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Influence of Organic Seed Priming on Germination Dynamics, Seedling Vigor, and Early Structural Growth of Sesame (*Sesamum indicum* L.) under Pot Culture Conditions

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Abstract

Securing uniform crop establishment in sesame (*Sesamum indicum* L.) is a persistent agronomic challenge owing to its inherently small seed size, erratic germination behavior, and vulnerability during the early seedling phase. The present investigation was designed to systematically assess the influence of seven organic seed treatments on germination percentage, root and shoot elongation, and the integrated Seedling Vigor Index (SVI) of sesame variety VRI 3 under Rabi 2026 pot culture conditions at PGP College of Agricultural Sciences, Namakkal, Tamil Nadu. A Completely Randomized Design (CRD) with three replications was adopted, encompassing: untreated control (T_1), *Azospirillum* @ 10 mL/kg (T_2), Zinc Solubilizing Bacteria @ 100 mL/kg (T_3), *Trichoderma viride* @ 4 g/kg (T_4), Pungam leaf extract @ 1% (T_5), Seaweed extract @ 5% (T_6), and Panchagavya @ 6% (T_7). Treatment T_6 recorded the highest germination percentage (49.3%) and the greatest SVI value (626.60), attributed to the phytohormonal constituents and bioactive polysaccharides present in Sargassum spp. extract. Post-emergence structural assessment at 15 and 20 Days After Sowing (DAS) revealed that T_2 (*Azospirillum*) produced the most vigorous root (6.90 cm) and shoot (13.70 cm) development by 20 DAS, driven by rhizosphere auxin biosynthesis and biological nitrogen fixation. *Trichoderma viride* (T_4) delivered a balanced performance, recording 33.3% germination and an SVI of 513.15. In contrast, Pungam leaf extract (T_5) exhibited pronounced allelopathic phytotoxicity, suppressing germination to 4.0% and causing complete seedling mortality by 20 DAS. These findings endorse the application of seaweed extract for rapid field establishment and *Azospirillum* or *Trichoderma viride* for sustained early seedling growth as part of an ecologically sound sesame production system.

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Introduction

The intensification of global oilseed cultivation to satisfy expanding population-driven demand has largely depended on synthetic agrochemical inputs, which, while effective in the short term, carry well-documented consequences for soil biological health, water quality, and long-term agroecosystem stability. Against this backdrop, low-input organic farming strategies anchored in bio-based seed enhancement technologies have attracted increasing scientific attention as durable alternatives for sustainable crop production.

Sesame (*Sesamum indicum* L.), belonging to the family Pedaliaceae, holds the distinction of being one of the earliest domesticated oilseed crops, with a cultivation history extending more than 5,000 years across tropical and subtropical agroecosystems. It is commercially prized for its seed oil content (45–55%), balanced fatty acid profile, high concentrations of antioxidants such as sesamin and sesamolin, and adaptability to semi-arid environments where water availability is limited. In India, sesame is cultivated across diverse agro-climatic zones, primarily as a kharif and rabi season crop, contributing significantly to the livelihoods of smallholder farming communities in rain-fed regions. Despite its agronomic resilience at maturity, sesame is notoriously susceptible during early establishment. The crop's diminutive seed size results in limited endosperm reserves, making it particularly vulnerable to soil surface crusting, suboptimal moisture distribution, temperature fluctuations, and pathogen pressure during the critical imbibition and radicle protrusion stages. Inadequate germination uniformity directly compromises plant population density, canopy closure, and ultimately, harvestable yield. Field germination rates under typical smallholder conditions often fall significantly below the laboratory germination standards of certified seed lots.

Pre-sowing seed enhancement through priming or bio-inoculation represents a physiologically targeted intervention that activates metabolic pathways associated with germination, accelerates proteolytic and hydrolytic enzyme activity, and conditions the seed for synchronized, vigorous emergence. Among biologically active seed treatments, microbial inoculants occupy a prominent position. *Azospirillum*, a free-living plant growth-promoting rhizobacterium (PGPR), improves seedling architecture through concurrent biological nitrogen fixation and the production of indole-3-acetic acid (IAA), an endogenous auxin that drives root meristematic activity and lateral root proliferation (Tholkappian and Ramakrishnan, 2022). Zinc Solubilizing Bacteria (ZSB) contribute to seedling nutrition by converting pedologically immobilized zinc fractions into plant-bioavailable forms, thereby supporting carbonic anhydrase function and tryptophan-mediated auxin synthesis at early growth stages.

