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Study of Papaya (*Carica papaya* Linn.) Germination Index and Seedling Growth in Agriculture Waste-Based Media and Plant Growth Regulators

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ABSTRACT

The ‘Red Lady’ papaya is typically and commercially cultivated from seed. However, its germination and seedling growth require improvement for optimal results. This experiment was designed in a factorial completely randomized design (CRD) with three replications, using six different agricultural waste-based growing media: soil, soil + farm yard manure (FYM), soil + vermicompost, soil + rice husk, soil + cocopeat, and a mix of soil + FYM + rice husk + vermicompost + cocopeat in equal ratios (1:1). Additionally, five levels of plant growth regulators (PGRs) were used for seed treatment: GA_3 (100 ppm, 150 ppm), NAA (100 ppm, 150 ppm), and a combination of GA_3 (100 ppm) + NAA (100 ppm). The experiment consisted of 36 treatment combinations, each replicated three times. The results showed that the mixed growing media (soil + FYM + rice husk + vermicompost + cocopeat) significantly increased the germination index, root length, root diameter, shoot length, and shoot diameter, compared to the control. Among the PGRs, the combination of GA_3 (100 ppm) and NAA (100 ppm) produced the best results. The study concluded that the soil + FYM + rice husk + vermicompost + cocopeat mix is an ideal growing medium for papaya germination. The GA_3 (100 ppm) + NAA (100 ppm) treatment was the most effective for enhancing seedling growth. Therefore, using mixed growing media combined with an optimal solution of GA_3 and NAA is beneficial for improving papaya seed germination and seedling development.

Introduction

In tropical and subtropical regions, papaya (*Carica papaya* Linn.), a member of the family Caricaceae, is widely cultivated. It is typically diploid (2n = 18) and originates from the Americas (Anburani & Shakila, 2010). In India, papaya was cultivated across 138,000 hectares, yielding 59.89 million metric tons (MT) with a productivity rate of 43.3 MT ha^{-1} (NHB, 2018). According to previous research, the papaya crop is favored for its low maintenance and high nutritional value (Ming et al., 2015). However, several challenges have led to a decline in papaya cultivation, including issues with propagation, varying sex forms, susceptibility to waterlogging, waterborne diseases, and frost.

Commercial papaya varieties are traditionally propagated by seed. Significant advances have been made in seminiferous propagation, allowing for the production of high-quality seeds by

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selecting mother plants with desirable traits (de Fátima Santana da Costa et al., 2019). However, the sarcotesta, the fleshy material surrounding the seed, and the seed coat contain germination inhibitors that must be removed prior to sowing to promote germination (Chauhan et al., 2014).

Growing media play a critical role in the supply of water and nutrients, enabling oxygen diffusion into roots and facilitating gaseous exchange between roots and the surrounding environment (Somerville & Proctor, 2013). Soil, commonly used due to its affordability and accessibility, is the most prevalent medium (Bhardwaj, 2013). Rice husk has been shown to support seed germination by maintaining an appropriate temperature, protecting seeds from fungal damage in moist soil, and providing a soft medium for germination and sprouting (Badar & Qureshi, 2014). Its high silica content allows it to act as a sorbent, improving nutrient retention and availability to plants (Radha et al., 2018; Parra et al., 2022; Omar et al., 2021).

Cocopeat, another growing medium, offers favorable pH and electrical conductivity (EC) values and other chemical properties conducive to plant growth. Its large and small pore spaces enhance aeration, while its water-holding capacity is up to eight times that of soil, allowing it to function like a sponge (Abad et al., 2002; Singh et al., 2019). Vermicompost supports adequate oxygen levels and stores water and nutrients, providing them for plant growth. The presence of humic compounds significantly increases nutrient availability, plant development, yield, and quality (Sinha et al., 2009).

Pre-soaking seeds in GA3 and NAA for 12 hours reduces the germination time required (Anburani & Shakila, 2010). Recently, various sizes and types of pots have been developed to optimize the growth of fruit seedlings. The ‘Red Lady’ papaya is a promising variety, and improving its germination rate could result in robust and healthy seedlings. Therefore, the present study aimed to accelerate seed germination and promote healthy growth through the application of different growth media and plant growth regulators (PGRs). The expected results can provide farmers with valuable insights into the most suitable methods for cultivating papaya seedlings.

