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Effect of potting media and nutrition protocols on growth and seedling vigour of acid lime (*Citrus aurantifolia* Swingle) cv. Sai Sharbati under shade-net nursery conditions

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ABSTRACT

The present investigation was conducted at the Sweet Orange Research Station, Badnapur, during 2025–26 to evaluate the effect of different potting media and nutrition protocols on germination, survival, vegetative growth, biomass accumulation and root development of acid lime (*Citrus aurantifolia* Swingle) cv. Sai Sharbati under shade-net nursery conditions. The experiment was laid out in a Completely Randomized Design (CRD) comprising seven treatments with three replications. The treatments consisted of different combinations of potting mixture, cocopeat and NPK nutrition. Significant differences were observed among the treatments for the major seed germination and seedling growth attributes. The treatment comprising potting mixture + cocopeat supplemented with 20:10:10 g NPK per seedling (T_7) recorded the earliest 50 per cent germination (14.67 days), highest germination percentage (88.21%), germination rate (6.05), survival percentage (88.05%) and vigour index (2019.00). T_7 also recorded maximum seedling height (22.86 cm), number of leaves (14.83 plant⁻¹), leaf area (26.83 cm²), root fresh weight (3.45 g), root dry weight (0.68 g), shoot fresh weight (16.55 g), shoot dry weight (4.19 g) and root volume (3.89 cm³). In contrast, cocopeat supplemented with 60:25:25 g NPK per seedling (T_4) showed comparatively poor performance, with delayed germination, lower germination and survival, reduced seedling growth and minimum biomass accumulation. The superior performance of T_7 indicates that combining potting mixture with cocopeat and a moderate nutrient dose provides a favourable balance of moisture retention, aeration, nutrient availability and root-zone conditions for acid lime seedling development. The study therefore demonstrates the potential of the potting mixture + cocopeat + 20:10:10 g NPK per seedling treatment for producing vigorous and uniform acid lime nursery seedlings under shade-net conditions.

Keywords: Acid lime, *Citrus aurantifolia*, Cocopeat, Potting media, NPK nutrition, Seed germination, Seedling vigour, Root development, Shade-net nursery

1. Introduction

Acid lime (*Citrus aurantifolia* Swingle) is an important citrus fruit crop belonging to the family Rutaceae and is widely cultivated in tropical and subtropical regions. The crop is valued for its characteristic flavour, refreshing aroma and high vitamin C content, while its fruits are consumed fresh and are also utilized in beverages, pickles, squash, cordial, juice concentrates and several processed products. Its adaptability, regular bearing habit, relatively early fruiting and sustained market demand contribute to its considerable commercial importance in India. India is among the major producers of lime and lemon, with cultivation distributed across several states, including Maharashtra, Karnataka, Andhra Pradesh, Gujarat, Odisha, Madhya Pradesh and Tamil Nadu. The crop provides an important source of income to growers because of its market demand and multiple uses. In addition to its economic value, acid lime fruits contain vitamin C, organic acids, flavonoids, antioxidants, minerals and essential oils, which contribute to their nutritional and functional importance.

The productivity and long-term performance of a citrus orchard depend greatly on the quality of planting material used for establishment. Healthy, vigorous and uniform nursery plants establish rapidly after transplanting, develop stronger root systems and provide better prospects for subsequent orchard productivity. Conversely, poor-quality planting material may exhibit weak root development, delayed establishment and reduced field performance. Therefore, efficient nursery management is an important component of successful citrus production (Donovan *et al.*, 2016). Among the various factors affecting nursery plant quality, the growing medium plays a crucial role by providing the physical and nutritional environment required for seed germination and root development. An ideal medium should possess adequate porosity, aeration, moisture-

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holding capacity, drainage and nutrient availability. Conventional citrus nursery production commonly utilizes mixtures of soil, sand and farmyard manure; however, increasing attention has been given to alternative substrates such as cocopeat because of their favourable physical properties. Cocopeat has high porosity, low bulk density and good water-holding capacity, which can promote root proliferation and seedling development (Yau and Murphy, 2000).

Nutrient availability is another major determinant of seedling growth and quality. Nitrogen is essential for chlorophyll synthesis, protein formation and vegetative growth, phosphorus contributes to root development and energy transfer, while potassium plays an important role in water regulation, enzyme activation and carbohydrate translocation. Balanced nutrient supply during the nursery stage is therefore essential for producing vigorous and transplantable seedlings. Appropriate combinations of organic and inorganic nutrient sources have been reported to improve seedling growth and nutrient uptake in acid lime (Marathe *et al.*, 2012; Pravin and Patel, 2020). Protected nursery structures such as shade-net houses provide a favourable microenvironment for raising young citrus plants by moderating solar radiation and temperature, maintaining relative humidity and reducing evapotranspiration losses. Such conditions can favour germination, seedling establishment and vegetative growth while providing protection from adverse weather conditions (Sengar and Kothari, 2009).

