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Enhancing Germination and Seedling Vigor in Papaya (*Carica papaya* L.) Through Herbal Extract-Based Seed Priming

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***Abstract*:** The present study was conducted at Lovely Professional University, Phagwara, Punjab, to evaluate the efficacy of herbal seed priming in enhancing germination, seedling vigor, biochemical attributes, and early growth performance of papaya seedlings. The experiment consisted of six treatments incorporating various combinations of aloe vera gel, coconut water, moringa leaf extract, neem leaf extract, turmeric extract, and garlic extract, with distilled water as the control. Papaya seeds were soaked in the respective herbal solutions for 12 hours at a 10% concentration, followed by germination under controlled conditions. Significant variations were observed across treatments, with (neem leaf extract + turmeric extract + aloe vera gel exhibited the highest germination percentage, seedling vigor, and chlorophyll content. Similarly, aloe vera gel + coconut water + moringa leaf extract showed notable improvements in root and shoot length, as well as seedling biomass accumulation. The increased germination speed and seedling vigor index in treated seeds suggest that herbal bioactive compounds play a crucial role in stimulating early seedling growth and metabolic activity. The findings indicate that herbal seed priming can serve as an eco-friendly and sustainable alternative to synthetic growth stimulants, improving seed performance while reducing reliance on chemical inputs.

Keywords: Papaya (*Carica papaya* L.) herbal, Neem leaf extract, Turmeric extract, Aloe vera gel, Ginger extract, Coconut water, Moringa leaf extract

Papaya (*Carica papaya* L.) is a tropical fruit crop widely cultivated for its high nutritional and economic value. It plays a vital role in global fruit production due to its rapid growth, short juvenile period, and high fruit yield (Yang et al., 2025). Among various agronomic practices that influence the germination and vigor of papaya seeds, seed priming has emerged as a promising technique to enhance seed performance under varying environmental conditions (Khajjak et al., 2022). Seed priming is a pre-sowing treatment that improves seed germination, accelerates seedling emergence, and enhances overall plant establishment. The extensive use of synthetic priming agents, such as chemical osmopriming and hormone treatments, has raised concerns due to their potential environmental impact and inconsistent effects on seed quality (Cañizares et al., 2025). In contrast, natural plant-derived bioactive compounds, including herbal extracts, offer a sustainable and eco-friendly alternative for improving seed germination and seedling vigor. Various studies have demonstrated the efficacy of herbal extracts such as Aloe vera, neem, moringa, turmeric, garlic, and coconut water in enhancing seed metabolism, boosting antioxidant activity, and improving stress tolerance in plants (Ansari et al., 2024). However, limited research has been conducted on the effect of herbal extract-based seed priming in papaya seeds, necessitating further exploration of this approach. Modern agricultural systems rely heavily on chemical interventions, which often degrade soil health, reduce microbial diversity, and contribute to environmental pollution. To address these challenges, herbal-based seed priming offers a novel strategy to enhance crop resilience while reducing reliance on synthetic agrochemicals. The present study aims to evaluate the effect of herbal extract combinations on papaya seed germination, seedling vigor, biochemical responses, and early growth performance (Pareek et al., 2025). By integrating plant-based priming treatments, this research seeks to identify cost-effective and sustainable alternatives for improving seedling establishment in papaya cultivation.

MATERIAL AND METHODS

The present investigation was undertaken at Lovely Professional University Research Farm, Punjab, during 2024–25 to examine the impact of herbal extract-based seed priming on the germination, growth, and biochemical attributes of papaya (*Carica papaya L.*). The study was carried out under controlled greenhouse conditions to ensure uniform environmental influences and minimize external variability.

The experiment was arranged in a completely randomized design (crd) with six treatments, including a control, and was replicated three times. The seeds underwent priming with herbal extracts, and subsequent growth observations were recorded at predefined intervals. The herbal solutions were prepared using fresh plant materials and standardized extraction procedures. The seed priming process was conducted in multiple phases (Table 1).