Material and Methods

The research was carried out from November 2021 to April 2022, under a hi-tech polyhouse at Lovely Professional University, Kapurthala, Punjab, India. A factorial, completely randomized design was used for statistical analysis, with three replications. The treatments included six growth media combinations, i.e., soil (T_1), soil + farm yard manure (T_2), soil + vermicompost (T_3), soil + rice husk (T_4), soil + cocopeat (T_5), and soil + FYM + rice husk + vermicompost + cocopeat (T_6), as well as five levels of plant growth regulators, including GA3 100 ppm (C_1), GA3 150 ppm (C_2), NAA 100 ppm (C_3), NAA 150 ppm (C_4), GA_3 100 ppm + NAA 100 ppm (C_5), and control (Table 1).

Table 1. Treatments details.

Factor A			Factor B	
Rooting media	Composition	Notation	PGRs concentrations	Notation
Soil	1	T_1	Control	C_1
Soil + vermicompost	1:1	T_2	GA_3 100 ppm	C_2
Soil + farm yard manure	1:1	T_3	GA_3 150 ppm	C_3
Soil + rice Husk	1:1	T_4	NAA 100 ppm	C_4
Soil + cocopeat	1:1	T_5	NAA 150 ppm	C_5
soil + farm yard manure + rice husk + vermicompost + cocopeat	1:1:1:1:1	T_6	GA_3 100 ppm + NAA 100 ppm	C_6

For the cultivation process, a mixture of the aforementioned growing media was placed into trays. Subsequently, 20 seeds of the ‘Red Lady’ papaya were used for each replication, and the seeds were pre-soaked for up to 12 hours in solutions of GA_3 and NAA (100 ppm and 150 ppm) and a combination of GA3 (100 ppm) + NAA (100 ppm). The experiment was conducted in a hi-tech polyhouse with controlled conditions, maintaining a temperature of 22 ± 4 °C and a relative humidity of 75 ± 5%. After sowing, the trays were lightly irrigated daily until seed emergence. Post-germination, light irrigation was performed every other day, as outlined.

For germination assessment, 20 seeds were sown in each of three replications, using the appropriate substratum. The number of seedlings emerging was recorded daily from the time the seeds were sown in the media until germination was complete.

Germination index
According to the Association of Official Seed Analysis (1993), the following formula was used for calculating the germination index (G.I.):

$$\text{Germination index} = \frac{n}{d}$$

where,
n = number of seedlings emerging on the day 'd'
d = day after planting
The seeds with a greater germination index were more vigorous.

Root and shoot length
The root and shoot length of five randomly selected seedlings from each replication were measured on a metric scale, 60 d after sowing (DAS), and average values were calculated (Huda et al., 2007).

Root and shoot diameter
The thickest root and shoot diameters in each replication of all treatments were measured with a physical vernier caliper, and then the ordinary diameter of the roots (mm) was reported for each treatment group (Huda et al., 2007).

Number of leaves
The leaves were counted after 60 d. The observations except germination index took 5 randomly selected seedlings of each replication, and the average value was calculated.

Statistical analysis
Statistical software SPSS was used to compute and analyze the generated data from the investigation. Duncan's multiple range test was applied to check the significance level at $p \leq 0.05$.

Results
The effect of growing media and PGRs was significant ($P \leq 0.05$) as presented in Tables 1 and 2, regarding germination index, seedling shoot, root length, and diameters.

Papaya germination index
Based on data analysis (Table 2; Figs. 1a and 2a), it can be interpreted that the soil + FYM + rice husk + vermicompost + cocopeat culture media caused maximum germination index (1.29), and the least germination index of papaya seeds was found in soil (Fig. 1a). However, among the PGRs, GA_3 100 ppm + NAA 100 ppm (C_5) resulted in the highest germination index (1.21), while at least 0.63% was obtained in the control treatment. The combination of soil + FYM + rice husk + vermicompost + cocopeat culture media and GA_3 100 ppm + NAA 100 ppm (2.29) resulted in the highest germination index (2.29) compared to other treatment combinations.

