PLANT SCIENCE TODAY
ISSN 2348-1900 (online)
Vol x(x): xx–xx
https://doi.org/10.14719/pst.5777

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RESEARCH ARTICLE

Seed germination, seedling vigor and survival of papaya (*Carica papaya* L.) cv. 'Red Lady' under GA_3 treatment and different nursery growing media

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OPEN ACCESS

ARTICLE HISTORY
Received: 13 October 2024
Accepted: 17 March 2025
Available online
Version 1.0 : 10 April 2025

Additional information

Peer review: Publisher thanks Sectional Editor and the other anonymous reviewers for their contribution to the peer review of this work.

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Patel SJ, Sandeep K, Priyanka K, Kushagra S, Karan M, Sunny S. Seed germination, seedling vigor, and survival of papaya (*Carica papaya* L.) cv. 'Red Lady' under GA_3 treatment and different nursery growing media. Plant Science Today (Early Access). https:/doi.org/10.14719/pst.5777

Abstract

Slow, partial and uneven germination of papaya, along with high seedling mortality, are common challenges faced by papaya growers. Consequently, papaya is commercially propagated by seeds. This study aimed to enhance papaya germination and seedling success by testing various combinations of gibberellic acid (GA_3) and nursery growing media under green shade net conditions. This experiment was conducted at the Department of Horticulture, Lovely Professional University (LPU), Jalandhar, Punjab from July to September 2022-2023. A field experiment was conducted using a factorial completely randomized design (F-CRD) with 16 treatments and three replications, comprising a total of 576 plants. The experiment involved in four levels of gibberellic acid: G_0(soaking in water), G_1(50 ppm), G_2(150 ppm) and G_3(250 ppm). Additionally, four levels of nursery growing media-GM_0(soil), GM_1 [soil: vermicompost (1:1)], GM_2[soil: cocopeat (1:1)] and GM_3[soil: cocopeat: vermicompost (1:1:1)] and their interactions were evaluated. The results revealed that among gibberellic acid treatments G_3 ($GA_3$250 ppm) significantly outperformed other treatments in terms of seedling parameters. Regarding the individual effect of nursery growing media, the maximum seedling parameters were observed under treatment GM_3 [soil: cocopeat: vermicompost (1:1:1)]. Among the interactions of GA_3 and nursery growing media levels, all seedling parameters, except petiole length, were significantly superior in treatment G_3 GM_3. Meanwhile, treatment G_2GM_3 was statistically at par with it for most of the seedling parameters studied. These findings suggest the potential of this treatment combination for improving papaya seedling success in a new environment, specifically under Punjab climatic conditions.

Keywords

gibberellic acid; growing media; papaya; plant growth regulators; seedling

Introduction

Papaya (*Carica papaya* L.) is a popular fruit plant due to its rapid growth, short juvenile period, high production, long fruiting season and excellent nutritional content. Papaya belongs to the family Caricaceae and originated in tropical America, especially Mexico (1). In India, papaya was introduced by the Portuguese in 1611. In addition to being a tasty and refreshing fruit, papayas is also a great source of essential vitamins and minerals. A 100 g edible amount of papaya contains 89.6% moisture, 2,020 IU (International Units) of carotene (vitamin A), 40 IU of thiamine (vitamin B_1) and 250 IU of riboflavin (vitamin B_2). In addition, it contains 4% calorific value, 0.5% protein, 9.5% carbohydrates and 0.1% fat. It also contains 0.4 mg of iron, 0.2 IU of nicotinic acid, 0.01% calcium, 0.01% phosphorus and 0.4% minerals (2). There are numerous cultivars of papaya, including dioecious, monoecious and gynodioecious. Papaya is predominantly cultivated in the United States of America, Mexico, China, Brazil, India, Egypt, Spain and Morocco. Papaya is commercially grown in several Indian states, including Maharashtra, Madhya Pradesh, Andhra Pradesh, Rajasthan, Punjab, Gujarat, Haryana, Assam and Karnataka. In India, papaya production is approximately 5.98 million tonnes from an area of 1.49 million hectares (MT), with a productivity of 57.44 MT/ha (3). It covers the largest area in Andhra Pradesh, followed by Gujrat and Karnataka.

The variety 'Red Lady/Taiwan' has a two-year life-span, during which it can produce around 50 tons per acre. A single tree can produce 50 to 120 fruits, weighing approximately 1.5 to 2 kilograms each. The fruit is of excellent quality, characterized by its thick, firm and red flesh, along with its aromatic and very sweet taste, containing a sugar content of 13-14%. Female plants bear short, oblong fruits, while bisexual or hermaphrodite plants produce long, round fruits. Furthermore, the 'Red Lady' variety exhibits high resistance to the papaya ring spot virus. The plants are typically ready for harvest approximately 8 - 9 months after sowing (2, 4).

Among the papaya varieties, 'Red Lady' is highly popular due to its hermaphrodite flowers and long shelf life of its fruit. However, the high cost of 'Red Lady' seeds poses a challenge for papaya growers. Improving germination percentages and producing healthier seedlings are essential goals for these growers. During the nursery stage, Red Lady papaya seeds face issues with low germination rates and high seedling mortality, often caused by soil-borne diseases such as damping off caused by *Pythium aphanidermatum* fungus. Incomplete germination and high mortality rates reduce the overall survival rate of papaya plants. In heavy soil media, root development is suppressed and plants become more susceptible to soil-borne diseases (5).