Fungal biocontrol agents, particularly *Trichoderma viride*, confer a dual advantage in seed treatment systems: they provide physical protection to emerging seedlings against soil-borne pathogens through mechanisms of mycoparasitism and competitive exclusion, while simultaneously promoting root branching and biomass accumulation via the secretion of secondary metabolites and cell wall-degrading enzymes that facilitate nutrient cycling in the rhizosphere. Among plant-derived botanical treatments, *Pongamia pinnata* (Pungam) leaf extracts contain a complex matrix of flavonoids, terpenoids, and the bioactive isoflavone karanjin, compounds known for their phytotoxic, antimicrobial, and insect-antifeedant properties. These attributes have prompted exploration of their application as botanical seed conditioners, though concentration-dependent phytotoxic effects on target crops remain an area of concern (Basra *et al.,* 2018).

Marine macroalgal extracts, particularly those derived from brown algae of the genus Sargassum, have emerged as versatile biostimulants in modern crop science. The mechanism of their action on seed germination involves a suite of naturally occurring cytokinins, gibberellins, and betaines that synergistically up-regulate hydrolytic enzyme systems during imbibition, promote cellular elongation in developing hypocotyls and radicles, and enhance tolerance to osmotic and thermal stress during germination (Nelson and Mahlangu, 2021; Sivasankari *et al.,* 2006).

Traditional fermented organic preparations such as Panchagavya formulated from five cow-derived products including milk, curd, ghee, cow urine, and dung constitute a complex microbial consortium enriched in amino acids, vitamins, and phytohormone-like substances that reportedly stimulate seed metabolic networks and accelerate early plant development. Given the limited systematic evaluation of these diverse organic seed treatment options specifically for sesame crop establishment under semi-arid sandy clay loam conditions, the present study was undertaken with the primary objective of quantitatively assessing the effect of seven organic seed treatments on the germination dynamics, root-shoot growth morphology, and integrated seedling vigor of sesame variety VRI 3 during the Rabi season.

Materials and Methods

Experimental Site and Agro-Climatic Conditions

The pot culture experiment was conducted during the Rabi season of 2026 at the Experimental Farm of the Department of Agriculture, PGP College of Agricultural

Sciences, Palani Nagar, Namakkal, Tamil Nadu, India. The site is geographically situated at 11°13 12″ N latitude and 78°10 55″ E longitude at an elevation of 252 m above mean sea level. The prevailing climate is tropical semi-arid, characterized by moderate temperatures and limited seasonal rainfall. Agrometeorological data during the crop growth period were recorded at the campus observatory.

Physicochemical Characterization of Experimental Soil

Composite soil samples were collected from the 0–15 cm surface layer of the experimental farm, air-dried under shade, pulverized, and sieved through a 2 mm mesh. Standard protocols were employed for the determination of key soil physicochemical parameters (Table 1). The experimental medium was a red soil classified texturally as sandy clay loam and taxonomically as a *Typic Ustropept*. Soil reaction was slightly alkaline (pH 7.85), electrical conductivity was non-saline (0.09 dSm^{-1}), organic carbon content was low (0.34%), available nitrogen was low (215 kg ha^{-1}), available phosphorus was high (20 kg ha^{-1}), and available potassium was medium (245 kg ha^{-1}).

Crop Variety Details

The certified sesame variety VRI 3, released in 2017 by the Regional Research Station of Tamil Nadu Agricultural University (TNAU), Vridhachalam, was used throughout the study. This variety was developed from the cross SVPR 1 × TKG 87 and is characterized by a crop duration of 75–80 days, an erect and profusely branching growth habit, 4-loculed capsules bearing white seeds, a seed oil content of 50%, and a documented irrigated yield potential of 1,025 kg ha^{-1} (Table 2).