Root length
The data presented in Table 2 and Figure 1b indicate that the growing medium consisting of soil, FYM (farmyard manure), rice husk, vermicompost, and cocopeat (T_6) produced the longest root length (9.53 cm), while the shortest root length (7.59 cm) was observed in soil (T_1) and soil + rice husk (T_4). Among the plant growth regulators, the treatment with GA3 (100 ppm) + NAA (100 ppm) resulted in the longest root length (8.91 cm), whereas the shortest root length (7.45 cm) occurred in the control group. Overall, the combination of soil, FYM, rice husk, vermicompost, and cocopeat (SFVRC) supplemented with 100 ppm GA_3 and 100 ppm NAA produced the longest roots (11.23 cm) among all tested treatments.

Root diameter
Based on the analysis (Table 2 and Fig. 1), it appears that the media T_6, i.e., soil + FYM + rice husk + vermicompost + cocopeat, enhanced maximum root diameter (1.06 mm) and the minimum value was found in T_2, i.e., soil + FYM (0.87 mm). However, based on the PGRs, we observed that the C_5, i.e., GA_3 (100 ppm) + NAA (100 ppm), resulted in the thickest roots (1.04 mm), and the thinnest roots were found in the control (0.79 mm). The combination of soil + FYM + rice husk + vermicompost + cocopeat culture media and GA_3 100 ppm + NAA 100 ppm resulted in the thickest root (1.40 mm) compared to other combinations.

Shoot length
Shoot length of papaya seedlings significantly increased (Table 3) among the growing media and PGRs. It appeared that the media T_6, i.e., soil + FYM + rice husk + vermicompost + cocopeat, increased the maximum shoot length (16.07 cm), and the minimum value occurred in T4, i.e., soil + rice husk (14.53 cm) among all growing media. However, among the PGR treatments, we observed that C_5, i.e., GA_3 (100 ppm) + NAA (100 ppm), enhanced the longest shoot (16.09 cm), whereas the shortest was found in the control (13.57 cm).

Table 2. Effect of growing media (T) and plant growth regulators (PGRs) on germination index, root length, and root diameter of the 'Red Lady' papaya cultivar under protected conditions.

