer obvious signs of pests and stress. The findings support LAB serum as a low-cost natural farming input, pending replicated field validation.

Keywords: Lactic acid bacteria; Indigenous microorganisms; Natural farming; Biostimulant; Plant growth promotion; Tomato; Sustainable agriculture

1. Introduction

Tomato (*Solanum lycopersicum* L.) is among the most widely cultivated and economically important vegetable crops in the world. It is a member of the Solanaceae family, which is the same as potato, brinjal, and chilli. It is native and domesticated in western South America and was introduced to the Old World in the sixteenth century during the Columbian exchange, and a century later, by the early 1900s, it was part of the mainstream diet in many parts of the world (Bergougnoux, 2014; Quezada et al., 2023). Tomato

is now commercially cultivated on all continents, and India is one of the largest producers in terms of volume (FAO, 2024).

The popularity of this crop is based on both its versatility as a food and its nutritional properties. Tomato fruits provide vitamin A, vitamin C, potassium, and folate, and are a major source of lycopene, a carotenoid antioxidant that has been linked to a decreased risk of cardiovascular disease and some cancers (Rao & Agarwal, 2000). The nutrient regime of cultivated plants, such as the application of organic biostimulants (Wise & Selby-Pham, 2025), has been shown to be a key factor influencing their fruit quality attributes, including flavour and antioxidant levels. Several hundred cultivars and hybrids are in commercial use, and the choice among them depends on local pest pressure, market demand and cropping practice. Cultivars are broadly classed as determinate, in which the main stem terminates in an inflorescence and growth ceases, or indeterminate, in which inflorescences arise at regular intervals, typically every third internode, while the main axis continues to elongate.

Since the Green Revolution, gains in tomato and other crop yields have depended heavily on synthetic fertilisers. While these inputs supply readily available nutrients, their prolonged and excessive use has been linked to soil acidification, loss of soil organic matter, contamination of surface and groundwater, and risks to human health (Savci, 2012; Kumari et al., 2014). Rising input costs further erode farm profitability, particularly for smallholders. These concerns have renewed interest in farming systems that restore soil biological function rather than substituting for it.

Natural farming is one such system. It avoids synthetic fertilisers and pesticides and relies instead of on-farm biological inputs, mulching and minimal soil disturbance. The approach was articulated by the Japanese farmer Masanobu Fukuoka (1978), developed in Korea by Cho Han-kyu as Korean Natural Farming built around indigenous microorganisms (IMOs) (Cho & Koyama, 1997), and adapted in India by Subhash Palekar as Zero Budget Natural Farming (ZBNF) (Palekar, 2006). ZBNF promotes microbially rich preparations such as *Jeevamrutha*, made from cow dung, cow urine, jaggery, pulse flour and soil, and *Beejamrutha*, a seed treatment, alongside mulching. The movement has spread widely among Indian farmers, and state-supported programmes, notably in Andhra Pradesh, have extended it to hundreds of thousands of households (Khadse et al., 2018). Despite this expansion, the agronomic evidence for many individual inputs remains thin, and controlled experiments that track crop response over time are scarce.

Among the IMO preparations used in natural farming, lactic acid bacteria (LAB) serum is one of the simplest to make. LAB are Gram-positive, acid-tolerant, generally non-sporulating, non-respiring rods and cocci that ferment carbohydrates predominantly to lactic acid. They have a low guanine–cytosine DNA content, are microaerophilic and lack cytochromes, and include genera such as *Lactobacillus* (sensu lato), *Lactococcus*, *Leuconostoc*, *Pediococcus* and *Aerococcus*. They occur naturally in milk, decaying plant material and soil, and their fermentative capacity underpins their long use in the food, beverage and pharmaceutical industries (Keddari et al., 2021; Raman et al., 2022). In farming practice, LAB serum is valued for accelerating the decomposition of organic residues, suppressing putrefactive odours and limiting pathogen growth (Ikeda et al., 2013).

The mechanisms by which LAB may benefit plants are increasingly well described. LAB secrete organic acids, enzymes and other bioactive metabolites that solubilise phosphorus and micronutrients, accelerate the decomposition of organic matter and improve soil structure (Higa & Kinjo, 1991; Lamont et al., 2017). Certain strains synthesize plant growth-regulating compounds that promote root and shoot growth, which is a characteristic of a larger group of rhizobacteria, known as plant growth-promoting rhizobacteria

(PGPR) (Vessey, 2003; Lugtenberg & Kamilova, 2009; Glick, 2012). LAB also produce bacteriocins, hydrogen peroxide, and organic acids, which are responsible for the inhibition of phytopathogenic bacteria and fungi, and they can induce systemic resistance in host plants (Jaffar et al., 2023). In tomato, LAB strains were shown to enhance germination and shoot and main root length (Limanska et al., 2013) as well as to inhibit Ralstonia solanacearum causing bacterial wilt (Murthy et al., 2012). Similar growth-promoting and disease-suppressing properties are reported in pepper (Shrestha et al., 2014). LAB-based inputs could also help promote other beneficial microorganisms that enhance the diversity of the rhizosphere and nutrient cycling in general (Wei et al., 2024).

Most of this evidence, however, derives from characterised laboratory strains applied as seed or foliar treatments, or from short-term seedling assays. Far less is known about the whole-season performance of the crude, farm-fermented LAB serum that natural farming practitioners actually prepare and apply as a soil drench. Such preparations differ from pure cultures in microbial composition, carry residual sugars and milk-derived nutrients, and are applied at high dilution. Whether they measurably influence crop growth, and at which developmental stages, remains an open empirical question (Raman et al., 2022).