Initially, fresh herbal materials were homogenized with distilled water in a 1:10 w/v ratio, filtered, and stored for immediate use. Papaya seeds were immersed in respective extract solutions for 12 hours at room temperature (25 ± 2°C), ensuring adequate absorption of bioactive compounds. Post-treatment, the seeds were air-dried in shade for 24 hours to restore moisture balance before sowing. The seeds were then sown in plastic trays containing a sterilized soil-sand mixture (2:1 ratio), and the trays were kept in the greenhouse under optimal conditions for germination and seedling growth. Six seed priming treatments were evaluated, including a control (T_1) with no priming using distilled water. The other treatments involved soaking seeds for 12 hours in different herbal extract combinations at 10% concentration: T_2 consisted of aloe vera gel, coconut water, and moringa leaf extract; T_3 included neem leaf extract, turmeric extract, and aloe vera gel; T_4 combined garlic extract, moringa leaf extract, turmeric extract, and coconut water; T_5 comprised aloe vera gel, neem leaf extract, and turmeric extract; and T_6 included garlic extract, moringa leaf extract, and coconut water.

Observations and Parameters Recorded

Seed germination and vigor attributes: Germination percentage was calculated at 7 and 14 days after sowing (DAS) by counting the number of emerged seedlings. Mean Germination Time (MGT) was determined to assess the average duration required for seed sprouting, while the Germination Index (GI) was computed to evaluate germination speed. Seedling vigor was assessed using the Seedling Vigour Index (SVI), which was derived by multiplying the germination percentage with the total seedling length.

Seedling growth and morphological parameters: Seedling growth was evaluated at 14 DAS by measuring shoot and root lengths. Fresh and dry biomass of seedlings was recorded, with drying carried out at 60°C for 48 hours to obtain accurate dry weight values. Leaf area was determined using a leaf area meter (LI-COR 3000) to quantify differences in foliage expansion across treatments.

Chlorophyll content and biochemical assays: Total chlorophyll content in the leaves was estimated using the DMSO extraction method (Hiscox and Israelstam, 1979). Absorbance was measured at 645 nm and 663 nm using a UV-VIS spectrophotometer, and chlorophyll content was expressed as mg g^{-1} fresh weight. Total soluble sugars were determined using the Anthrone reagent method, and proline accumulation was assessed following the Bates et al. (1973) protocol. Membrane stability was evaluated by estimating the Membrane Stability Index (MSI) using standard procedures.

Statistical analysis: Duncan's Multiple Range Test (DMRT) with SPSS software (version 25.0)

RESULTS AND DISCUSSION

Seed germination and vigor attributes: Germination percentage varied significantly among different treatments at 7 and 14 DAS. The highest germination percentage (94.0%) at 14 DAS was in T_2 (neem leaf extract + turmeric extract + aloe vera gel), followed by T_1 (aloe vera gel + coconut water + moringa leaf extract) and T_3 (garlic extract + moringa leaf extract + turmeric extract + coconut water). The lowest germination percentage (85.1%) was observed in the control (T_6). Mean germination time (MGT) was lowest in T_2 (4.1 days), indicating a faster emergence rate, while the control (T_6) longest MGT (5.1 days). Germination indexwas highest in T_2 (19.2), followed by T_1 and T_3, suggesting that herbal seed priming treatments improved germination speed. Seedling vigour index (SVI) was significantly higher in T_2 (1702), followed by T_1 and T_3, while the lowest SVI was in T_6. The improved germination and vigor in treated seeds may be due to the presence of bioactive compounds in plant extracts, which stimulate enzyme activity, enhance water absorption, and provide essential nutrients (Table 1). Singh et al. (2024) also reported that organic seed treatments enhance early seedling establishment.

Seedling growth and morphological parameters: Seedling growth parameters, including shoot length, root length, and biomass accumulation, showed significant variations among treatments. The tallest seedlings were observed in T_2 (neem leaf extract + turmeric extract + aloe vera gel), followed by T_1 and T_3, whereas the shortest seedlings were in the control (T_6).

Root length was also maximum in T_2, which was statistically at par with T_1 and T_3. Fresh and dry biomass accumulation followed a similar trend, with T_2 exhibiting the highest values, indicating improved nutrient assimilation and seedling robustness. Leaf area was significantly greater in T_2 compared to other treatments, suggesting enhanced photosynthetic efficiency (Table 2). The superior seedling growth observed in herbal priming treatments may be attributed to the presence of growth-promoting compounds, antioxidants, and antimicrobial properties that protect emerging seedlings from stress conditions. Abir et al (2022) and Arraf and Al-madhagi (2025) found that organic formulations enhance seedling establishment by promoting root development and nutrient uptake.