Growing Media (T)	Plant Growth Regulators (C)					
	100ppm GA$_3$ (C$_1$)	150 ppm GA$_3$ (C$_2$)	100 ppm NAA (C$_3$)	150 ppm NAA (C$_4$)	100 ppm each GA$_3$ + NAA (C$_5$)	Control (C$_0$)
	Germination index					
Soil (T$_1$)	0.59 ± 0.16^{n-p}	0.92 ± 0.06^{d-k}	0.69 ± 0.17^{k-n}	0.67 ± 0.10^{l-n}	0.92 ± 0.08^{d-k}	0.33 ± 0.00^{q}
FYM (T$_2$)	0.63 ± 0.09^{m-o}	0.82 ± 0.14^{h-n}	0.94 ± 0.08^{c-j}	0.59 ± 0.16^{n-p}	0.87 ± 0.23^{f-l}	1.08 ± 0.08^{b-f}
Soil + VC (T$_3$)	0.95 ± 0.11^{c-i}	0.98 ± 0.13^{b-i}	0.67 ± 0.10^{l-n}	0.75 ± 0.08^{i-n}	1.11 ± 0.04^{b-e}	0.39 ± 0.10^{pq}
Soil + RH (T$_4$)	0.41 ± 0.07^{pq}	0.85 ± 0.04^{e-m}	0.77 ± 0.10^{i-n}	0.96 ± 0.12^{c-i}	1.02 ± 0.02^{b-h}	0.44 ± 0.10^{o-q}
Soil + CP (T$_5$)	1.05 ± 0.13^{b-h}	1.14 ± 0.10^{b-d}	0.90 ± 0.19^{e-l}	0.98 ± 0.15^{b-i}	1.06 ± 0.19^{b-g}	0.71 ± 0.19^{j-n}
SFVRC (T$_6$)	1.21 ± 0.06^{b}	1.16 ± 0.01^{bc}	1.12 ± 0.11^{b-e}	1.17 ± 0.01^{bc}	2.29 ± 0.25^{a}	0.84 ± 0.06^{g-m}
	Root length (cm)					
Soil (T$_1$)	7.57 ± 0.97^{j-m}	7.50 ± 0.26^{j-m}	7.33 ± 0.15^{l-n}	7.97 ± 0.15^{g-j}	7.93 ± 0.32^{g-k}	7.27 ± 0.06^{l-n}
FYM (T$_2$)	7.93 ± 0.12^{g-k}	7.43 ± 0.23^{k-m}	7.53 ± 0.31^{j-m}	7.23 ± 0.12^{mn}	8.37 ± 0.15^{fg}	7.43 ± 0.23^{k-m}
Soil + VC (T$_3$)	7.70 ± 0.10^{i-n}	7.73 ± 0.31^{h-m}	7.50 ± 0.10^{j-m}	7.63 ± 0.40^{j-m}	8.50 ± 0.40^{ef}	7.53 ± 0.06^{j-m}
Soil + RH (T$_4$)	7.77 ± 0.06^{h-l}	8.17 ± 0.15^{f-i}	6.60 ± 0.26^{o}	7.60 ± 0.00^{j-m}	8.53 ± 0.15^{ef}	6.90 ± 0.17^{no}
Soil + CP (T$_5$)	8.50 ± 0.17^{ef}	8.97 ± 0.25^{de}	8.57 ± 0.23^{ef}	8.20 ± 0.20^{f-h}	8.87 ± 0.21^{de}	7.67 ± 0.23^{j-m}
SFVRC (T$_6$)	9.23 ± 0.45^{cd}	9.93 ± 0.38^{b}	9.43 ± 0.29^{c}	9.43 ± 0.21^{c}	11.23 ± 0.45^{a}	7.90 ± 0.10^{g-k}
	Root diameter (mm)					
Soil (T$_1$)	0.97 ± 0.06^{b-f}	0.93 ± 0.12^{c-f}	0.93 ± 0.06^{c-f}	0.93 ± 0.15^{c-f}	0.93 ± 0.06^{c-f}	0.77 ± 0.12^{g-i}
FYM (T$_2$)	0.83 ± 0.06^{f-i}	0.90 ± 0.10^{d-g}	1.03 ± 0.06^{b-d}	0.93 ± 0.15^{c-f}	0.83 ± 0.06^{f-i}	0.70 ± 0.00^{i}
Soil + VC (T$_3$)	1.03 ± 0.06^{b-d}	1.00 ± 0.10^{b-e}	0.73 ± 0.06^{hi}	0.87 ± 0.06^{e-h}	1.03 ± 0.06^{bd}	0.93 ± 0.12^{c-f}
Soil + RH (T$_4$)	0.87 ± 0.06^{e-h}	0.97 ± 0.06^{b-f}	0.70 ± 0.00^{i}	1.00 ± 0.10^{b-e}	1.07 ± 0.06^{bc}	0.73 ± 0.06^{hi}
Soil + CP (T$_5$)	1.03 ± 0.06^{b-d}	1.07 ± 0.06^{bc}	1.03 ± 0.06^{b-d}	0.93 ± 0.15^{c-f}	1.00 ± 0.10^{b-e}	0.77 ± 0.06^{g-i}
SFVRC (T$_6$)	1.03 ± 0.06^{b-d}	1.10 ± 0.00^{b}	0.97 ± 0.06^{b-f}	0.97 ± 0.12^{b-f}	1.40 ± 0.10^{a}	0.87 ± 0.06^{e-h}

Values are mean ± SD of 3 replications, containing 20 seeds each. Letters indicate a significant difference from the control ($P \leq 0.05$).

Where FYM: farm yard manure, VC: vermicompost, RH: rice husk, CP: cocopeat, SFVRC: soil + FYM + VC + RH + CP.