Experimental Design and Treatments

The trial was laid out in a Completely Randomized Design (CRD) with seven treatments and three replications. Sowing was carried out on April 17, 2026. The seven treatments evaluated were:

T_1 – Control (Untreated seeds, no pre-sowing treatment)
T_2 – *Azospirillum* liquid inoculant @ 10 mL per kg seed
T_3 – Zinc Solubilizing Bacteria (ZSB) liquid inoculant @ 100 mL per kg seed
T_4 – *Trichoderma viride* talc-based powder formulation @ 4 g per kg seed
T_5 – Aqueous Pungam (*Pongamia pinnata*) leaf extract @ 1% (16-hour seed soak)
T_6 – Seaweed (*Sargassum spp*.) liquid extract @ 5% (8-hour seed soak)
T_7 – Panchagavya fermented formulation @ 6% (20-minute seed soak)

Preparation and Application of Organic Seed Treatments

For T_2 (*Azospirillum*) and T_3 (ZSB), a cooled 10% jaggery solution was used as a natural adhesive to ensure uniform microbial cell attachment to seed surfaces. Seeds were shade-dried for 20–30 minutes before sowing within 24 hours of treatment. For T_4 (*Trichoderma viride*), dry powder was hand-mixed with seeds until a uniform talc coating was achieved on each seed surface. For T_5, fresh *Pongamia pinnata* leaves were macerated, steeped in distilled water at a ratio of 10 g per liter for 16 hours, filtered through double-layered muslin cloth, and used for a 16-hour seed immersion. Seeds for T_6 were immersed in a freshly prepared 5% Sargassum extract solution for 8 hours, drained, and shade-dried on analytical paper. For T_7, 60 mL of fermented Panchagavya was dissolved in 1 liter of distilled water, and seeds were soaked for 20 minutes before shade drying.

Observations Recorded

Germination percentage was computed as the ratio of successfully germinated seeds to total seeds sown, multiplied by 100, after germination stabilization was confirmed. Root length (measured from the root-shoot junction to the primary taproot apex) and shoot length (measured from the cotyledonary node to the apical bud tip) were recorded at 15 and 20 DAS through destructive sampling. Total seedling length was computed as the sum of root and shoot measurements. The Seedling Vigor Index (SVI) was calculated as:

SVI = Germination (%) × Mean Total Seedling Length (cm)

Statistical Analysis

Data were subjected to one-way Analysis of Variance (ANOVA) as per the CRD model. Standard errors of deviation (SEd) were computed, and the significance of treatment differences was assessed through Critical Difference (CD) values at the 5% probability level (P = 0.05).

Results and Discussion

Effect on Seed Germination Percentage

Organic pre-sowing seed treatments imposed statistically distinct effects on germination percentage of sesame VRI 3 (Table 3). Treatment T_6 (Seaweed extract 5%) recorded the highest germination of 49.3%, significantly surpassing all other treatments. T_4 (Trichoderma viride) ranked second at 33.3%, followed by T_2 (Azospirillum) at 29.3%, both significantly exceeding the untreated control (T_1: 17.3%). T_7 (Panchagavya) recorded 21.3%, while T_3 (ZSB) at 17.3% performed at par with the control. Critically, T_5 (Pungam leaf extract) recorded the lowest germination percentage of 4.0%, representing a severe phytotoxic suppression relative to all other treatments.

The superior germination response elicited by Seaweed extract (T_6) is mechanistically attributable to its rich complement of naturally occurring cytokinins, gibberellins, and auxin-like molecules derived from Sargassum spp. thallus. During the imbibition phase, these phytohormonal compounds accelerate the de-repression of hydrolytic enzyme systems particularly α-amylase and β-glucanase that mobilize endosperm starch reserves, providing the energetic substrate for radicle protrusion. Additionally, betaines and osmo-compatible solutes within seaweed extracts confer a degree of osmotic buffering, reducing the sensitivity of germinating seeds to surface drying conditions (Nelson and Mahlangu, 2021). These findings are in agreement with Sivasankari *et al.,* (2006), who demonstrated enhanced germination and biochemical activity in Sesamum indicum following seaweed extract application.

The improved germination under *Trichoderma viride* (T_4) is linked to the enzymatic activity of *T. viride* on seed coat integrity and its production of volatile organic compounds and secondary metabolites—including indole derivatives and gibberellin analogues that prime the internal seed environment for synchronized emergence. Similarly, *Azospirillum* (T_2) contributes through IAA-mediated activation of root cap cells, facilitating earlier and more complete radicle emergence through the seed coat.