Chlorophyll content and biochemical assays: Total chlorophyll content was highest in T_3 followed by T_2 and T_1. The control (T_6) had the lowest chlorophyll content, indicating that herbal priming treatments positively influenced photosynthetic efficiency. Total soluble sugars were significantly higher in T_2, reflecting better carbohydrate accumulation, which is crucial for early seedling

Table 1. Effect of seed priming on germination and vigor attributes

Treatment	Germination (%)		Mean germination time (days)	Germination index	Seedling vigor index
	(7 DAS)	(14 DAS)			
T_1 (Control)	78.5	92.3	4.2	18.6	1650
T_2	80.2	94	4.1	19.2	1702
T_3	77	91.5	4.4	17.8	1623
T_4	75.8	89.7	4.5	17.2	1580
T_5	72.6	86.9	4.8	16.4	1503
T_6	70.3	85.1	5.1	15.7	1438
CD (p=0.05)	2.5	2.8	0.3	1.2	55

Table 2. Impact of seed priming on seedling growth and morphological parameters

Treatment	Shoot length (cm)	Root length (cm)	Leaf area (cm²)	Fresh biomass (g)	Dry biomass (g)
T_1 (Control)	12.4	7.3	42.27	1.92	0.68
T_2	13.1	7.9	45.42	2.08	0.72
T_3	12.0	7.1	43.75	1.87	0.66
T_4	11.7	6.8	44.08	1.82	0.64
T_5	11.2	6.5	43.98	1.74	0.61
T_6	10.8	6.1	44.42	1.68	0.59
CD (p=0.05)	0.9	0.5	NS	0.12	0.05

Table 3. Effect of seed priming on chlorophyll content and biochemical parameters

Treatment	Chlorophyll a (mg/g)	Chlorophyll b (mg/g)	Total soluble sugars (mg/g)	Proline content (µg/g)	Membrane stability index (%)
T_1 (Control)	1.45	0.86	18.9	4.3	72.4
T_2	1.52	0.91	19.5	4.7	74.1
T_3	1.39	0.83	18.2	4.1	71.2
T_4	1.35	0.80	17.8	3.9	70.6
T_5	1.28	0.76	17.2	3.7	69.5
T_6	1.21	0.72	16.5	3.4	67.8
CD (p=0.05)	0.08	0.05	0.9	0.4	2.1

establishment. Proline accumulation was also higher in T_2, suggesting enhanced stress tolerance due to the antioxidant properties of herbal extracts (Table 3). Membrane Stability Index (MSI) was highest in T_2, followed by T_1 and T_3, while the control exhibited the lowest MSI, indicating greater susceptibility to oxidative damage. The enhanced biochemical attributes in herbal priming treatments may be linked to the bioactive compounds that improve membrane integrity and physiological efficiency. Hassan et al. (2020) and Megbowon et al. (2024), also highlighted the role of organic formulations in improving stress tolerance and seedling quality.

CONCLUSION

The integration of herbal seed priming treatments demonstrated a significant impact on seed germination, seedling vigor, biochemical composition, and overall plant growth. Among the different treatments, the combination of neem leaf extract, turmeric extract, and aloe vera gel consistently outperformed other treatments by enhancing germination speed, seedling vigor, root development, and chlorophyll accumulation. The improved physiological and biochemical responses observed in treated seedlings highlight the potential of plant-derived bioactive compounds in stimulating early growth and stress tolerance. The herbal seed priming could serve as a sustainable and eco-friendly alternative to conventional seed treatments, reducing dependency on synthetic chemicals while promoting robust seedling establishment. The enhanced seedling vigor and biochemical efficiency observed in primed seeds could lead to improved crop resilience under varying environmental conditions. Future research could explore the molecular mechanisms behind these effects, as well as the potential of herbal priming for large-scale agricultural applications.

AUTHORS CONTRIBUTION

Vikanksha: Experimentation, data collection, Arun Kumar: Conceptualization, supervision, manuscript writing, Ankit: – Statistical analysis, literature review, Jatinder Singh: Guidance, critical review, editing.

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