The performance of nursery seedlings is influenced by the combined effects of growing media and nutrient supply. Different substrates differ in their moisture retention, aeration, nutrient-holding capacity and other physical and chemical characteristics, which consequently affect nutrient uptake and plant development. Marathe *et al.* (2020) [1] reported that suitable combinations of cocopeat-based growing media and balanced fertilizer application improved germination, survival, root development and seedling growth in acid lime. Despite the availability of information on individual nursery management practices, comparatively limited information is available on the combined optimization of potting media and nutrition protocols for acid lime cv. Sai Sharbati under shade-net nursery conditions. Identification of a suitable growing medium and nutrient regime could help in producing healthy, vigorous and uniform planting material while reducing nursery duration and improving transplanting success. Therefore, the present investigation was undertaken to evaluate the influence of different potting media and nutrition protocols on germination, survival, vegetative growth, biomass accumulation and root development of acid lime (*Citrus aurantifolia* Swingle) cv. Sai Sharbati under shade-net nursery conditions.

2. Materials and methods

2.1 Experimental site and plant material

The investigation was conducted during 2025–26 at the shade-net nursery of the Sweet Orange Research Station, Badnapur, District Jalna, Maharashtra, under Vasantrao Naik Marathwada Krishi

Vidyapeeth, Parbhani. The experimental material comprised acid lime (*Citrus aurantifolia* Swingle) cv. Sai Sharbati. The experimental site falls under a semi-arid agro-climatic region, with the experimental period coinciding with the rainy season.

2.2 Experimental design and treatments

The experiment was laid out in a Completely Randomized Design (CRD) with seven treatments and three replications. Seedlings were raised in plastic trays measuring 40 × 30 × 10 cm, with six seedlings maintained per treatment unit. A total of 126 seedlings were maintained under observation.

The treatments consisted of different combinations of conventional potting mixture, cocopeat and NPK nutrition protocols. The conventional potting mixture comprised sand, soil and well-decomposed farmyard manure, while cocopeat was used either alone or in combination with the potting mixture. The treatment combinations were:

Treatment	Treatment combination
T ₁	Potting mixture – 2:1:1 (Sand:Soil:FYM)
T ₂	Potting mixture + 60:25:25 g NPK seedling ⁻¹
T ₃	Potting mixture + 40:25:25 g NPK seedling ⁻¹
T ₄	Cocopeat + 60:25:25 g NPK seedling ⁻¹
T ₅	Cocopeat + 40:25:25 g NPK seedling ⁻¹
T ₆	Potting mixture + cocopeat + 40:25:25 g NPK seedling ⁻¹
T ₇	Potting mixture + cocopeat + 20:10:10 g NPK seedling ⁻¹

The potting mixture and cocopeat were combined in a 1:1 ratio wherever specified. Nutrient treatments were applied after seedling emergence as described in the experimental protocol.

2.3 Nursery management and seedling establishment

Plastic trays having a capacity of approximately 8–10 kg growing medium were filled with the respective treatment media. Acid lime seeds of cv. Sai Sharbati were sown in the prepared media and seedlings were maintained under shade-net nursery conditions. The seedlings were allowed to grow until they attained the desired nursery growth stage. Observations were recorded periodically throughout the experimental period.

2.4 Germination and survival parameters

The number of days required to attain 50 per cent germination was recorded by daily monitoring of seed emergence. Germination percentage was calculated as:

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

The rate of germination was calculated following the method of Maguire (1962):

$$\text{Rate of germination} = G_1/N_1 + G_2/N_2 + G_3/N_3 + \dots + G_n/N_n$$

where G represents the number of seeds germinated on a particular day and N represents the corresponding number of days after sowing.

$$\text{Survival (\%)} = \frac{\text{Number of surviving seedlings}}{\text{Number of germinated seedlings}} \times 100$$

Seedling survival was determined by recording the number of healthy seedlings remaining at the end of the experimental period and expressed as percentage of germinated seedlings:

Seedling vigour index was calculated according to Abdul-Baki *et al.* (1973) [2]:

$$\text{Vigour index} = \text{Germination (\%)} \times \text{Mean seedling length (cm)}$$

2.5 Vegetative growth parameters

Seedling height was measured from the collar region to the growing tip using a measuring scale and expressed in centimetres. The number of fully expanded leaves was counted manually and expressed as leaves seedling⁻¹. Leaf area was determined using a digital leaf-area meter and expressed in cm².

2.8 Statistical analysis

The experiment was conducted using a Completely Randomized Design with seven treatments and three replications. Treatment means were compared using the statistical procedure followed in the original experimental analysis. Standard error of the mean (SEm), critical difference at the 5 per cent probability level (CD at 5%) and coefficient of variation (CV%) were used to assess the magnitude and significance of treatment differences.