The present study addresses this gap. Its objectives were (i) to prepare LAB serum using a standard farmer-level protocol based on rice-wash water, cow milk and jaggery; (ii) to compare the vegetative growth and biomass accumulation of tomato plants irrigated with diluted LAB serum against untreated controls across seven developmental stages from 15 to 105 days after sowing; and (iii) to document differences in reproductive onset and visible plant health. By tracking growth over the full vegetative-to-reproductive transition, the study aims to show not only whether LAB serum promotes growth, but when its effects emerge and how they change over the cropping cycle.

2. Materials and Methods

2.1 Study site and experimental period

The experiment was conducted under open, naturally lit pot-culture conditions at the Department of Botany, Girraj Government College (Autonomous), Nizamabad, Telangana, India. Nizamabad lies in the semi-arid Deccan plateau region and experiences a tropical climate with hot summers and a south-west monsoon. The experiment was carried out from July to October 2025, spanning the south-west monsoon and early post-monsoon period. The tomato hybrid Arka Rakshak (F_1, IIHR, Bengaluru) was used, with seed obtained from a certified local supplier in Nizamabad. Plants were raised in HDPE grow bags of 35 cm diameter × 35 cm height (approximately 15 L capacity), each filled with 12 kg of garden soil amended with well-decomposed farmyard manure in a 3:1 ratio by volume. The soil was a sandy clay loam of pH 7.4 and electrical conductivity 0.38 dS m^{-1}.

2.2 Preparation of lactic acid bacteria serum

LAB serum was prepared following the farmer-level protocol widely used in Korean and Indian natural farming (Cho & Koyama, 1997; Ikeda et al., 2013), summarised in Figure 1. One kilogram of rice was washed in water, and 600 mL of the resulting starch-rich rice-wash water was transferred to a clean clay pot. The pot was covered with porous paper, secured with a rubber band and kept in a shaded, dry place at room temperature for 24 h. During this period, airborne and rice-associated microorganisms colonised the medium, and the development of a mild sour odour was taken as an indication of LAB activity.

After 24 h, 1.8 L of cow milk was added to the fermented rice-wash water, giving a milk-to-serum ratio of 3:1. The pot was covered again and left undisturbed in the shade at room temperature for 5–7 days,

during which LAB multiplied using lactose as the principal substrate. By the seventh day the contents had separated into an upper curd-like layer, composed mainly of coagulated casein and fat, and a lower yellowish whey containing the LAB. The curd was removed and the whey was recovered by sieving. To stabilise the serum, an equal weight of jaggery (1:1, w/w) was added and stirred until fully dissolved. The stock was stored under refrigeration and diluted immediately before use.

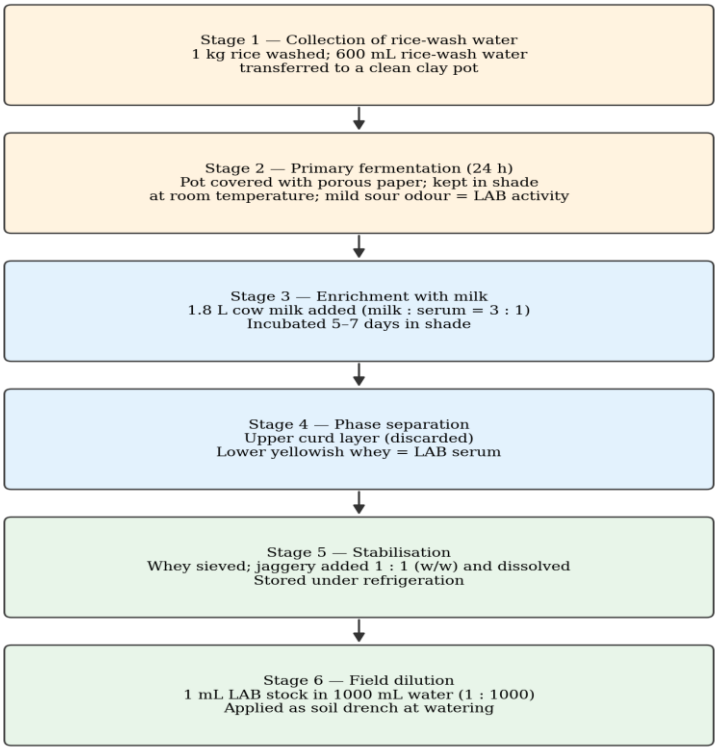

Figure 1. Workflow for the preparation of lactic acid bacteria (LAB) serum from rice-wash water and cow milk, and its dilution for soil application.

2.3 Experimental design and crop management

Fifty grow bags were filled with garden soil and assigned equally to two treatments (Figure 2). Tomato seeds were sown in all bags on the same day (0 DAS). Twenty-five bags constituted the control (T0) and were irrigated with plain water throughout the experiment. The remaining 25 bags constituted the LAB treatment (T1) and were irrigated with diluted LAB serum prepared by mixing 1 mL of stock with 1000 mL of water (1:1000). Apart from the irrigation solution, both groups received identical management. No synthetic fertilisers or pesticides were applied to either group. Soil moisture was monitored regularly by touch, and irrigation volume was adjusted to avoid both water stress and waterlogging.