The near-total suppression of germination under Pungam leaf extract at 1% (T_5) is consistent with the well-characterized allelopathic chemistry of *Pongamia pinnata*, whose tissues contain karanjin, pongapin, and associated flavonoid glycosides. Prolonged (16-hour) seed immersion in this extract at the applied concentration appears to permit substantial uptake of these phytotoxic molecules through the seed coat, leading to disruption of oxidative phosphorylation, membrane permeability, and mitotic cell division in the embryo (Basra *et al.,* 2018). This finding carries an important management implication: raw Pungam leaf extracts at concentrations of 1% or above are contra-indicated as seed soaking agents for sesame.

Seedling Morphological Growth at 15 DAS

Evaluation of seedling morphological attributes at 15 DAS (Table 4) revealed a clear shift in treatment hierarchy compared to the germination phase. T_2 (*Azospirillum*) produced the longest root length (5.30 cm), shoot length (13.36 cm), and total seedling length (18.66 cm) among all treatments. T_4 (*Trichoderma viride*) followed with 4.30 cm root length, 12.30 cm shoot length, and a total of 16.60 cm.

The untreated control (T_1) recorded 3.36 cm root, 10.26 cm shoot, and 13.62 cm total seedling length. T_6 (Seaweed extract), despite its germination supremacy, demonstrated comparatively modest growth at this stage, with 2.56 cm root, 9.36 cm shoot, and 11.92 cm total length. T_5 (Pungam extract) continued to exhibit suppressed growth (12.00 cm total), with T_3 (ZSB) and T_7 (Panchagavya) recording 10.50 cm and 11.60 cm total seedling length, respectively.

Seedling Morphological Growth at 20 DAS

By 20 DAS (Table 5), T_2 (*Azospirillum*) consolidated its position as the most effective treatment for structural seedling development, registering a root length of 6.90 cm, shoot length of 13.70 cm, and a cumulative total of 20.60 cm. T_4 (*Trichoderma viride*) maintained close ranking at 6.20 cm root, 12.40 cm shoot, and 18.60 cm total.

The control (T_1) recorded 4.30 cm root, 11.90 cm shoot, and 16.20 cm total seedling length. T_6 (Seaweed extract) showed only marginal advancement in root growth (2.70 cm), indicating its primary phytohormonal action is concentrated in triggering the germination event rather than sustaining post-emergence structural growth. T_5 (Pungam extract) exhibited complete seedling mortality by this stage, with all measurements recording 0.00 cm, unequivocally confirming the progressive lethality of its allelopathic constituents on juvenile sesame tissue.

Table.1 Initial physicochemical properties of the experimental soil (Rabi 2026)

Sl. No.	Soil Parameter	Analytical Method	Observed Value / Status
1	Textural Class	International Pipette Method (Piper, 1966)	Sandy Clay Loam
2	Soil pH (1:2.5 soil-water)	Glass Electrode pH Meter (Jackson, 1973)	7.85 (Slightly Alkaline)
3	Electrical Conductivity (dSm^{-1})	EC Bridge Method (Jackson, 1973)	0.09 (non-saline)
4	Organic Carbon (%)	Walkley and Black (1934)	0.34% (Low)
5	Available Nitrogen (kg ha^{-1})	Subbiah and Asija (1956)	215 (Low)
6	Available Phosphorus (kg ha^{-1})	Olsen *et al.,* (1954)	20 (High)
7	Available Potassium (kg ha^{-1})	NH_4OAc Flame Photometry	245 (Medium)

Table.2 Botanical and agronomic characteristics of sesame variety VRI 3

Attribute	Details
Year of Release	2017
Parentage	SVPR 1 × TKG 87
Crop Duration	75–80 days
Cultivation Season	Masipattam and Margazhipattam windows
Seed Yield (irrigated)	1025 kg ha^{-1}
Growth Habit	Erect, profusely branching
Seed Oil Content	50%
Salient Features	Indeterminate growth, 4-loculed alternate capsules, white seeds