3. Results and Discussion

3.1 Effect of potting media and nutrition protocols on seed germination

3.1.1 Days to 50% germination

Significant differences were observed among the treatments for the number of days required to attain 50% germination. The earliest attainment of 50% germination was recorded in T₇ (potting mixture + cocopeat + 20:10:10 g NPK seedling⁻¹), which required only 14.67 days. This treatment was statistically at par with T₁ (potting mixture 2:1:1 Sand:Soil:FYM), which required 15.44 days. In contrast, T₄ (cocopeat + 60:25:25 g NPK seedling⁻¹) required the longest period of 23.72 days. The treatment means ranged from 14.67 to 23.72 days, with a critical difference of 1.67 days at the 5% probability level and a coefficient of variation of 5.10%.

The accelerated germination under T₇ can be attributed to the complementary physical properties of the blended substrate. Cocopeat improves moisture retention and porosity, whereas the conventional potting mixture contributes mineral nutrients and organic matter. The combination therefore likely maintained a more favourable air–water relationship around the seeds, facilitating imbibition and subsequent metabolic activity. The moderate nutrient dose of 20:10:10 g NPK seedling⁻¹ may also have avoided the excessive soluble-salt concentration associated with the higher fertilizer regime.

The present finding is consistent with Prajapati *et al.* (2017) [3], who reported earlier 50% germination of acid lime seeds in soil:cocopeat (1:1) medium. Similarly, Parmar *et al.* (2019) [4] recorded 50% germination at 15.33 days with soil, sand and *Azotobacter* combined with GA₃, while Yadav *et al.* (2012) [5] reported earlier germination in a multi-component substrate containing soil, sand, vermicompost, vermiculite and cocopeat with *Azotobacter*.

These findings collectively indicate that substrate architecture may be as important as nutrient supply during the initial phase of acid lime establishment, particularly because germinating seeds require simultaneous access to water and oxygen.

2.6 Root and shoot biomass

At the final stage of the experiment, seedlings were carefully uprooted and washed to remove adhering growing medium. Roots and shoots were separated for biomass determination.

Root and shoot fresh weights were recorded immediately after separation using an electronic balance and expressed in grams. For dry-weight determination, root and shoot samples were oven-dried at 65 ± 2 °C until constant weight and subsequently weighed.

2.7 Root development parameters

Root–shoot ratio was calculated on a dry-weight basis as:

$$\text{Root–shoot ratio} = \frac{\text{Dry weight of root (g)}}{\text{Dry weight of shoot (g)}}$$

3.1.2 Germination percentage

Treatment effects on germination percentage were statistically significant. T₇ recorded the highest germination percentage (88.21%), followed by T₃ (84.69%) and T₁ (83.38%). The lowest germination percentage was observed in T₄ (54.23%). Thus, the blended potting mixture–cocopeat substrate supplied with moderate NPK resulted in substantially better establishment than sole cocopeat supplemented with the higher fertilizer dose.

The higher germination under T₇ may be related to the improved physical environment created by combining conventional potting material with cocopeat. The potting mixture supplied organic matter and mineral components, while cocopeat enhanced water retention and aeration. The moderate nutrient regime probably provided adequate nutrient availability without generating excessive osmotic pressure around the germinating seed.

In contrast, the poor germination observed under T₄ suggests that cocopeat alone was insufficient to provide a balanced chemical environment for acid lime seed germination, particularly when combined with the higher NPK dose. Excess soluble salts can adversely affect water uptake during germination, while excessive moisture retention may reduce oxygen diffusion.

The present results agree with Parmar *et al.* (2019) [4], who obtained 88.33% germination in acid lime using soil + sand + *Azotobacter* with GA₃, and with Khan *et al.* (2006), who demonstrated improved germination in peat-amended nursery media. Similar benefits of optimized media have also been reported by Das and Sharma (2022) in citrus nursery stock.

3.1.3 Rate of germination

The rate of germination followed a pattern similar to final germination percentage. T₇ recorded the highest germination rate (6.05), followed by T₁ (5.44), T₃ (4.88) and T₆ (4.67). The lowest rate was recorded in T₄ (2.29). The difference was statistically significant, with a CD of 0.48 and CV of 6.46%.

The faster germination under T₇ suggests that the blended medium provided favourable conditions not only for a greater proportion of seeds to germinate but also for more rapid and uniform emergence. Adequate moisture availability combined with sufficient pore space may have supported faster hydration and oxygen supply to the embryo.

Yadav *et al.* (2012) [5] reported enhanced germination rate in acid lime using a complex substrate containing soil, sand, vermicompost, vermiculite and cocopeat with *Azotobacter*. Joshi *et al.* (2015) also reported enhanced germination following optimized media and GA₃ treatment, while Marathe *et al.* (2020) [1] found superior germination in a potting mixture:cocopeat combination supplemented with NPK.

3.2 Seedling survival and vigour

3.2.1 Survival percentage

A pronounced treatment effect was recorded for seedling survival. T₇ produced the highest survival percentage (88.05%), statistically comparable with T₃ (83.50%) and T₁ (83.37%). In contrast, survival de-

clined drastically to 22.82% under T₄. T₅ also showed poor survival (34.03%).