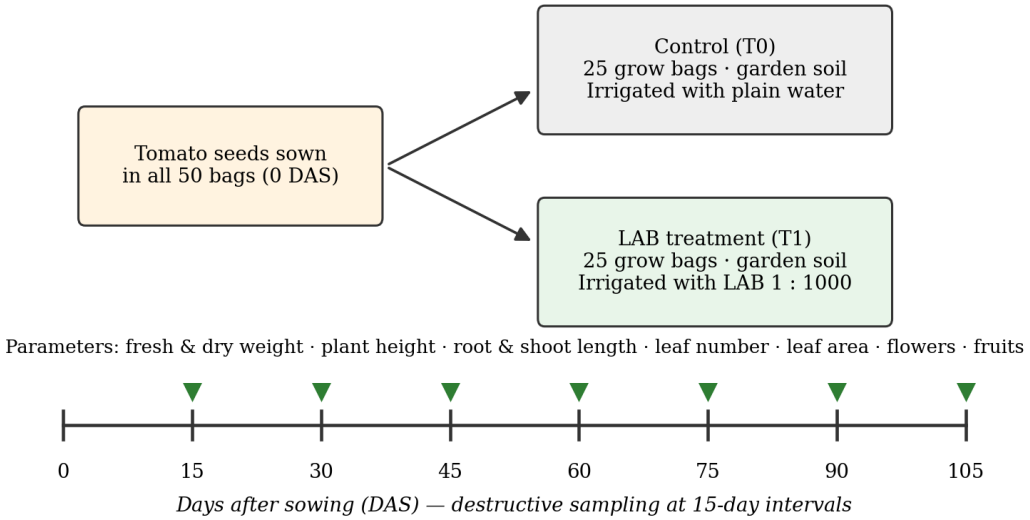

Figure 2. Experimental layout and sampling schedule. Growth parameters were recorded at seven intervals from 15 to 105 days after sowing (DAS).

2.4 Growth and reproductive measurements

Growth parameters were recorded at 15, 30, 45, 60, 75, 90, and 105 DAS in both groups. At each interval, representative plants were carefully uprooted, the roots were washed free of soil, and the following parameters were recorded: plant fresh weight (g), total plant height (cm), root length (cm), shoot length (cm), number of leaves per plant, and leaf area (cm²). Dry weight (g) was determined from 30 DAS onward after oven-drying the sampled plants to constant weight. The number of flowers and fruits per plant was counted from the onset of flowering. Visible symptoms of pest infestation and physiological stress, including leaf wilting and yellowing, were noted during routine observation throughout the growing period. Values presented are means of the plants sampled at each interval. At each sampling, [n = 3] plants were destructively sampled from each treatment, and all reported values are means of these plants. Leaf area was measured on [all leaves / the third fully expanded leaf] per sampled plant using [a graph-paper tracing method / a leaf-area meter, model and make]. For dry-weight determination, sampled plants were oven-dried at [65 °C] to constant weight, requiring approximately [48–72 h], and weighed on an electronic balance with [0.01 g] precision.

2.5 Data analysis

For each parameter and sampling interval, the relative response to LAB was expressed as percentage change over the control: $\Delta\% = [(T1 - T0) / T0] \times 100$. Relative growth rate (RGR) of fresh biomass between two sampling dates was calculated following Hunt (1990) as $RGR = (\ln W_2 - \ln W_1) / (t_2 - t_1)$, where W is plant fresh weight (g) and t is time in days. Mean daily increments in plant height and leaf number were calculated over the full experimental period. Root allocation was assessed from the root-to-shoot length ratio. Treatment consistency was summarised as the proportion of paired treatment–control comparisons in which the LAB-treated value exceeded the control. Because replicate-level measurements were not retained, the analysis is descriptive; inferential testing is identified as a priority for follow-up work (Section 5).

3. Results

Mean values of all recorded parameters across the seven sampling intervals are presented in Table 1, and their trajectories are plotted in Figure 3. Figure 4 summarises the relative response of each parameter to LAB treatment, and Table 2 presents derived growth indices.

Table 1. Mean growth and reproductive parameters of control and LAB-treated tomato plants from 15 to 105 days after sowing (DAS). Bold LAB values exceed the corresponding control.

Parameter	Group	15 DAS	30 DAS	45 DAS	60 DAS	75 DAS	90 DAS	105 DAS
Plant height (cm)	*Control*	8.93	11.10	15.30	18.13	40.03	42.40	67.25
	LAB	7.90	**15.50**	15.16	**24.16**	**47.40**	**48.43**	**71.10**
Root length (cm)	*Control*	1.63	3.40	5.90	5.73	14.03	13.43	33.60
	LAB	**1.86**	**6.10**	5.83	**8.23**	**17.23**	**15.73**	31.10
Shoot length (cm)	*Control*	5.36	5.90	6.30	9.83	23.56	27.03	32.25
	LAB	4.26	**6.16**	**7.53**	**12.43**	**28.90**	**29.46**	**38.45**
Leaves (no.)	*Control*	4	6.6	8.3	12	29.6	34.6	36.5
	LAB	4	**9.6**	**10.6**	**23.3**	**31**	**48**	**58**
Leaf area (cm²)	*Control*	0.91	1.00	1.06	1.41	1.47	1.47	1.47
	LAB	0.83	**1.90**	**1.26**	**1.65**	1.27	1.25	**1.72**
Fresh weight (g)	*Control*	0.16	0.25	0.54	0.62	3.35	5.40	5.40
	LAB	0.11	**0.61**	**0.82**	**1.60**	**5.49**	**7.27**	**14.50**
Dry weight (g)	*Control*	—	0.57	0.08	0.15	0.87	2.42	2.42
	LAB	—	0.23	**0.13**	**0.67**	**2.03**	**2.98**	**3.15**
Flowers (no.)	*Control*	0	0	0	0	0	1.6	1.6
	LAB	0	0	0	0	**3**	**2.3**	1
Fruits (no.)	*Control*	0	0	0	0	0	0	1
	LAB	0	0	0	0	0	0	**2**