Table.3 Effect of organic seed treatments on germination percentage of sesame VRI 3

Organic Seed Treatment	Germination (%)
T_1 – Control (Untreated seeds, no pre-sowing treatment)	17.3
T_2 – *Azospirillum* liquid inoculant @ 10 mL per kg seed	29.3
T_3 – Zinc Solubilizing Bacteria (ZSB) liquid inoculant @ 100 mL per kg seed	17.3
T_4 – *Trichoderma viride* talc-based powder formulation @ 4 g per kg seed	33.3
T_5 – Aqueous Pungam (*Pongamia pinnata*) leaf extract @ 1% (16-hour seed soak)	4.0
T_6 – Seaweed (*Sargassum spp.*) liquid extract @ 5% (8-hour seed soak)	49.3
T_7 – Panchagavya fermented formulation @ 6% (20-minute seed soak)	21.3
SEd	1.6
CD (P = 0.05)	3.5

Table.4 Seedling growth parameters of sesame at 15 Days After Sowing (DAS)

Treatment	Root Length (cm)	Shoot Length (cm)	Total Seedling Length (cm)
T_1 – Control (Untreated seeds, no pre-sowing treatment)	3.36	10.26	13.62
T_2 – *Azospirillum* liquid inoculant @ 10 mL per kg seed	5.30	13.36	18.66
T_3 – Zinc Solubilizing Bacteria (ZSB) liquid inoculant @ 100 mL per kg seed	2.30	8.06	10.50
T_4 – *Trichoderma viride* talc-based powder formulation @ 4 g per kg seed	4.30	12.30	16.60
T_5 – Aqueous Pungam (*Pongamia pinnata*) leaf extract @ 1% (16-hour seed soak)	2.20	9.80	12.00
T_6 – Seaweed (*Sargassum spp.*) liquid extract @ 5% (8-hour seed soak)	2.56	9.36	11.92
T_7 – Panchagavya fermented formulation @ 6% (20-minute seed soak)	2.70	8.90	11.60
SEd	0.21	0.67	0.89
CD (5%)	0.46	1.47	1.93

Table.5 Seedling growth parameters of sesame at 20 Days After Sowing (DAS)

Treatment	Root Length (cm)	Shoot Length (cm)	Total Seedling Length (cm)
T_1 – Control (Untreated seeds, no pre-sowing treatment)	4.30	11.90	16.20
T_2 – *Azospirillum* liquid inoculant @ 10 mL per kg seed	6.90	13.70	20.60
T_3 – Zinc Solubilizing Bacteria (ZSB) liquid inoculant @ 100 mL per kg seed	3.10	11.50	14.60
T_4 – *Trichoderma viride* talc-based powder formulation @ 4 g per kg seed	6.20	12.40	18.60
T_5 – Aqueous Pungam (*Pongamia pinnata*) leaf extract @ 1% (16-hour seed soak)	0.00	0.00	0.00
T_6 – Seaweed (*Sargassum spp.*) liquid extract @ 5% (8-hour seed soak)	2.70	10.80	13.50
T_7 – Panchagavya fermented formulation @ 6% (20-minute seed soak)	2.60	11.50	14.10
SEd	0.28	0.78	1.02
CD (5%)	0.61	1.70	2.21

Table.6 Consolidated Seedling Vigor Index (SVI) of sesame under different organic seed treatments

Treatment	Germination (%)	Mean SL (cm)	SVI
T_1 – Control (Untreated seeds, no pre-sowing treatment)	17.3	14.75	255.18
T_2 – *Azospirillum* liquid inoculant @ 10 mL per kg seed	29.3	19.63	575.16
T_3 – Zinc Solubilizing Bacteria (ZSB) liquid inoculant @ 100 mL per kg seed	17.3	12.55	217.12
T_4 – *Trichoderma viride* talc-based powder formulation @ 4 g per kg seed	33.3	15.41	513.15
T_5 – Aqueous Pungam (*Pongamia pinnata*) leaf extract @ 1% (16-hour seed soak)	4.0	12.00	48.00
T_6 – Seaweed (*Sargassum spp.*) liquid extract @ 5% (8-hour seed soak)	49.3	12.71	626.60
T_7 – Panchagavya fermented formulation @ 6% (20-minute seed soak)	21.3	12.85	273.71
SEd	1.6	0.93	32.19
CD (5%)	3.5	2.03	70.14