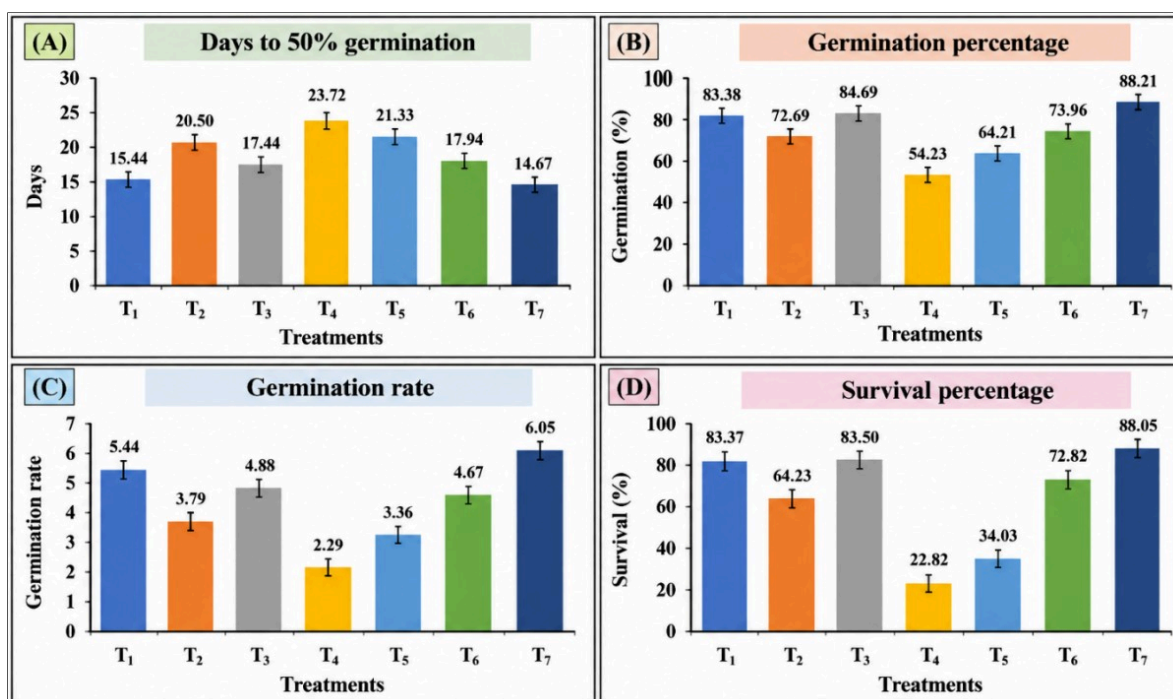


Figure 1. Effect of different nutrition protocols and potting media on germination and establishment of acid lime (*Citrus aurantifolia* Swingle) seedlings under shade-net nursery conditions. (A) Days to 50 per cent germination, (B) germination percentage, (C) rate of germination and (D) seedling survival percentage.

The superior survival under T₇ indicates that the blended medium was capable of sustaining an appropriate balance between water availability, aeration and nutrient supply during seedling establishment. In contrast, the poor survival under sole cocopeat treatments may be associated with inadequate nutrient availability combined with excessive moisture retention.

This result closely agrees with Marathe *et al.* (2020) [1], who reported maximum survival when potting mixture and cocopeat were combined with a relatively moderate NPK dose. Parmar *et al.* (2019) [4] similarly reported improved survival in acid lime following the use of *Azotobacter* and GA₃, whereas Das and Sharma (2022) associated improved citrus seedling survival with the use of suitable nursery media. The large difference between T₇ and T₄ is particularly important from a nursery-production perspective because survival determines the number of marketable plants produced per unit nursery area.

3.2.2 Seedling vigour index

The vigour index was significantly influenced by the treatment combinations. The highest value was observed in T₇ (2019.00), followed by T₃ (1731.94) and T₆ (1612.06). The lowest value, 180.28, was recorded under T₄.

The superiority of T₇ is biologically important because the vigour index integrates germination performance with seedling growth. The high value under T₇ therefore reflects the combined effect of its high germination percentage and superior seedling development.

The result is consistent with observations of Joshi *et al.* (2015), Prajapati *et al.* (2017) [3] and Parmar *et al.* (2019) [4], who reported improved vigour of acid lime seedlings when favourable growing media were combined with appropriate seed treatments or nutrient-management practices.

3.3 Effect on vegetative growth

3.3.1 Seedling height

Marked differences were observed in seedling height. T₇ recorded the maximum seedling height of 22.86 cm, followed by T₃ (20.46 cm) and T₆ (19.49 cm). The minimum height of only 3.33 cm was observed under T₄.