— = not recorded. Control dry weight at 30 DAS (0.57 g) exceeds the fresh weight recorded at the same stage (0.25 g); and control fresh weight, dry weight, flowers, and leaf area at 105 DAS are identical to the 90 DAS values, suggesting a possible transcription error.

3.1 Early establishment (15 DAS)

At the first sampling, LAB-treated seedlings were marginally smaller than the controls. Fresh weight was 31% lower (0.11 g against 0.16 g), plant height 12% lower (7.9 cm against 8.93 cm), and shoot length 21% lower (4.26 cm against 5.36 cm). Leaf area was also slightly reduced (0.83 cm² against 0.91 cm²), while leaf number was identical in both groups (four leaves). The single parameter favouring the treatment at this stage was root length, which was 14% greater in LAB-treated seedlings (1.86 cm against 1.63 cm). The root-to-shoot length ratio was correspondingly higher in the LAB group (0.44 against 0.30; Figure 5a), indicating a relative early investment in root growth.

3.2 Active vegetative phase (30–60 DAS)

From 30 DAS onward, the pattern reversed decisively. At 30 DAS, LAB-treated plants had 144% greater fresh weight (0.61 g against 0.25 g), 40% greater height (15.5 cm against 11.1 cm), 79% longer roots (6.1 cm against 3.4 cm), 45% more leaves (9.6 against 6.6) and 90% greater leaf area (1.90 cm^2 against 1.00 cm^2). The fresh-weight RGR of treated plants between 15 and 30 DAS was 0.114 g g^{-1} d^{-1}, nearly four times that of the controls (0.030 g g^{-1} d^{-1}), which accounts for the rapid reversal of the early deficit.

At 45 DAS, the two groups converged temporarily in height (15.16 cm against 15.3 cm) and root length (5.83 cm against 5.9 cm), coinciding with a pause in height gain in the LAB group between 30 and 45 DAS. Even so, the treatment-maintained advantages in fresh weight (+52%), shoot length (+20%), leaf number (+28%), leaf area (+19%), and dry weight (+62%). By 60 DAS the separation was at its widest across the vegetative period: fresh weight was 158% higher (1.60 g against 0.62 g), leaf number 94% higher (23.3 against 12.0), root length 44% higher (8.23 cm against 5.73 cm), plant height 33% higher (24.16 cm against 18.13 cm) and shoot length 26% higher (12.43 cm against 9.83 cm). Dry weight at 60 DAS was more than four times that of the controls (0.67 g against 0.15 g).