The robust root and shoot growth advantage of *Azospirillum* (T_2) across both time points is best explained by its documented capacity to produce and secrete indole-3-acetic acid (IAA) in concentrations sufficient to stimulate root meristematic expansion, lateral root initiation, and shoot apical elongation. The resulting enhanced root system architecture improves the contact surface area between roots and the soil nutrient pool, facilitating greater ion uptake of nitrogen, phosphorus, and zinc from the slightly alkaline sandy clay loam. Tholkappian and Ramakrishnan (2022) have reported analogous root architectural benefits of *Azospirillum lipoferum* in oilseed crop systems, corroborating the present observations.

The limited structural growth promotion by ZSB (T_3) at 15 and 20 DAS, despite its theoretical zinc mobilization capacity, may be attributed to the inherently low organic carbon level of the experimental soil (0.34%). ZSB populations depend substantially on rhizospheric organic carbon turnover for metabolic energy and colonization efficiency, and the nutrient-limited soil environment may have restricted the microbial biomass development necessary to meaningfully improve bioavailable zinc supply during the early seedling window.

Seedling Vigor Index (SVI)

The composite Seedling Vigor Index, integrating both germination percentage and mean seedling length, provided the most comprehensive ranking of treatment efficacy (Table 6). T_6 (Seaweed extract 5%) achieved the highest SVI of 626.60, primarily propelled by its exceptional germination rate (49.3%). T_2 (*Azospirillum*) registered the second-highest SVI of 575.16, driven by its outstanding mean seedling length of 19.63 cm despite a moderate germination rate of 29.3%. T_4 (*Trichoderma viride*) achieved an SVI of 513.15, reflecting a well-balanced contribution of germination (33.3%) and seedling growth (15.41 cm). T_7 (Panchagavya) and T_1 (Control) produced SVI values of 273.71 and 255.18, respectively. The lowest SVI values were recorded for T_3 (ZSB: 217.12) and T_5 (Pungam extract: 48.00), the latter being the result of catastrophic allelopathic failure.

The SVI data collectively affirm that seaweed extract (T_6) is the most effective treatment for ensuring high initial field establishment density a critical factor in determinate-seeded small-grain crops where plant population uniformity directly governs yield potential. However, for cropping situations demanding long-term seedling stamina and architectural robustness, *Azospirillum* (T_2) and *Trichoderma viride* (T_4) represent superior biological choices whose growth-promoting attributes extend well beyond the germination window. These findings align with the biostimulant framework proposed for marine-derived seaweed concentrates by Nelson and Mahlangu (2021), and with the PGPR-mediated seedling development literature reviewed by Tholkappian and Ramakrishnan (2022).

In conclusion, the present investigation conclusively establishes that pre-sowing organic seed treatments differentially influence the germination dynamics and early seedling development of sesame variety VRI 3 under Rabi season pot culture conditions in sandy clay loam soil. Among the treatments evaluated:

- Seaweed extract at 5% concentration (T_6) is the most effective treatment for maximizing field germination percentage and achieving the highest integrated Seedling Vigor Index, making it the preferred choice for situations where uniform crop stand establishment is the primary agronomic priority.
- *Azospirillum* @ 10 mL/kg (T_2) is recommended when the objective is robust root system architecture and extended seedling structural vigor, supported by its rhizosphere IAA biosynthesis and nitrogen-fixation capabilities.
- *Trichoderma viride* @ 4 g/kg (T_4) offers an effective balanced strategy, combining satisfactory germination with solid seedling growth, while simultaneously providing biocontrol protection against soil-borne pathogens.
- Pungam (*Pongamia pinnata*) leaf extract at 1% concentration (T_5) must be categorically avoided as a seed soaking agent for sesame due to its severe allelopathic phytotoxicity, which causes near-complete germination failure and progressive seedling mortality.

Future research should explore field-scale validation of these treatments under varying soil types and climatic conditions, as well as combined application strategies (e.g., seaweed extract + *Azospirillum*) to assess potential additive or synergistic bio-stimulatory effects on sesame crop performance.

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