Papaya is primarily propagated through seeds (6). Conventional methods of vegetative propagation, such as cutting, grafting and budding, have not been effective for a variety of reasons. Seed quality, treatment with various plant growth regulators and favourable environmental conditions all play a role in seedling vigor. Papaya seedling vigor must be enhanced at the nursery stage to ensure better growth and development (7). Papaya growers face several challenges during nursery raising including poor seedling quality, excessive seedling mortality, slow and inconsistent germination due to several soil-borne diseases, nutrition deficiencies in nursery soil, insufficient use of plant growth regulators and improper nursery management. Some growing media like vermicompost and farmyard manure also support and supply various essential nutrients (nitrogen, phosphorus and potassium) for plant germination and survival as mentioned (8, 9). Using of appropriate growing media or substrates is crucial for cultivating high-quality horticultural crops. Field soils are generally unsuitable for growing plants in containers because they lack adequate aeration, drainage, and water holding capacity required (10). This directly affects the development and maintenance of a robust root system. An ideal growing medium should provide adequate support to the plant, function as a reservoir for water and nutrients, facilitate oxygen diffusion to the roots and allow gaseous exchange between the roots and the surrounding atmosphere (11, 12).

The quality of seedlings produced in a nursery is influenced by the potting medium used. The quality of seedlings obtained from a nursery is a significant factor affecting their survival and productivity after transplanted into the field (13). Cocopeat, a by-product of coconut husk fibre extraction, can be used as a growing medium for producing crops in tropical regions with acceptable quality. Cocopeat has desirable physical characteristics, such as high porosity, great water retention, low shrinkage, low bulk density, and slow decomposition (14). Cocopeat is also considered a suitable growing medium due to its optimal pH, electrical conductivity (EC) and favorable chemical properties (11). Vermicompost is a type of manure that is produced by earthworms (especially *Eudriculus eugeniae* or *Eisenia fetida*) and microorganisms breaking down organic waste materials, such as agro-wastes, food wastes and sewage sludge (15-17). Many studies have demonstrated that using vermicompost as a fertilizer can boost plant production, improve the germination success by providing essential nutrients and indirectly enhance soil quality by promoting microbial activity, improving soil structure and increasing nutrient concentration. These benefits have been observed to be greater than those achieved with conventional chemical fertilization methods (18, 19).

The importance of plant growth regulators (PGRs) in agriculture has been widely acknowledged and the use of chemical treatments to break dormancy, stimulate germination and promote plant growth and development has proven to be significant (20, 21). For instance, soaking seeds in gibberellic acids has been found to accelerate and enhance the germination process, as well as enhance seedling growth (22). Therefore, the present study evaluates the performance of different growing media- soil, vermicompost and cocopeat along with GA_3 as a plant growth regulator (PGR) in various combinations to enhance seed germination and seedling growth of ‘Red Lady’ papaya under new environmental conditions.

Materials and Methods

Experimental site, treatments and procedure

This experiment was conducted from July to September 2022 under shade net (30 × 50 feet with 70% shade, with an optimum temperature was 26°C) at the Department of Horticulture, LPU, Phagwara, Punjab. Geographically, LPU is located at 31.253609°N, 75.70367°E, at an altitude of 234 m above mean sea level. The experiment was designed in four levels of gibberellic acid, including G_0 (control-soaking in water), G_1 (50 ppm), G_2 (150 ppm) and G_3 (250 ppm). Additionally, four levels of nursery growing media GM_0 (control-soil), GM_1 [soil:vermicompost (1:1)], GM_2 [soil:cocopeat (1:1)] and GM_3 [soil:cocopeat:vermicompost (1:1:1)] along with their interactions. An average temperature of 32±6°C and relative humidity of 85±3% were recorded under shade net conditions during the study. Table 1 presents the treatment combinations of the experiment.

Seed preparation and sowing

Red Lady papaya seeds were obtained from Known-you Seed (India) Pvt. Ltd. Before sowing, the seeds were soaked individually in GA_3 solutions of 50 ppm, 150 ppm and 250 ppm, as well as tap water (0 ppm- control) for 12 hours. One seed was sown per polybag with the respective growing media at a depth of 2 cm. The polybags used had dimensions of 12×10 inches. Immediate irrigation was provided after sowing, and light irrigation was repeated every third day to facilitate germination.

Preparation of GA_3 concentrations

Different concentrations of GA_3 solutions (50 ppm, 150 ppm and 250 ppm) were prepared using 100% pure GA_3 powder. The required amount of GA_3 powder (in grams) for each concentration was calculated.

The amount of GA_3 powder (in grams) was determined using the following equation:

1 ppm = approximately 1 mg/L (also written as mg/L) of the substance in water

Preparation of growing media

Four levels of growing media were used in the experiment like soil, vermicompost and cocopeat, which were measured volume-wise based on the respective treatments. The soil (sandy loam with a pH of 7.8 and an EC 0.42 dS/m) was obtained from the LPU field at a depth of about 15-20 cm from the soil surface. Vermicompost and cocopeat were collected from the Department of Horticulture, LPU, Punjab. The collected soil was spread on the floor surface to a height of about 20 cm. A 1.5% formalin solution was prepared in a container, and the soil with 4 L of water/m^2. It was covered with a 200-gauge polythene sheet, which was removed after 15 days. Soil treatment was conducted 20 days before seed sowing**.**

Data collection

***Growth parameters*:** Five randomly selected seedlings from each treatment were measured from the base to the shoot tip at the 4th and 6th weeks after sowing to determine the growth rate in terms of physical attributes using a meter scale. The average height of the five selected seedlings was computed as mean plant height. The stem diameter was measured using a digital vernier calliper, and number of leaves was counted. The petiole length, leaf length and leaf width were measured using a measuring scale. The average increase in leaf length and width was calculated based on increase in initial value. Leaf area was measured with the help of leaf area meter 211 ((Systronics, Leaf Area Meter-211) and the average leaf area per square centimeter was recorded. Five randomly selected papaya seedlings were separated and weighed using an electronic balance at the end of the experiment (6th week after sowing) to record their fresh weight. The average weight was calculated. Seed emergence was monitored daily for up to 390 days after sowing. The same five papaya seedlings were selected for fresh weight measurement were dried in an oven at 60°C for 48 hr. After drying, the dry weight of the seedling was measured using an electronic balance, and the average weight was calculated. At the end of the study (six weeks after sowing), the seedling vigor index (SVI) was estimated using germination percentage, seedling length and root length in cm. The SVI was calculated using the formula suggested in equation 1 (23).