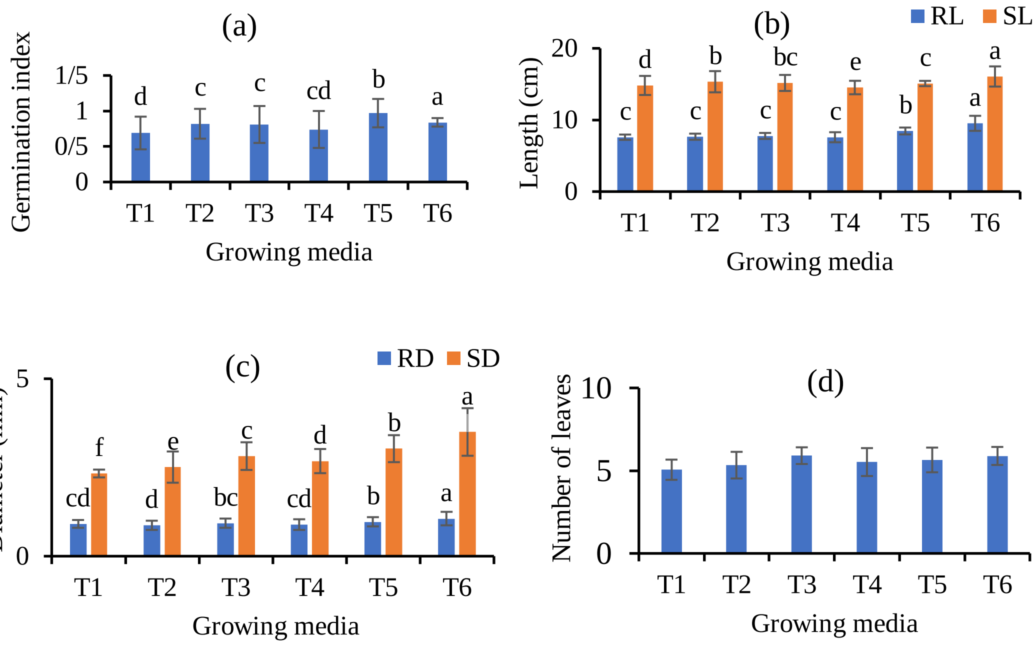

Fig. 1. Variations in growth characteristics, (a) germination index, (b) root and shoot length, (c) root and shoot diameter, (d) number of leaves, by different growing media in germinated papaya seeds: where, T_1- soil, T_2- soil + FYM, T_3- soil + vermicompost, T_4- soil + rice husk, T_5 - soil+ cocopeat, T_6 – soil + FYM + vermicompost + rice husk + cocopeat. Bars, RL, SL, RD, and SD indicate root length, shoot length, root diameter, and shoot diameter, respectively. Values are mean ± SD of 3 replications, containing 20 seeds each. Letters indicate a significant difference from the control (P≤0.05).