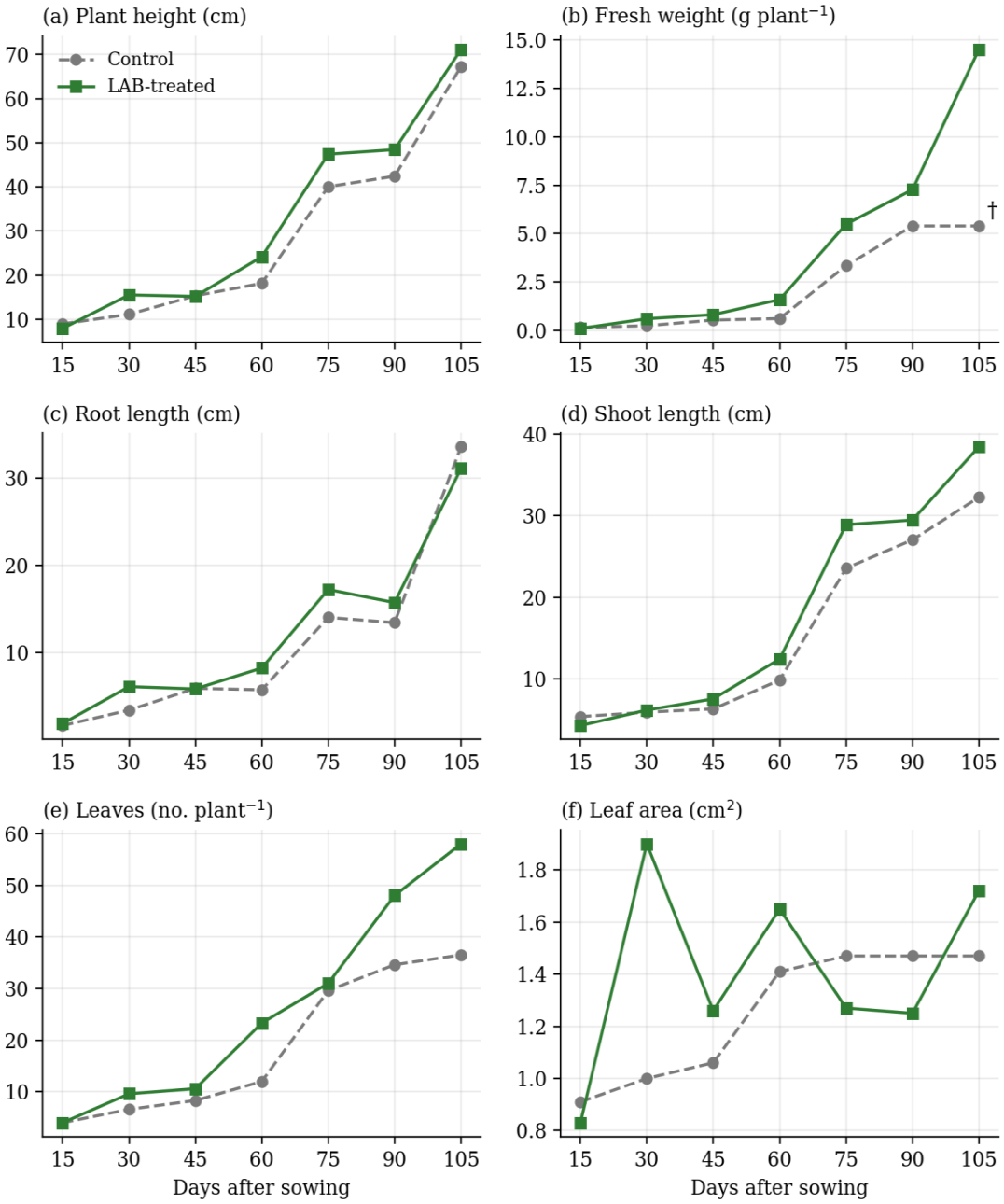

Figure 3. Growth trajectories of control and LAB-treated tomato plants from 15 to 105 DAS: (a) plant height, (b) fresh weight, (c) root length, (d) shoot length, (e) leaf number and (f) leaf area. † Control fresh weight at 105 DAS is identical to the 90 DAS value (see Table 1 note).

3.3 Late vegetative and reproductive phase (75–105 DAS)

Both groups entered a phase of rapid elongation between 60 and 75 DAS, when height increased at approximately 1.5 cm d^{-1} in each. LAB-treated plants retained their advantage in fresh weight (+64%), height (+18%), root length (+23%), shoot length (+23%) and dry weight (+133%) at 75 DAS, although the leaf-number difference narrowed to 5% (31.0 against 29.6). At 90 DAS, treated plants were heavier by 35% (7.27 g against 5.40 g), taller by 14% (48.43 cm against 42.4 cm) and bore 39% more leaves (48.0 against 34.6). At the final sampling (105 DAS), the LAB group had 59% more leaves (58.0 against 36.5),

19% longer shoots (38.45 cm against 32.25 cm) and 6% greater height (71.1 cm against 67.25 cm), with fresh weight nearly 2.7 times that of the controls (14.5 g against 5.40 g). Control root length increased sharply between 90 and 105 DAS, and at the final sampling it slightly exceeded that of the treated plants (33.6 cm against 31.1 cm).

Leaf area was the least consistent parameter. After exceeding the controls from 30 to 60 DAS, mean leaf area in the LAB group fell below the control at 75 DAS (−14%) and 90 DAS (−15%) before recovering to exceed it at 105 DAS (+17%). Because treated plants produced substantially more leaves over the same period, total canopy leaf area per plant, estimated as the product of leaf number and mean leaf area, was higher in the LAB group at every sampling from 30 DAS onward except 75 DAS, when the two groups were close (approximately 39 cm² against 44 cm²).