Table 1. Treatment combinations

Notations	Treatment combinations
$G_0 GM_0$	Soaking in water + soil (control)
$G_0 GM_1$	Soaking in water + soil: vermicompost (1:1)
$G_0 GM_2$	Soaking in water + soil: cocopeat (1:1)
$G_0 GM_3$	Soaking in water + soil: cocopeat: vermicompost (1:1:1)
$G_1 GM_0$	GA_3 50 ppm + soil
$G_1 GM_1$	GA_3 50 ppm + soil: vermicompost (1:1)
$G_1 GM_2$	GA_3 50 ppm + soil: cocopeat (1:1)
$G_1 GM_3$	GA_3 50 ppm + soil: cocopeat: vermicompost (1:1:1)
$G_2 GM_0$	GA_3 150 ppm + soil
$G_2 GM_1$	GA_3 150 ppm + soil: vermicompost (1:1)
$G_2 GM_2$	GA_3 150 ppm + soil: cocopeat (1:1)
$G_2 GM_3$	GA_3 150 ppm + soil: cocopeat: vermicompost (1:1:1)
$G_3 GM_0$	GA_3 250 ppm + soil
$G_3 GM_1$	GA_3 250 ppm + soil: vermicompost (1:1)
$G_3 GM_2$	GA_3 250 ppm + soil: cocopeat (1:1)
$G_3 GM_3$	GA_3 250 ppm + soil: cocopeat: vermicompost (1:1:1)

Seedling vigor index = Germination percentage × Shoot length + Root length (Eqn. 1)

The papaya germination percentage was calculated at 30 days after sowing and the number of germinated seeds was counted by averaging their numbers from the seeds sown in the polybags. The germination percentage was calculated using the formula suggested equation 2 (24).

$$\text{Germination (\%)} = \frac{\text{Number of seeds germinated}}{\text{Total number of seeds sown}} \times 100 \quad \text{(Eqn. 2)}$$

Root parameters: Five randomly selected papaya seedlings per treatment were measured for root length after uprooting the plant. The measurement was taken from the point of root initiation to the root tip using a centimeter scale at the end of the experiment (6th week after sowing) and the average length was calculated. The diameter of tap root was also measured using a centimeter scale. Five randomly selected papaya seedlings in each treatment were used to measure fresh root weight. The seedling roots were cut, and their fresh weight was recorded using an electronic balance at the end of the experiment (6th week after sowing). The average fresh weight was calculated. The same five papaya seedling roots selected for fresh weight measurement were dried in the oven at 60°C for 48 hours. After drying, the dry weight of seedling roots was recorded using an electronic balance, and the average weight was calculated. The weight of root and shoot of randomly selected five papaya seedlings per treatment were recorded separately and their ratio was calculated.

Leaf chlorophyll content measurement: The chlorophyll content was measured with the help of SPAD (soil plant analysis development) meter at 4th-and 6th week interval.

Survival to field environment (%): The papaya seedling was transferred from the shade net to the main field after 45 days after sowing. The survival rate of the papaya seedlings was measured 30 days after transplanting and calculated using the suggested equation 3 (25).

$$\text{Survival rate (\%)} = \frac{\text{Total number of live seedlings}}{\text{Total number of planted seedlings}} \quad \text{(Eqn. 3)}$$

Data analysis: The data obtained during the trial were statistically analysed using the analysis of variance (ANOVA) technique by the F-CRD method (26). The significance level was set at $p < 0.05$ and Duncan's multiple range test (DMRT) was applied. Data analysis was carried out with OPSTAT software.

Results

Effect of gibberellic acid and growing media on growth parameters of papaya seedling

The growth parameters of papaya seedlings influenced by different levels of gibberellic acid and growing media are presented in Fig. 1 & 2. The results indicate that the individual effects of gibberellic acid and growing media had a significant ($p \leq 0.05$) impact on seedling parameters. Maximum height of papaya seedlings, stem diameter, number of leaves, leaf length, leaf width, petiole length, leaf area, fresh weight of seedlings, dry weight of seedlings, seedling vigor index, germination percentage and the minimum number of days for seed emergence was observed in papaya seedlings treated with G_3. Conversely, the control (G_0) exhibited the least improvement in all these parameters. Regarding growing media, the maximum increase in height of papaya seedling, stem diameter, number of leaves, leaf length, leaf width, petiole length, leaf area, fresh weight of seedlings, dry weight of seedlings, seedling vigor index, germination percentage and the minimum number of days for seed emergence, was significantly superior under the treatment GM_3, which was significantly ($p \leq 0.05$) superior to other media treatments. The least improvement in these parameters was found in treatment GM_0 (soil). For the interaction effect of gibberellic acid and growing media, the maximum height of papaya seedlings, stem diameter, number of leaves, leaf length, leaf width, leaf area, fresh weight of seedlings, dry weight of seedlings, seedling vigor index, germination percentage and the minimum number of days for seed emergence was significantly superior under treatment G_3GM_3. Most parameters were found at par with treatment G_2GM_3, while the least seedling growth was observed under treatment G_0GM_0 (Table 2). The petiole length was found non-significant at the end of the experiment.