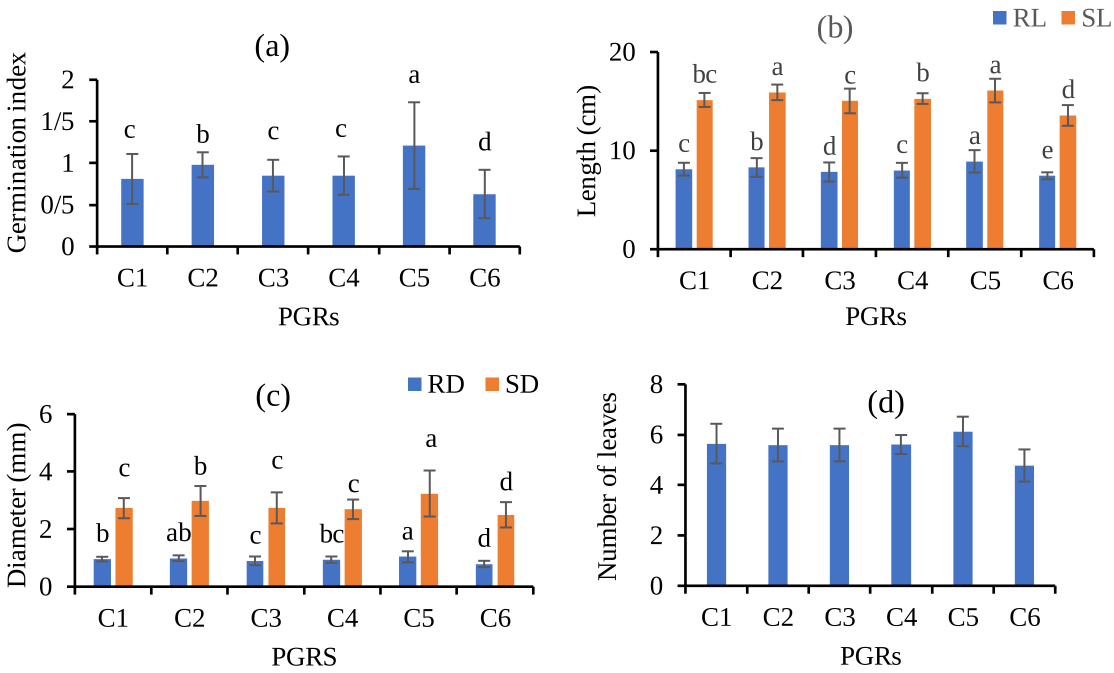

Fig. 2. Variation in growth characteristics, (a) germination index, (b) root and shoot length, (c) root and shoot diameter, (d) number of leaves, by different levels of plant growth regulators in germinated papaya seeds: where, C_1-100ppm GA_3, C_2- 150ppm GA_3, C_3-100 ppm NAA, C_4-150 ppm NAA, C_5- 100 ppm each NAA and GA_3, CO- Control. Bars, RL, SL, RD, and SD indicate root length, shoot length, root diameter, and shoot diameter, respectively. Values are mean ± SD of 3 replications, containing 20 seeds each. Letters indicate a significant difference from control at P ≤ 0.05.

Table 3. Effect of growing media (T) and plant growth regulators (PGRs) on shoot length and shoot diameter of 'Red Lady' papaya cultivar seedlings under controlled conditions.

Growing Media (T)	Plant growth regulators (C)					
	100ppm GA_3 (C_1)	150 ppm GA_3 (C_2)	100 ppm NAA (C_3)	150 ppm NAA (C_4)	100 ppm each GA_3+NAA (C_5)	Control (C_O)
	Shoot length (cm)					
Soil (T_1)	14.23 ± 0.32^{lm}	$15.30 \pm 0.10^{e-i}$	16.17 ± 0.15^{cd}	$15.43 \pm 0.35^{e-h}$	$15.53 \pm 0.21^{e-g}$	12.27 ± 0.06^{o}
FYM (T_2)	$14.97 \pm 0.42^{g-k}$	15.77 ± 0.50^{de}	16.50 ± 0.30^{c}	16.20 ± 0.46^{cd}	16.20 ± 0.70^{cd}	12.43 ± 0.23^{o}
Soil + VC (T_3)	16.30 ± 0.36^{c}	16.40 ± 0.40^{c}	13.53 ± 0.15^{n}	$14.90 \pm 0.26^{h-k}$	$15.70 \pm 0.20^{d-f}$	14.20 ± 0.26^{m}
Soil + RH (T_4)	$14.80 \pm 0.17^{i-k}$	$15.27 \pm 0.31^{e-j}$	13.37 ± 0.06^{n}	$15.27 \pm 0.21^{e-j}$	$15.27 \pm 0.15^{e-j}$	13.20 ± 0.40^{n}
Soil + CP (T_5)	$15.23 \pm 0.42^{e-j}$	$15.43 \pm 0.23^{e-h}$	$15.27 \pm 0.15^{e-j}$	$14.73 \pm 0.15^{j-l}$	$15.30 \pm 0.10^{e-i}$	$14.60 \pm 0.17^{k-m}$
SFVRC (T_6)	$15.33 \pm 0.32^{e-i}$	17.27 ± 0.15^{b}	$15.40 \pm 0.26^{e-h}$	$15.27 \pm 0.06^{f-j}$	18.53 ± 0.15^{a}	$14.73 \pm 0.25^{j-l}$
	Shoot diameter (mm)					
Soil (T_1)	$2.37 \pm 0.06^{k-n}$	$2.40 \pm 0.00^{k-m}$	$2.37 \pm 0.12^{k-n}$	$2.33 \pm 0.15^{k-o}$	$2.37 \pm 0.06^{k-n}$	$2.17 \pm 0.12^{m-o}$
FYM (T_2)	$2.23 \pm 0.06^{l-o}$	$2.30 \pm 0.10^{k-o}$	$2.83 \pm 0.06^{e-h}$	$2.30 \pm 0.17^{k-o}$	3.30 ± 0.10^{bc}	2.10 ± 0.00^{o}
Soil + VC (T_3)	$3.10 \pm 0.10^{c-d}$	3.40 ± 0.17^{b}	$2.30 \pm 0.20^{k-o}$	$2.73 \pm 0.12^{g-i}$	$2.87 \pm 0.12^{d-h}$	$2.53 \pm 0.12^{i-k}$
Soil + RH (T_4)	$2.67 \pm 0.06^{h-j}$	$2.87 \pm 0.12^{d-h}$	2.13 ± 0.06^{no}	$2.93 \pm 0.12^{d-g}$	$3.07 \pm 0.06^{c-e}$	$2.40 \pm 0.00^{k-m}$
Soil + CP (T_5)	$3.07 \pm 0.12^{c-e}$	3.43 ± 0.12^{b}	3.43 ± 0.06^{b}	$2.80 \pm 0.20^{f-h}$	$3.00 \pm 0.20^{d-f}$	$2.43 \pm 0.12^{j-l}$
SFVRC (T_6)	$2.93 \pm 0.12^{d-g}$	3.50 ± 0.00^{b}	3.37 ± 0.06^{b}	$3.03 \pm 0.40^{d-f}$	4.83 ± 0.29^{a}	3.37 ± 0.12^{b}
	Number of leaves					
Soil (T_1)	$4.56 \pm 0.51^{b-d}$	$4.56 \pm 0.51^{b-d}$	$5.44 \pm 0.51^{a-d}$	$5.44 \pm 0.51^{a-d}$	$5.89 \pm 0.19^{a-d}$	4.44 ± 0.51^{cd}
FYM (T_2)	$5.00 \pm 0.00^{a-d}$	$5.56 \pm 0.51^{a-d}$	$6.44 \pm 0.51^{a-c}$	$5.44 \pm 0.51^{a-d}$	$5.56 \pm 0.51^{a-d}$	4.00 ± 0.00^{d}
Soil + VC (T_3)	$6.44 \pm 0.51^{a-c}$	$5.44 \pm 0.51^{a-d}$	$5.44 \pm 0.51^{a-d}$	$6.00 \pm 0.00^{a-d}$	6.56 ± 0.51^{ab}	$5.56 \pm 0.51^{a-d}$
Soil + RH (T_4)	$5.56 \pm 0.51^{a-d}$	$6.44 \pm 0.51^{a-c}$	$4.56 \pm 0.51^{b-d}$	$5.56 \pm 0.51^{a-d}$	$6.44 \pm 0.51^{a-c}$	$4.56 \pm 0.51^{b-d}$
Soil + CP (T_5)	6.56 ± 0.51^{ab}	$6.11 \pm 0.19^{a-c}$	$6.11 \pm 0.19^{a-c}$	$5.11 \pm 0.19^{a-d}$	$5.44 \pm 0.51^{a-d}$	$4.56 \pm 0.51^{b-d}$
SFVRC (T_6)	$5.78 \pm 0.69^{a-d}$	$5.44 \pm 0.51^{a-d}$	$5.56 \pm 0.51^{a-d}$	$6.11 \pm 0.19^{a-c}$	6.89 ± 0.84^{a}	$5.56 \pm 0.51^{a-d}$