The strong response of T₇ can be explained by the interaction between substrate physical properties and nutrient availability. Cocopeat provides a porous environment with good moisture retention, while the potting mixture supplies organic and mineral nutrients. Under these conditions, root exploration and nutrient acquisition are likely to be improved, ultimately supporting shoot elongation.

Nitrogen availability is particularly important for vegetative growth because of its role in protein synthesis and photosynthetic apparatus development. However, the present results indicate that more fertilizer was not necessarily associated with greater growth. The moderate 20:10:10 treatment in the blended medium performed better than the higher fertilizer concentration in sole cocopeat.

The findings are in agreement with Marathe *et al.* (2020) [1], who recorded 24.5 cm plant height in a 50:50 potting mixture:cocopeat substrate supplemented with NPK. Kumari *et al.* (2018) reported 28.5 cm in a vermiculite:cocopeat (1:1) medium, while Bhutiya *et al.* (2017) recorded 24.6 cm in soil:sand:vermicompost (2:1:1).

3.3.2 Number of leaves

The number of leaves was significantly influenced by treatments. T₇ produced the highest number of leaves (14.83 plant⁻¹), followed by T₃ (13.78) and T₆ (13.28). The lowest value was recorded in T₄, with only 2.94 leaves plant⁻¹.

The greater leaf production under T₇ may be attributed to sustained nutrient and moisture availability. Nitrogen supplied through the nutrient regime supports chlorophyll synthesis and vegetative meristem activity, while adequate moisture facilitates continued cell division

and leaf expansion. The poor leaf production under T₄ suggests that the physical advantages of cocopeat alone could not compensate for

an inadequate overall nutritional environment.

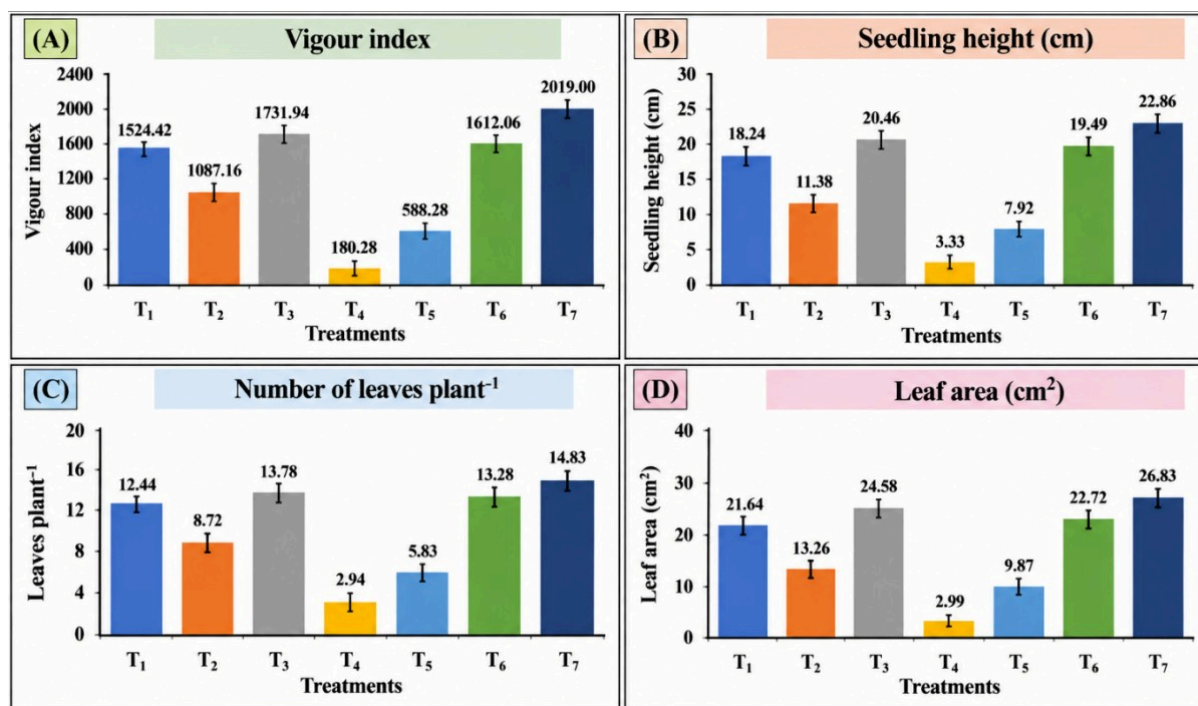


Figure 2. Effect of different nutrition protocols and potting media on seedling vigour and vegetative growth of acid lime (*Citrus aurantifolia* Swingle) under shade-net nursery conditions. (A) Vigour index, (B) seedling height, (C) number of leaves plant⁻¹ and (D) leaf area.

Comparable responses have been reported by Kumar and Raj (2019), Mishra and Gupta (2018) and Reddy and Rao (2017), who observed increased leaf production when organic amendments, biofertilizers or nutrient-rich substrates were incorporated into citrus nursery media.