Effect of gibberellic acid and growing media on root parameters of papaya seedling

The individual effect of gibberellic acid and growing media on root parameters of seedlings was highly significant ($p \leq 0.05$) for tap root length, fresh root weight, dry root weight, root/shoot ratio, main tap root length and main tap root diameter (Fig. 3). Treatment G_3 resulted in the maximum increase in tap root length, tap root diameter, fresh root weight, dry root weight and root/shoot ratio, while the minimum values were observed under treatment G_0 (soaking in water). Among the growing media, GM_3 led to the maximum increase in tap root length, tap root diameter, fresh root weight, dry root weight and root/shoot ratio, while the minimum values were observed under treatment GM_0. The interaction effect of gibberellic acid and growing media on root parameters of seedlings was highly significant ($p \leq 0.05$) and the data are presented in Table 3. The combination treatment G_3GM_3 was identified as the most effective for tap root length, tap root

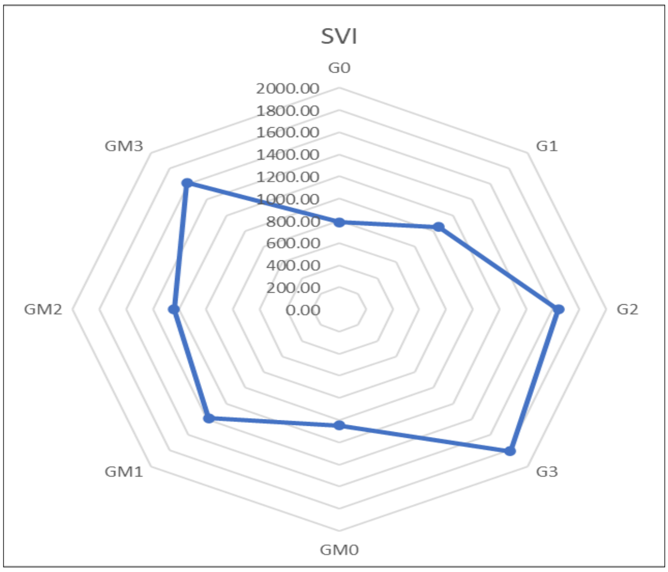

Fig. 2. Individual effect of GA_3 and growing media on seedling vigour index of papaya seedlings.

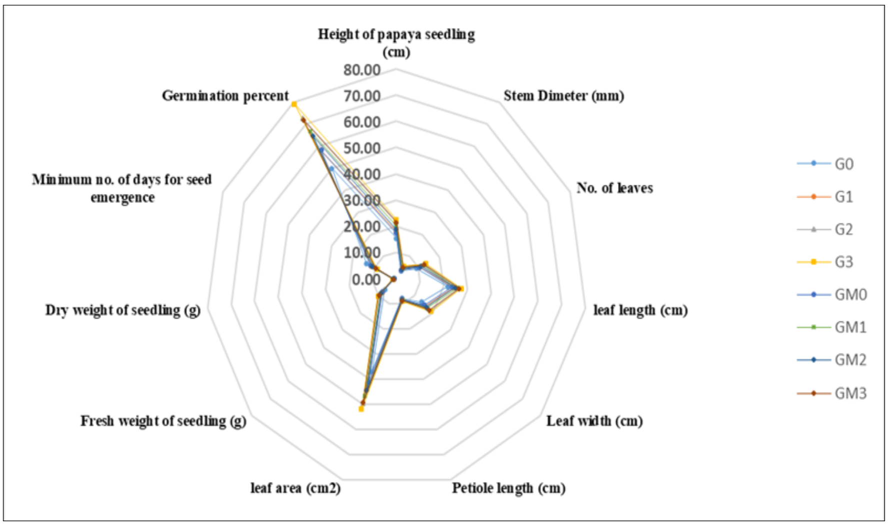

Fig. 1. Individual effect of GA_3 and growing media on growth parameters of papaya seedlings.

Table 2. Interaction effect of GA_3 and growing media on growth parameters of papaya cv. Red Lady