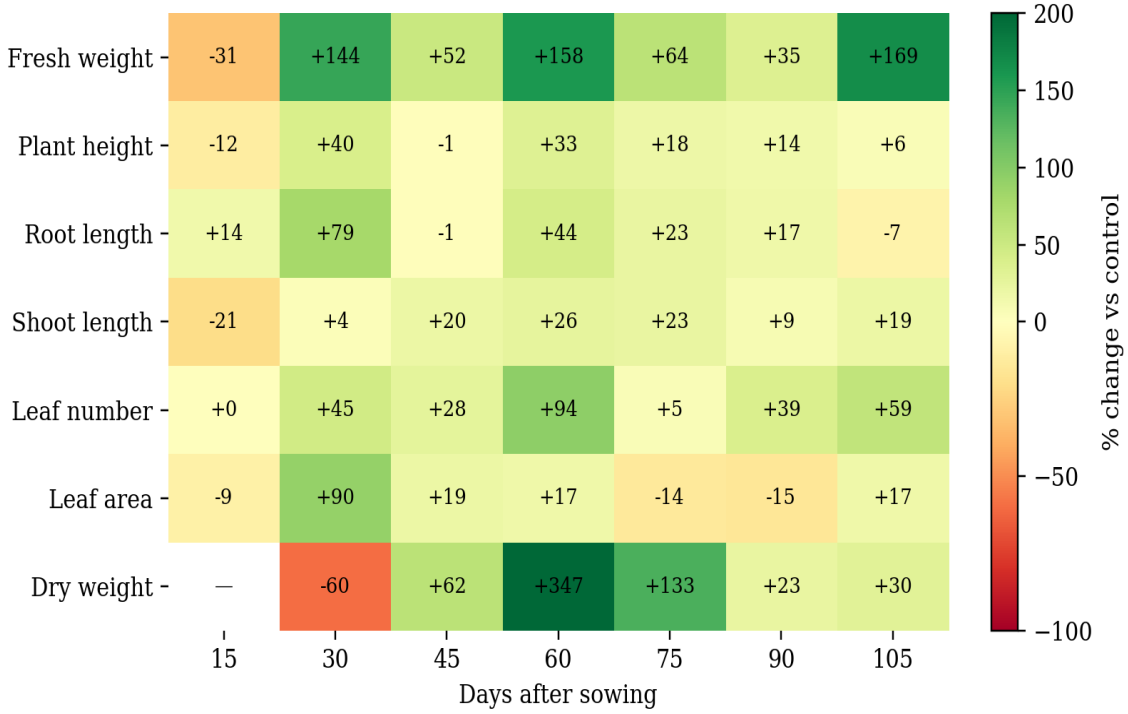

Figure 4. Heatmap of the percentage change in each growth parameter of LAB-treated plants relative to the control at each sampling interval. Green cells indicate a positive response; orange-to-red cells indicate a negative response.

3.4 Consistency of the treatment response and derived growth indices

Across the six vegetative parameters recorded at every interval from 30 to 105 DAS (fresh weight, plant height, root length, shoot length, leaf number and leaf area), LAB-treated plants exceeded the controls in 31 of 36 comparisons (86%). The five exceptions were plant height and root length at 45 DAS, where differences were within 1.2%, leaf area at 75 and 90 DAS, and root length at 105 DAS (Figure 4). Over the period from 15 to 90 DAS, the mean fresh-weight RGR of treated plants was 0.056 g g^{-1} d^{-1}, against 0.047 g g^{-1} d^{-1} in the controls. Treated plants also produced new leaves at a mean rate of 0.60 leaves d^{-1} over the full experiment, compared with 0.36 leaves d^{-1} in the controls (Table 2). The root-to-shoot length ratio followed broadly similar trajectories in the two groups from 60 to 90 DAS (Figure 5a), suggesting

that LAB enhanced overall growth without substantially altering the allocation pattern during the main vegetative phase.

Table 2. Derived growth indices of control and LAB-treated tomato plants.

Index	Control	LAB-treated	LAB/Control
Fresh-weight RGR, 15–30 DAS (g g^{-1} d^{-1})	0.030	0.114	3.83
Fresh-weight RGR, 15–90 DAS (g g^{-1} d^{-1})	0.047	0.056	1.19
Mean height increment, 15–105 DAS (cm d^{-1})	0.65	0.70	1.08
Mean leaf production, 15–105 DAS (leaves d^{-1})	0.36	0.60	1.66
Root : shoot length ratio at 60 DAS	0.58	0.66	1.14
First sampling with flowers (DAS)	90	75	—
Fruits per plant at 105 DAS	1	2	2.00

RGR = relative growth rate, calculated as $(\ln W_2 - \ln W_1)/(t_2 - t_1)$ (Hunt, 1990). Flowering dates reflect the 15-day sampling resolution.

3.5 Reproductive attributes

Flowering began earlier under LAB treatment. At 75 DAS, treated plants carried a mean of 3.0 flowers per plant, while no flowers were recorded on the controls (Figure 5b). Controls first flowered by the 90 DAS sampling (1.6 flowers per plant), when treated plants carried 2.3. By 105 DAS the treated plants had set a mean of two fruits per plant against one fruit in the controls, while carrying fewer open flowers (1.0 against 1.6), consistent with the progression of earlier flowers to fruit set.

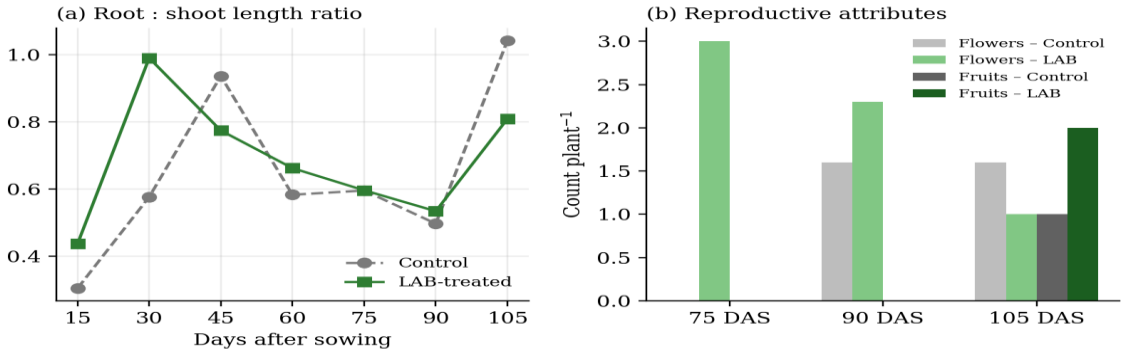

Figure 5. (a) Root-to-shoot length ratio of control and LAB-treated plants across the sampling period. (b) Mean number of flowers and fruits per plant at 75, 90 and 105 DAS.

3.6 Plant health observations

Visible differences in plant health emerged during the reproductive phase. Mealybug infestation was observed on the stems of control plants at 75 DAS, and leaf wilting and yellowing were recorded in the control group at around 95 DAS. These symptoms were markedly less pronounced or absent in the LAB-treated plants during the same period. Plate 1. Comparative appearance of control and LAB-treated tomato plants. (a, b) Whole plants at 60 DAS, showing the denser canopy and greater leaf number of LAB-treated plants. (c, d) Plants at 105 DAS, with leaf yellowing and wilting visible in the control. (e) Mealybug

colonies on the stem of a control plant at 75 DAS. (f) Prepared LAB serum after seven days of fermentation, showing the clear whey-coloured supernatant separated from the curd layer.