Values are mean ± SD of 3 replications, containing 20 seeds each. Letters indicate a significant difference from control at $P \leq 0.05$.

where, FYM- farm yard manure, VC- vermicompost, RH- rice husk, CP- cocopeat, SFVRC- Soil + FYM + VC + RH + CP.

The combination of soil + FYM + rice husk + vermicompost + cocopeat culture media and GA3 100 ppm + NAA 100 ppm resulted in the longest shoot (18.53 cm) compared to other combinations.

Shoot diameter

Shoot diameter significantly varied between the treatment groups (Table 3). Among all the growing media, T_6, i.e., soil + FYM + rice husk + vermicompost + cocopeat, had the maximum shoot diameter (3.51 mm), while the minimum shoot diameter was found in the soil treatment (2.33 mm). On the other hand, based on plant growth regulators, GA_3 (100 ppm) + NAA (100 ppm) had the maximum shoot diameter (3.24 mm), and the minimum was found in the control (2.50 mm). The combination of soil, FYM, rice husk, vermicompost, and cocopeat as the culture media, along with GA_3 at 100 ppm and NAA at 100 ppm, produced the thickest shoots at 4.83 mm, compared to the other combinations.

Number of leaves

Leaf count was not significantly different between the treatments (Table 3). Among all the growing media, T_3, i.e., soil + vermicompost, caused the highest leaf count (5.91), while the minimum was found in the soil treatment (5.06). On the other hand, based on the plant growth regulators, GA3 (100 ppm) had maximum leaf count (5.59), and the minimum was found in the control (4.78). The addition of 100 ppm GA_3 and NAA to the soil + FYM + rice husk + vermicompost + cocopeat media resulted in the highest number of leaves (6.89) compared to the other combinations.