Treatments	Growth parameters of papaya seedling											
	Height of papaya seedling (cm)	Stem diameter (mm)	No. of leaves	Leaf length (cm)	Leaf width (cm)	Petiole length (cm)	Leaf area (cm^2)	Fresh weight of seedling (g)	Dry weight of seedling (g)	Minimum no. of days for seed emergence	Germination percentage	SVI
$G_0 GM_0$ (control)	12.67^{j}	3.21^{l}	8.82^{k}	19.39^{j}	12.40^{h}	7.69^{a}	34.11^{p}	6.03^{h}	0.83^{i}	15.84^{a}	41.67^{g}	534.3^{i}
$G_0 GM_1$	16.73^{h}	3.43^{kl}	9.46^{jk}	22.77^{hi}	13.80^{g}	7.84^{a}	37.51^{n}	6.62^{gh}	0.91^{hi}	12.96^{bc}	50^{f}	844.31^{h}
$G_0 GM_2$	15.58^{i}	3.34^{kl}	9.15^{k}	21.86^{i}	13.50^{gh}	7.76^{a}	36.91^{o}	6.58^{gh}	0.89^{hi}	13.41^{b}	58.33^{e}	915.87^{gh}
$G_0 GM_3$	16.92^{h}	3.57^{jk}	9.78^{ij}	22.98^{hi}	15.20^{f}	7.98^{a}	39.30^{m}	6.81^{g}	0.94^{ghi}	12.52^{bc}	50^{f}	854.19^{h}
$G_1 GM_0$	17.15^{gh}	3.72^{ij}	10.22^{hi}	23.9^{gh}	15.60^{ef}	8.02^{a}	40.60^{l}	7.47^{f}	0.95^{ghi}	12.03^{cd}	58.33^{e}	1009.09^{fg}
$G_1 GM_1$	18.02^{fg}	3.91^{hi}	10.92^{fg}	24.74^{fg}	16.10^{def}	8.21^{a}	43.90^{j}	8.16^{e}	0.99^{fgh}	11.16^{def}	58.33^{e}	1060.4^{f}
$G_1 GM_2$	17.56^{gh}	3.85^{hi}	10.54^{gh}	24.47^{fg}	15.80^{def}	8.17^{a}	43.11^{k}	7.54^{f}	0.97^{fgh}	11.46^{de}	58.33^{e}	1033.29^{f}
$G_1 GM_3$	18.89^{ef}	4.06^{gh}	11.13^{f}	24.84^{fg}	16.51^{de}	8.39^{a}	44.51^{i}	8.35^{de}	1.03^{fg}	10.84^{efg}	58.33^{e}	1111.64^{f}
$G_2 GM_0$	19.48^{de}	4.29^{fg}	11.49^{ef}	25.27^{ef}	16.92^{d}	8.44^{a}	44.78^{h}	8.93^{cd}	1.07^{ef}	10.33^{fgh}	66.67^{d}	1309.21^{e}
$G_2 GM_1$	22.54^{bc}	5.68^{d}	13.61^{c}	27.17^{c}	19.31^{c}	8.91^{a}	51.80^{d}	9.89^{b}	1.53^{b}	8.72^{ij}	75^{c}	1703.19^{d}
$G_2 GM_2$	20.31^{d}	4.96^{e}	12.37^{d}	26.56^{cde}	18.82^{c}	8.72^{a}	47.21^{f}	9.78^{b}	1.22^{d}	9.91^{gh}	66.67^{d}	1365.85^{e}
$G_2 GM_3$	24.87^{a}	6.38^{b}	14.93^{a}	28.69^{ab}	20.61^{ab}	9.23^{a}	55.41^{b}	11.67^{a}	1.69^{a}	7.88^{jk}	87.33^{ab}	2185.83^{b}
$G_3 GM_0$	19.83^{de}	4.52^{f}	11.84^{de}	25.71^{def}	17.01^{d}	8.65^{a}	45.11^{g}	9.04^{c}	1.16^{de}	10.05^{gh}	66.67^{d}	1333.48^{e}
$G_3 GM_1$	23.18^{b}	5.94^{c}	14.17^{b}	27.65^{bc}	19.51^{bc}	9.15^{a}	53.91^{c}	10.26^{b}	1.57^{b}	8.19^{jk}	83.33^{b}	1944.84^{c}
$G_3 GM_2$	21.65^{c}	5.20^{e}	13.28^{c}	26.70^{cd}	19.01^{c}	8.86^{a}	51.30^{e}	9.86^{b}	1.34^{c}	9.55^{hi}	75.00^{c}	1635.82^{d}
$G_3 GM_3$	25.16^{a}	6.73^{a}	15.36^{a}	29.91^{a}	21.10^{a}	9.41^{a}	57.81^{a}	11.98^{a}	1.78^{a}	7.23^{k}	91.67^{a}	2320.56^{a}
SE (m) ±	0.335	0.154	0.332	0.446	0.398	0.241	1.28	0.24	0.03	0.02	0.84	30.45
CD at 5 %	0.970	0.446	0.961	1.291	1.147	NS	3.72	0.71	0.11	0.07	5.33	88.38

Different superscript letters with mean data values indicate statistically significant differences among the different treatments ($p \leq 0.05$).

diameter, fresh root weight, dry root weight, root/shoot ratio and main tap root diameter. Root parameters were found to be at par with treatment G_2GM_3, while the lowest values were observed under treatment $G_0 GM_0$.

Effect of gibberellic acid and growing media on leaf chlorophyll content of papaya seedling

The variations in leaf chlorophyll content of papaya seedlings, as affected by different levels of gibberellic acid and growing media are shown in Fig. 4. Treatment G_3 resulted in the highest increase in leaf chlorophyll content, while the lowest was observed under treatment G_0. This treatment was found to be significantly ($p \leq 0.05$) superior to all other treatments. Regarding growing media, the highest increase in chlorophyll content was recorded in treatment GM_3, which was significantly superior ($p \leq 0.05$) to other growing media treatments. The lowest increase in chlorophyll content was observed in treatment GM_0. For the combined effect of GA_3 and growing media, the highest increase was noticed in treatment G_3GM_3. This treatment was found to be significantly superior to all combination treatments at the end of the experiment and was at par with treatment G_2GM_3. The lowest increase in chlorophyll content was found with treatment G_0 GM_0 (Fig. 5).

Effect of gibberellic acid and growing media on survival to field environment

ANOVA results indicated significant ($p \leq 0.05$) effects of gibberellic acid and growing media on seedling survival in the field environment (Fig. 4). The data show that the highest survival rate in the field environment was observed in treatment G3, while the lowest was recorded in G0 soaking in water (control). Among the individual effects of growing media GM3 was found to be the most suitable for seedling survival in the field environment, whereas the lowest survival rate was recorded in GM0. For the interaction effect of gibberellic acid and growing media, treatment G3GM3 resulted in the highest survival rate (89.67%), was found to be significantly superior ($p \leq 0.05$). Seedling survival in the field environment was found to be at par under treatment G2GM3, while G0 GM0 recorded the lowest survival rate (56.33%) (Fig. 5).