4. Discussion

This study tracked the response of tomato to a farm-fermented LAB serum over a 105-day cropping cycle. The central finding is that, after a short establishment lag, LAB-treated plants accumulated more biomass, produced more leaves and developed longer shoots than the controls through most of the vegetative period, and they progressed to flowering and fruit set earlier. The treatment effect was not uniform over time. It was largest between 30 and 60 DAS, when the plants were building canopy and root systems, and it narrowed for several parameters once both groups entered rapid stem elongation after 60 DAS. This temporal pattern is itself informative, because it indicates when LAB inputs are most likely to influence crop development.

4.1 Early establishment lag

The slightly lower shoot growth and fresh weight of LAB-treated seedlings at 15 DAS may reflect a transient adjustment of the rhizosphere to the introduced serum. LAB serum is acidic, and fresh applications also introduce readily fermentable sugars from jaggery. Both factors can briefly shift microbial activity and root-zone chemistry before a new equilibrium is reached (Raman et al., 2022). Notably, root length was already higher in treated seedlings at this stage, and the root-to-shoot ratio was elevated. Early root proliferation in response to LAB and other PGPR has been widely reported (Vessey, 2003; Limanska et al., 2013) and may represent an investment that underpinned the rapid shoot and biomass gains observed from 30 DAS. The nearly fourfold higher RGR of treated plants between 15 and 30 DAS is consistent with this interpretation.

4.2 Mechanisms of vegetative growth promotion

Several complementary mechanisms could explain the enhanced vegetative growth (Figure 6). First, the organic acids produced by LAB, principally lactic and acetic acid, can mobilise sparingly soluble phosphates and micronutrients, increasing their availability to roots (Lamont et al., 2017; Raman et al., 2022). Second, LAB are known to accelerate the decomposition of organic matter and the formation of humus-like substances in soil, as first described in the Kyusei nature farming literature (Higa & Kinjo, 1991). Third, some LAB strains synthesise indole-type growth regulators, vitamins and other metabolites that stimulate root and shoot development, in common with other PGPR (Glick, 2012; Jaffar et al., 2023). Finally, LAB serum is not a pure culture but a consortium carried in a nutrient-rich matrix of whey and jaggery. These residual sugars, amino acids, and minerals are unlikely to be nutritionally significant at a 1:1000 dilution, but they may feed native soil microbes and stimulate broader rhizosphere activity (Wei et al., 2024). The present design cannot separate these pathways, but the sustained advantage in leaf number and biomass is consistent with improved nutrient acquisition rather than a transient hormonal effect.

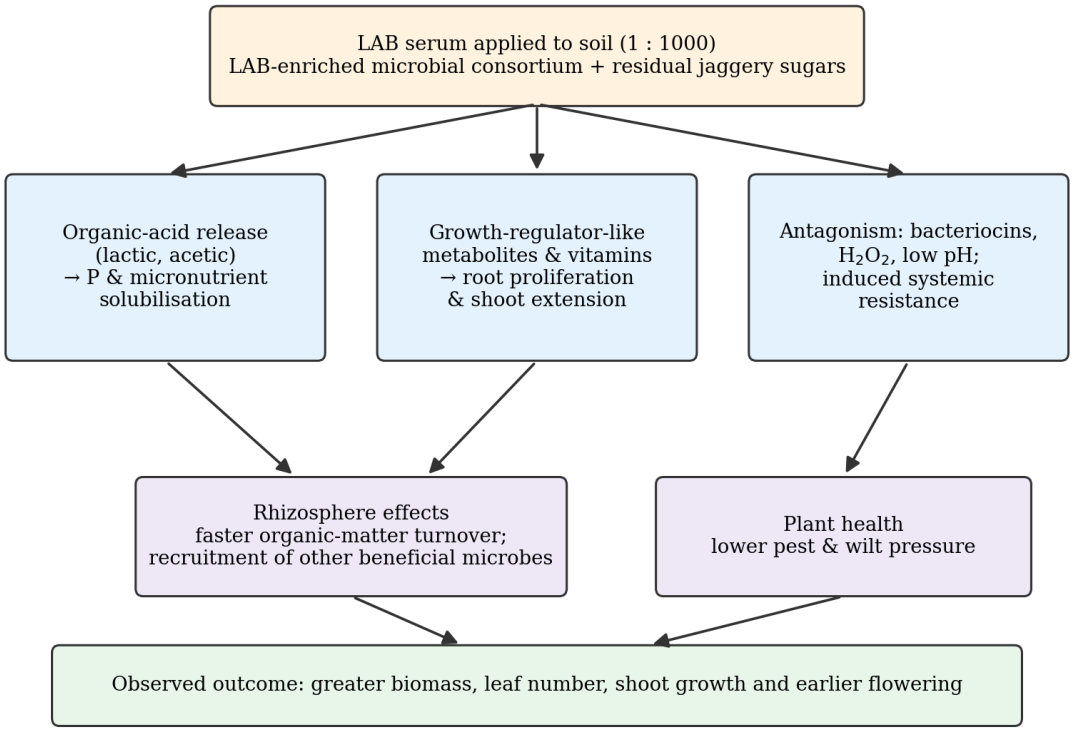

Figure 6. Proposed mechanisms linking soil-applied LAB serum to the growth and health responses observed in tomato, synthesised from the present results and the literature.