3.3.3 Leaf area

The highest leaf area was recorded in T₇ (26.83 cm²), followed by T₃ (24.58 cm²) and T₆ (22.72 cm²), whereas T₄ recorded only 2.99 cm². The greater leaf area under T₇ suggests improved vegetative development resulting from balanced moisture and nutrient availability. A larger photosynthetically active surface can increase radiation interception and carbon assimilation, thereby contributing to greater biomass accumulation.

The present results are consistent with Choudhary and Jat (2021), who reported 21.4 cm² leaf area in AMF-inoculated citrus seedlings, Das and Mukherjee (2020), who recorded 20.2 cm² under organic amendment-enriched media, and Singh and Chauhan (2019), who observed enhanced leaf expansion in vermicompost-enriched media.

3.4 Biomass accumulation

3.4.1 Fresh weight of root

Root fresh weight was significantly affected by the treatments. T₇ recorded the maximum root fresh weight (3.45 g), followed by T₃ (3.07 g) and T₁ (2.82 g). The lowest value was observed under T₄

(0.74 g).

The greater root fresh biomass under T₇ indicates that the blended medium created a favourable rhizosphere for root proliferation. Cocopeat probably improved moisture retention and aeration, while the potting mixture provided a more complete nutrient environment. The result is comparable with Patel and Singh (2021), who reported 4.65 g root fresh weight using a substrate containing soil, sand, vermicompost and cocopeat. Mishra and Das (2018) and Choudhary and Sharma (2022) also reported enhanced root biomass under organic amendment-based growing media.

3.4.2 Dry weight of root

Root dry weight followed a similar trend. T₇ recorded the highest value (0.68 g), followed by T₃ (0.61 g), while T₁ and T₆ each recorded 0.56 g. The lowest root dry weight was observed in T₄ (0.15 g).

The greater dry biomass indicates enhanced structural development of the root system under the blended medium. Adequate phosphorus availability may have contributed to root development, while improved physical conditions allowed greater root exploration and dry matter accumulation.

The findings are consistent with Singh and Rajput (2021), Joshi and Sharma (2022) and Gupta and Bhatnagar (2019), who reported enhanced root dry matter accumulation under cocopeat-, AMF- and integrated nutrient-management systems, respectively.

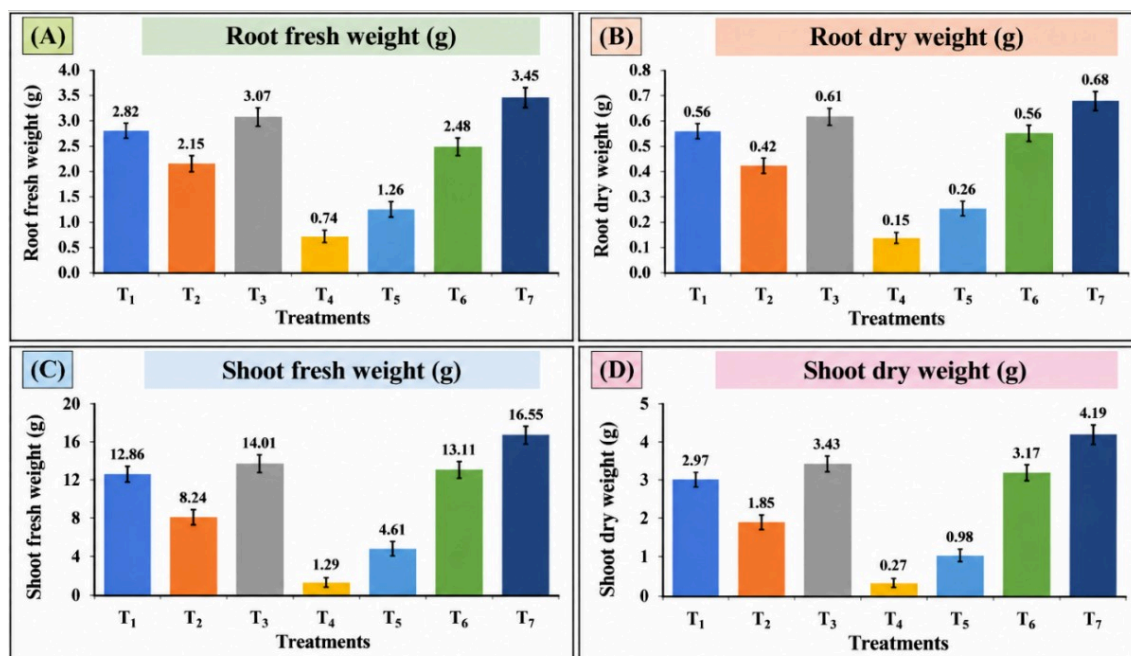


Figure 3. Effect of different nutrition protocols and potting media on root and shoot biomass production of acid lime (*Citrus aurantifolia* Swingle) seedlings under shade-net nursery conditions. (A) Root fresh weight, (B) root dry weight, (C) shoot fresh weight and (D) shoot dry weight.