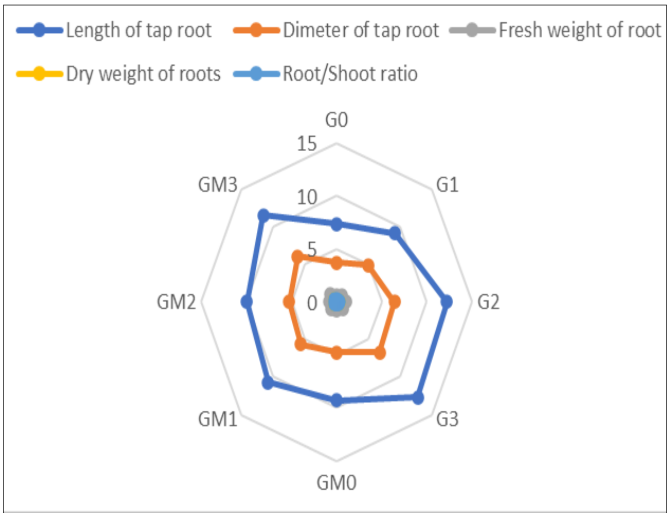

Fig. 3. Individual effect of GA_3 and growing media on root parameters of papaya seedlings.

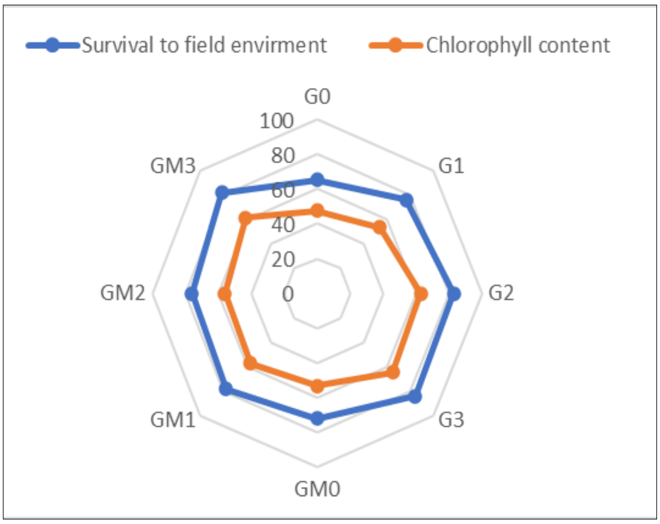

Fig. 4. Individual effect of GA_3 and growing media on chlorophyll content and survival to field environment of papaya seedlings.

Table 3. Interaction effect of GA_3 and growing media on growth parameters of papaya cv. Red Lady

Treatments	Root parameters of papaya seedling				
	Length of tap root (cm)	Diameter of taproot (mm)	Fresh weight of root (g)	Dry weight of root (g)	Root/Shoot ratio
G_0 GM_0 control)	6.38^{l}	3.07^{m}	0.56^{m}	0.13^{h}	0.19^{i}
G_0 GM_1	7.81^{jk}	3.98^{kl}	0.71^{l}	0.21^{fg}	0.22^{h}
G_0 GM_2	7.04^{kl}	3.67^{l}	0.7^{l}	0.17^{gh}	0.19^{i}
G_0 GM_3	8.19^{ij}	4.11^{jk}	0.72^{kl}	0.23^{ef}	0.23^{h}
G_1 GM_0	8.67^{hij}	4.46^{ij}	0.77^{jk}	0.23^{ef}	0.25^{g}
G_1 GM_1	9.23^{gh}	5.03^{gh}	0.81^{ij}	0.27^{cde}	0.26^{g}
G_1 GM_2	8.96^{ghi}	4.79^{hi}	0.79^{ij}	0.25^{def}	0.25^{g}
G_1 GM_3	9.72^{fg}	5.31^{fg}	0.84^{hi}	0.28^{cde}	0.28^{f}
G_2 GM_0	10.54^{f}	5.54^{ef}	0.89^{gh}	0.28^{cde}	0.28^{f}
G_2 GM_1	12.69^{cd}	6.63^{b}	1.03^{cd}	0.31^{bcd}	0.33^{c}
G_2 GM_2	11.85^{de}	6.15^{cd}	0.96^{ef}	0.29^{cde}	0.3^{de}
G_2 GM_3	13.93^{ab}	7.29^{a}	1.13^{b}	0.36^{ab}	0.37^{b}
G_3 GM_0	11.48^{e}	5.93^{de}	0.92^{fg}	0.28^{cde}	0.29^{ef}
G_3 GM_1	13.17^{bc}	6.88^{b}	1.05^{c}	0.32^{bc}	0.33^{c}
G_3 GM_2	12.07^{de}	6.47^{bc}	0.98^{de}	0.31^{bcd}	0.31^{d}
G_3 GM_3	14.23^{a}	7.68^{a}	1.20^{a}	0.38^{a}	0.39^{a}
SE (m) ±	0.29	0.14	0.025	0.009	0.007
CD at 5 %	0.85	0.41	0.075	0.026	0.021

Different superscript letters with mean data values indicate statistically significant differences among the different treatments ($p \leq 0.05$).

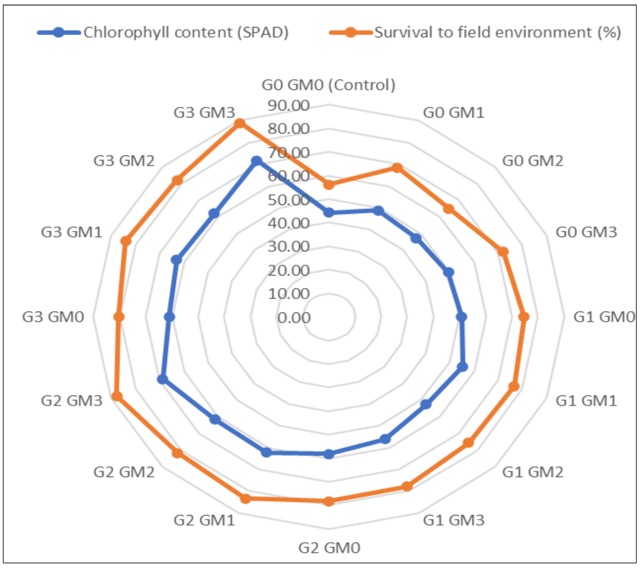

Fig. 5. Interaction effect of GA_3 and growing media on chlorophyll content and survival to field environment of papaya cv. 'Red Lady'.