The magnitude of the responses recorded here, with fresh weight increasing by 35–158% between 30 and 90 DAS, is larger than the 10–30% increases in root and shoot length reported for tomato seedlings inoculated with characterised *L. plantarum* strains (Limanska et al., 2013). The difference is plausible given that the present study applied LAB repeatedly as a soil drench over a full season rather than as a single seed treatment, and measured whole-plant biomass rather than seedling organ length. Nevertheless, the absence of replicate-level variance means these effect sizes should be regarded as indicative until confirmed by a replicated trial.

4.3 Leaf area and canopy development

The dip in mean leaf area under LAB treatment at 75 and 90 DAS, at a time when leaf number was rising steeply, most likely reflects the recruitment of many new, still-expanding leaves into the sample. A larger population of young leaves lowers the mean area per leaf even as total canopy area increases. Because estimated canopy leaf area was higher in the treated plants at five of the six samplings from 30 DAS, this pattern does not indicate a negative effect on photosynthetic capacity. It does, however, show that mean leaf area alone is an unreliable indicator of canopy development when treatments differ in leaf production rate, and future work should record total leaf area per plant or leaf area index.

4.4 Reproductive development

Earlier flowering in the LAB group, by approximately one sampling interval, is agronomically meaningful because earlier reproductive onset can shorten time to first harvest and extend the harvest window.

Enhanced vegetative vigour before the reproductive transition is a common precursor of earlier flowering in tomato, since carbohydrate supply to the shoot apex influences inflorescence initiation. The higher fruit number at 105 DAS, two against one per plant, points in the same direction, although fruit counts at this stage are small and fruit yield and quality were not assessed. The lower flower count in the LAB group at 105 DAS likely reflects the conversion of earlier flowers to fruit rather than reduced flowering.

4.5 Plant health

The absence or reduced severity of mealybug infestation and leaf yellowing in LAB-treated plants agrees with reports that LAB suppress plant pathogens through bacteriocins, hydrogen peroxide, and acidification, and prime induced systemic resistance (Jaffar et al., 2023). In tomato, LAB have been shown to reduce bacterial wilt (Murthy et al., 2012), and in pepper to reduce bacterial spot (Shrestha et al., 2014). The mechanism by which LAB might reduce mealybug pressure is less direct. Mealybugs are sap-feeding insects rather than pathogens, and more vigorous, less stressed plants may simply be less attractive or more tolerant hosts. Wilting and yellowing in the controls at around 95 DAS may reflect nutrient depletion in the confined soil volume of the grow bags, which the LAB treatment may have delayed through improved nutrient mobilisation. As these observations were qualitative, they should be treated as preliminary.

4.6 Implications for natural farming

The serum evaluated here is made from rice-wash water, milk and jaggery, materials available on most Indian farms, and it is applied at a 1:1000 dilution. One litre of stock is therefore sufficient for 1,000 L of irrigation solution. This makes it among the lowest-cost inputs in the natural farming toolkit. The results provide experimental support for its inclusion in natural farming protocols for tomato, particularly during the early and mid-vegetative stages when the response was strongest. For extension programmes promoting natural farming, stage-specific evidence of this kind can help farmers target applications and set realistic expectations.

5. Limitations and Future Directions

Several limitations qualify these findings and define priorities for follow-up. First, the analysis is descriptive: replicate-level data were not retained, so standard deviations and formal tests of significance could not be computed. A follow-up trial should record individual plant values and analyse them by two-way ANOVA (treatment × time) or repeated-measures designs appropriate to agricultural experiments (Gomez & Gomez, 1984). Second, the LAB serum was not characterised microbiologically. Viable counts (CFU mL^{-1} on MRS agar), pH, and the identity of dominant isolates would make the input reproducible and allow comparison with published strains. Third, the experiment compared LAB serum only with water. Including a jaggery-and-whey control without live bacteria, and a conventional fertiliser treatment, would separate microbial from nutritional effects and position LAB against current practice. Fourth, soil chemical and biological properties were not measured before and after treatment, so the proposed mechanisms remain inferred. Fifth, the study ended at 105 DAS, before full harvest, and fruit yield and quality, including lycopene content, were not assessed. Finally, pot culture in a single location and season limits generalisation to field conditions. Multi-location field trials under farmer management are the logical next step.

6. Conclusion

This study shows that a farm-fermented lactic acid bacteria serum, prepared from rice-wash water, cow milk and jaggery and applied to the soil at a 1:1000 dilution, improved the growth of tomato plants across most of a 105-day cropping cycle. After a brief lag at 15 DAS, treated plants exceeded the controls in 86% of vegetative comparisons from 30 DAS onward, with the strongest responses in fresh weight, leaf number and dry weight between 30 and 60 DAS. LAB treatment also brought forward flowering by about 15 days, increased early fruit set and was associated with fewer visible pest and stress symptoms. These results support LAB serum as a practical, low-cost biostimulant for natural farming systems, with the greatest benefit likely during early and mid-vegetative growth. Confirmation through replicated, statistically analysed field trials with microbiologically characterised inputs and yield-quality measurements is now required before firm recommendations can be made.

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