3.4.3 Fresh weight of shoot

Shoot fresh weight was highest under T₇ (16.55 g), followed by T₃ (14.01 g) and T₆ (13.11 g). The minimum value of 1.29 g was recorded under T₄.

The enhanced shoot biomass under T₇ was associated with its greater seedling height, leaf number and leaf area. Increased leaf development would provide greater photosynthetic surface, potentially increasing assimilate production and subsequent biomass accumulation. The continuous availability of moisture from cocopeat may also have helped maintain tissue hydration and turgidity.

The result agrees with Reddy and Patil (2019), who reported enhanced shoot fresh weight in cocopeat-enriched media. Yadav and Singh (2022) and Sharma and Kadam (2021) likewise reported higher shoot biomass under blended substrates containing cocopeat and organic amendments.

3.4.4 Dry weight of shoot

The maximum shoot dry weight was recorded under T₇ (4.19 g), which was significantly higher than T₃ (3.43 g) and T₆ (3.17 g). The lowest value was recorded under T₄ (0.27 g).

The greater shoot dry matter under T₇ indicates improved net biomass accumulation under the combined substrate and moderate nutrient regime. The development of a larger photosynthetic canopy under T₇ likely enhanced assimilate production and subsequent partitioning towards structural shoot biomass.

Comparable results were reported by Rao and Reddy (2022), who obtained 3.40 g shoot dry weight using cocopeat-based media supplemented with NPK and VAM. Kumar and Singh (2020) recorded 3.25 g using vermiculite, perlite and vermicompost, while Tiwari and Baghel (2021) reported 3.05 g under integrated nutrient management.

3.5 Root development

3.5.1 Root volume

Root volume showed a pronounced treatment response. T₇ recorded the maximum root volume (3.89 cm³) and was statistically comparable with T₃ (3.50 cm³), followed by T₁ (3.36 cm³). The minimum root volume was recorded under T₄ (0.94 cm³).

The superior root volume under T₇ indicates favourable root-zone conditions created by the blended medium. The combination of con-

ventional potting material and cocopeat may have provided an improved balance between water retention and air-filled pore space, allowing greater root exploration. Adequate nutrient availability, particularly phosphorus, may have further supported root initiation and lateral development.

These findings are consistent with Desai and Patel (2021), who reported enhanced root volume under integrated nutrient management in container-grown acid lime. Sharma *et al.* (2018) similarly recorded improved root volume in soil + sand + cocopeat enriched with neem cake and AMF, while Kadam and Patil (2015) reported enhanced root volume in VAM-treated media.

3.5.2 Root–shoot ratio

Interestingly, the highest root–shoot ratio was recorded under T₄ (0.59), followed by T₅ (0.40) and T₂ (0.25), whereas T₇ recorded the lowest ratio (0.16).

The higher root–shoot ratio under the poorly performing cocopeat treatments should not automatically be interpreted as superior root development. Rather, the ratio reflects the relative allocation of biomass between root and shoot. In T₄, both root and shoot growth were severely restricted; therefore, the relatively larger proportion allocated to roots resulted in a higher ratio. Conversely, T₇ produced vigorous shoot growth together with substantial root development, resulting in a lower ratio.

This interpretation is important because root–shoot ratio should be considered together with absolute root and shoot biomass rather than as an isolated indicator of seedling quality. Similar emphasis on balanced biomass partitioning has been reported by Marathe *et al.* (2020) [1] and Kumar *et al.* (2017) in acid lime nursery studies.

3.6 Integrated interpretation of treatment response

Across the fourteen measured attributes, a consistent treatment pattern emerged. T₇ (potting mixture + cocopeat + 20:10:10 g NPK seedling⁻¹) produced the most favourable overall response, with earlier germination, greater germination and survival, higher vigour, stronger vegetative growth, greater biomass accumulation and enhanced root volume. The treatment recorded 14.67 days to 50% germination, 88.21% germination, 88.05% survival, 2019.00 vigour index, 22.86 cm seedling height, 14.83 leaves plant⁻¹, 26.83 cm² leaf area, 3.45 g root fresh weight, 0.68 g root dry weight, 16.55 g shoot fresh weight, 4.19 g shoot dry weight and 3.89 cm³ root volume.