Correlation between chlorophyll content, seedlings height and field survival

The leaf chlorophyll content manifested a strong positive correlation (0.875) with the height of papaya seedlings and survival in the field environment (Fig. 6). It means that with one unit change in leaf chlorophyll content, the height of papaya seedlings and survival in the field environment changed by 0.875 units.

Discussion

In the present study, seedlings grown with adequate gibberellic acid and growing media showed significant increases in growth parameters, root parameters, chlorophyll content and survival in the field environment. The enhanced growth parameters observed in G_3GM_3 could be attributed to the synergistic effects of gibberellic acid and organic growing media, such as vermicompost, which enhance organic acid production and promote seed emergence. Gibberellic acid enhances the activity of the α-amylase enzyme in the seed, which assists in breaking down the aleurone layer and encourages auxin production, ultimately reducing the number of days required for seed emergence (23). This effect may be due to the positive influence of the soil, cocopeat and vermicompost combination, which improves the physical, biological and chemical properties of the nursery growing medium, thereby enhancing the germination percentage.

Gibberellic acid promotes cell division, elongation and the emergence of the seed radical from the seed coat. Papaya seeds treated with gibberellic acid have been shown to break dormancy and improve the germination percentage of seedlings (23). The findings on seedling vigor index and growth parameters align with previous studies (27, 28). The appropriate proportion of nursery growing media (soil, cocopeat and vermicompost 1:1:1) delivers an appropriate level of oxygen and nutrients (nitrogen, phosphorus and

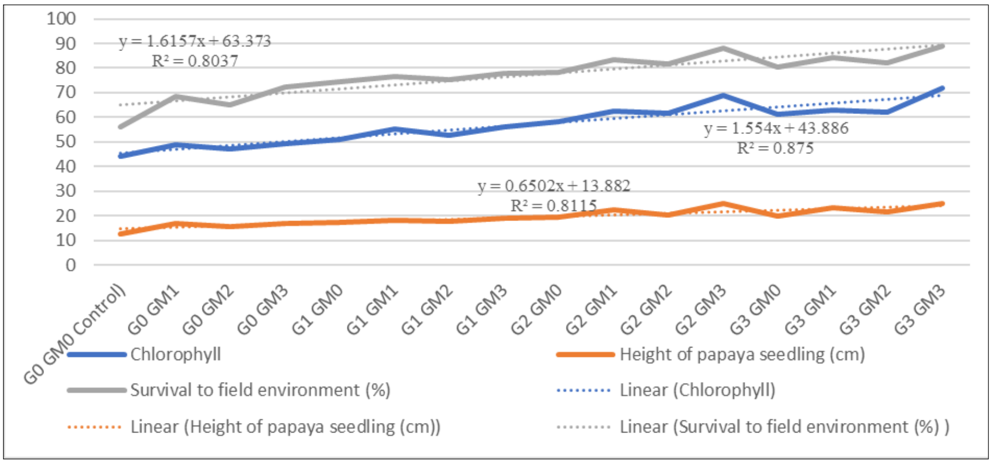

Fig. 6. Correlation between chlorophyll content, height of papaya seedlings and survival to field environment of papaya cv. Red Lady.

potassium) and adequate water to papaya seedlings. Cocopeat possesses favorable chemical properties, like EC and pH. Additionally, cocopeat has a high water-holding capacity (WHC), retaining up to eight times more water than soil, which allows it to function like a sponge while maintaining high porosity. The growth parameters observed in this study are consistent with previous findings (29, 30). The maximum growth parameters of seedling in treatment G_3GM_3 may be due to the combined effects of gibberellic acid and growing media, which enhance the osmotic uptake of nutrients (nitrogen, phosphorus and potassium) from the growing medium. This, in turn, promotes cell elongation, reflects in greater internodal length, ultimately increasing growth parameters, root parameters, chlorophyll content and survival in the field environment of papaya seedlings (31, 32).

Root length might be enhanced due to, GA_3 promoting cell multiplication and elongation in the meristematic region of the roots (Fig. 7) (32). The vermicompost and soil create close contact between the seed and the growing medium, enhancing root respiration, improving moisture retention, and encouraging the development of root parameters of seedlings (33, 34). The soil, cocopeat and vermicompost exhibit hormone-like action and help in root growth parameters, encouraging plant nutrient intake and enhancing the growth of seedlings resulting in improved survival in the field environment (25, 35). In gibberellic acid, it was pointed out the germination and survival in the field environment, but the variation slightly increased in comparison to the control which exhibited survival to the field environment and grow faster after the application of gibberellic acid. The better results concerning growth parameters were recorded in treatment G_3GM_3 might have occurred owing to cell-division and cell-elongation, which in turn would have improved overall vegetative growth and chlorophyll content (31). Vermicompost is a good source of nitrogen, phosphorus and potassium content it provides nutrient content in the root zone system resulting in improved photosynthetic rate and leaf chlorophyll content resulting in increased growth parameters (23).