Discussion

This research focused on agricultural waste media, with plant growth regulators (PGRs) having significant integrated roles in stimulating papaya seed growth. One of the strains, Red Lady papayas, was studied for its propagation aspects. The seedlings were healthiest at 150 ppm NAA, 100 ppm GA_3 + 100 ppm NAA, and in a mix of growing media consisting of soil, FYM, rice husk, vermicompost, and cocopeat. The germination index was attributed to favorable growing media that contained more nutrients and had good moisture-holding capacity. It was well known that GA_3 was utilized to disrupt seed dormancy and increase the germination rate, while NAA accelerated growth through rapid cell division and broke the aleurone layer of the seed (Mirheidari et al., 2022). Optimal temperature was a basic requirement for germination, and the protected structure helped maintain it (Mahmood et al., 2019).

The results regarding the seed germination index aligned with those of Shrivastava et al. (2021) for papaya seeds. The increase in seedling growth recorded in this investigation reflected the combination of high moisture retention and significant air space in the mixed growing media. The results for shoot length were consistent with Rana et al. (2020) and Khadijah et al. (2020), while Meena et al. (2017) supported the findings on root diameter in germinated papaya seedlings. Khadijah et al. (2020) corroborated the findings on root length, and Vemula et al. (2020) defended the data on seedling growth. Additionally, Dash et al. (2019) and Nagar et al. (2017) supported the results regarding shoot diameter.

In terms of root and shoot length, the greatest difference was observed with soil + FYM, while for root and shoot diameter, the most significant differences were found with soil + FYM + rice husk + vermicompost + cocopeat (Fig. 1). This may have been due to the higher nitrogen content in FYM, which dominated apical growth, while root and shoot diameter varied due to the mixed qualities and characteristics of different growing media. Vermicompost delivered suitable oxygen levels to roots, along with adequate water and nutrient storage for plants (el Hamdaoui et al., 2021). Rice husk improved seed germination by maintaining optimal temperature and protecting seeds from fungal damage in moist soil.

For root and shoot length, 150 ppm GA_3 produced the largest difference, while for root and shoot diameter, 100 ppm GA_3 plus 100 ppm NAA had the greatest impact (Fig. 2). This could be attributed to GA_3's properties and concentration, which accelerated cell elongation and increased shoot and root length. Variation in diameter, on the other hand, may have resulted from rapid cell division and elongation, which increased turgor pressure, leading to vertical and radial seedling growth (Kutschera and Niklas, 2013).

The mixture of growing media improved nutritional availability and the seed environment, promoting better germination. Additionally, protein content increased rapidly in seeds a few days after germination due to enzyme activity that enhanced germination (Pérez-Rodríguez et al., 2022; Prattipati et al., 2021). The combination of SFVRC as the growing media, with 100 ppm each of GA3 and NAA, was the most effective in increasing the number of leaves. Control treatments and certain other combinations generally resulted in the fewest leaves, highlighting the positive impact of growth regulators and enriched growing media. The improvement in leaf number observed in this study could be attributed to the ability of these organic amendments to enhance soil fertility and nutrient availability (Vedpathak and Chavan, 2016; Prabhakar et al., 2017). Organic amendments also stimulated the activity of beneficial soil microorganisms, contributing to enhanced nutrient uptake and plant growth (Swami, 2020).

Conclusion

Our study revealed a significant difference among the treatments for raising 'Red Lady' papaya seedlings. While the cost of chemicals may pose a challenge for some growers, the growing media are readily available at a low cost. Moreover, PGRs are required in small quantities for seed treatment, with NAA being a relatively inexpensive hormone, making it a manageable expense for most nursery producers. Thus, it can be concluded that a mixture of agricultural waste media (soil, FYM, rice husk, vermicompost, and cocopeat) combined with plant growth regulator treatments (GA_3 100 ppm + NAA 100 ppm) is the most effective approach for promoting rapid germination and healthy papaya seedlings.

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Author contributions

AK conceptualization, methodology, data curation investigation. VJ and SV investigation, writing, original draft. MK formal analysis, supervision, review. FA writing, review, and editing.

Conflict of Interest

The authors indicate no conflict of interest in this work.

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