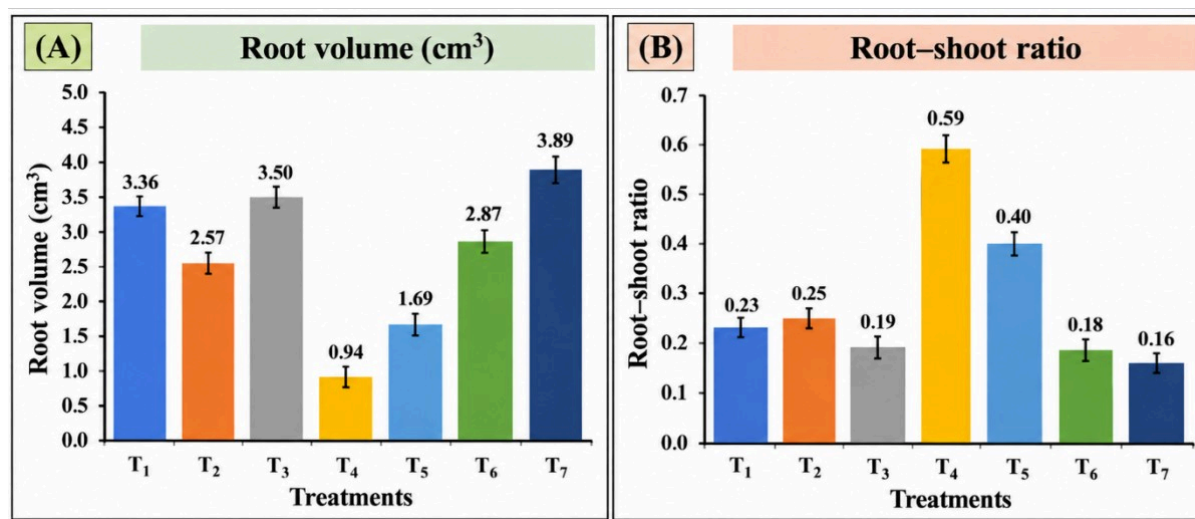


Figure 4. Effect of different nutrition protocols and potting media on root development of acid lime (*Citrus aurantifolia* Swingle) seedlings under shade-net nursery conditions. (A) Root volume and (B) root-shoot ratio.

The response suggests a substrate $\times$ nutrient interaction, in which the physical benefits of cocopeat were complemented by the nutrient and structural contribution of the conventional potting mixture. Importantly, the higher NPK dose did not improve performance when applied to sole cocopeat. Instead, the 20:10:10 regime in the blended substrate produced the strongest overall seedling response.

This agrees particularly well with Marathe *et al.* (2020) [1], who reported that a potting mixture-cocopeat combination with controlled NPK nutrition improved acid lime seedling performance. The present findings therefore reinforce the concept that nursery nutrition should be optimized in relation to the physical characteristics of the growing substrate rather than considered independently.

Conversely, the poor performance of T₄ (cocopeat + 60:25:25 g NPK seedling⁻¹) across germination, survival, shoot growth and biomass parameters indicates that a high fertilizer dose in an unblended cocopeat substrate was unsuitable under the experimental conditions. The treatment recorded only 54.23% germination, 22.82% survival, 3.33 cm seedling height, 2.94 leaves plant⁻¹, 2.99 cm² leaf area, 0.74 g root fresh weight, 0.15 g root dry weight, 1.29 g shoot fresh weight, 0.27 g shoot dry weight and 0.94 cm³ root volume.

Thus, the results demonstrate that the quality of acid lime nursery stock depends on achieving an appropriate balance among substrate aeration, moisture retention and nutrient availability. The superiority of T₇ was not attributable to the highest nutrient dose, but rather to the compatibility between the blended growing medium and a moderate nutrient supply.

Conclusion

The present investigation demonstrated that the interaction between growing media composition and nutrient supply plays a decisive role in the successful production of quality acid lime (*Citrus aurantifolia* Swingle) seedlings under shade-net nursery conditions. Among the seven treatment combinations evaluated, the integrated use of potting mixture and cocopeat supplemented with a moderate NPK dose of 20:10:10 g seedling⁻¹ (T₇) resulted in consistently superior nursery performance.

Treatment T₇ recorded the earliest attainment of 50 per cent germination (14.67 days), highest germination percentage (88.21%), highest germination rate (6.05), maximum seedling survival (88.05%) and highest vigour index (2019.00). It also produced the greatest seedling height (22.86 cm), number of leaves (14.83 plant⁻¹) and leaf area (26.83 cm²). The superiority of T₇ extended to biomass accumulation, with maximum root fresh weight (3.45 g), root dry weight (0.68 g), shoot fresh weight (16.55 g), shoot dry weight (4.19 g) and root volume (3.89 cm³). The lower root-shoot ratio (0.16) under T₇ was asso-

ciated with greater shoot development relative to root biomass rather than poor root development, as evidenced by its highest absolute root biomass and root volume. The superior performance of T₇ indicates that combining potting mixture with cocopeat provided a more favourable physical environment for seedling establishment, while the moderate 20:10:10 NPK dose supplied adequate nutrients without the adverse effects associated with excessive fertilizer application. This interpretation is consistent with earlier work on acid lime, where mixtures containing potting media and cocopeat, together with appropriate nutrient management, improved seedling emergence, survival and growth. Marathe *et al.* (2020) [1], for example, reported maximum emergence and survival in a potting-mixture + cocopeat combination and emphasized the usefulness of cocopeat when blended with nursery potting media and supplemented with appropriate fertilizer doses.

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