The beneficial effect on root parameters due to the application of growing media treatment consisting of soil, cocopeat and vermicompost (1:1:1) might be due to improved soil structure, texture, porosity, water holding capacity, activity of useful soil microfauna and flora, maintained soil temperature and improved soil health and nutrient status of media (36). Additionally, the vermicompost and soil also provide close contact between seed and media. Increase stable moisture supply facilities, root respiration and enhance overall root growth (37). Vermicompost is observed to have bioactive principles which are helpful for root growth and development this has been hypothesized to result in better root initiation (38). The seeds treated with gibberellic acid might enhance the translocation and assimilation of auxins, reasons for well root growth and vegetative characteristics are due to the inclusive assimilation and redistribution of materials within the plant enhancing the growth attributes (39, 40).

In summary, the combined use of appropriate growing media and gibberellic acid enhances the seedling characteristics of papaya by providing favourable conditions for germination, seedling growth and establishment. The growing media components contribute to improved soil structure, nutrient availability and moisture retention, while gibberellic acid stimulates important physiological processes in the seeds, leading to enhanced seedling development. These findings have been supported by scientific studies laid out on various plant species, providing a sound basis for the observed positive effects on papaya seedlings.

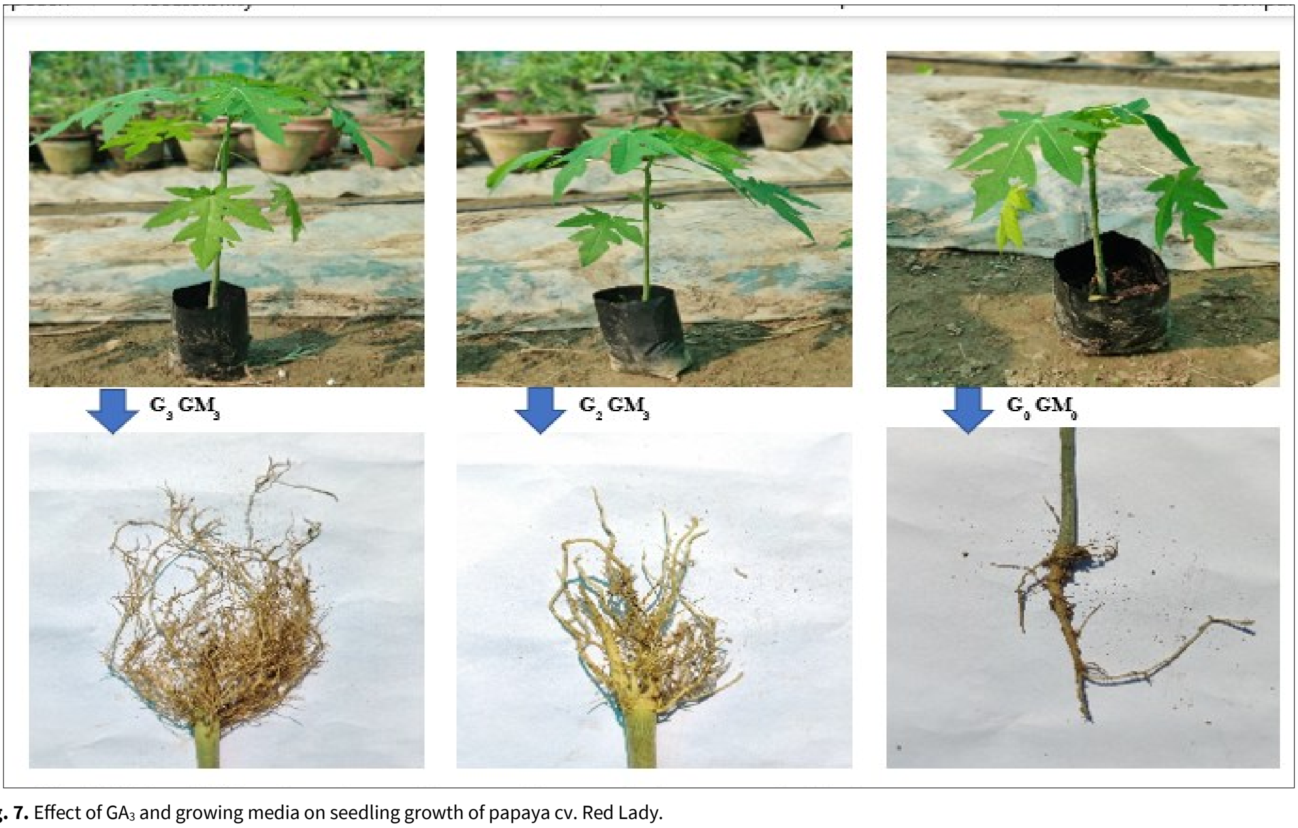

Fig. 7. Effect of GA_3 and growing media on seedling growth of papaya cv. Red Lady.

Conclusion

Based on the present investigation it may can be concluded that the treatment G_3 and growing media composition GM_3 were the most in enhancing growth parameters, root parameters, chlorophyll content and survival in the field environment of papaya cv. Red Lady. Among the combined treatments, G_2GM_3 demonstrated the overall best performance in promoting seedling vigor and establishment.

Acknowledgements

The authors would be thankful to Lovely Professional University (LPU), Phagwara, Punjab, India, precisely the Department of Horticulture in the School of Agriculture for providing the farm as well as lab facilities for conducting the trial.

Authors' contributions

PSJ, SK and SS contributed to the conceptualization of the study. The methodology was developed by PSJ, SK and PK. Software support was provided, and validation was conducted by SK and PK. Formal analysis was performed by PSJ, KM and SS. The investigation was carried out by PSJ, SK, PK, KS, KM and SS. The original draft was prepared by PSJ, SK, PK, KS, KM and US, with contributions from SS. All authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interests to declare.

Ethical issues: None

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