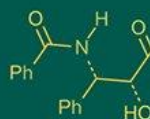


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## Effect of indole-3-butyric acid (IBA) and growing media on shoot and root growth characteristics of sour lime (*Citrus aurantifolia* Swingle.) hardwood cuttings grown under submontaneous zone of Punjab

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### Abstract

The present study was conducted to evaluate the 'Effect of indole-3-butyric acid (IBA) and growing media on shoot and root growth characteristics of sour lime (*Citrus aurantifolia* Swingle.) hardwood cuttings grown under submontaneous zone of Punjab' during the years 2023-24 and 2024-25 at Punjab Agricultural University, Regional Research Station, Gurdaspur. The healthy and disease free hardwood stem cuttings were obtained from one year old shoots of 5-6 years old mother plants of sour lime in the month of February. The basal portion of the cuttings was dipped for one minute in different doses (1000 ppm, 2000 ppm, 3000 ppm and control) of IBA to induced rootings and planted in different growth media (garden soil, sand, farmyard manure, cocopeat, vermicompost) in polythene bags with different treatment combinations and garden soil used as control. It has been reported that hardwood stem cuttings of sour lime treated with IBA 3000 ppm and grown in garden soil + sand + vermicompost + cocopeat (1:1:1:1) media showed minimum number of days taken to first sprout with maximum number of the sprouts, sprouting percentage, plant height, number of shoot, shoot length, shoot diameter, number of leaves, leaf length, leaf breadth, rooting percentage, number of primary roots, longest root length, thick root diameter, fresh root weight, dry root weight, fresh shoot weight, dry shoot weight, root spread and survival percentage. The beneficial effect of present work can develop protocol for optimum rooting hormone concentration and growth media for faster and true to type multiplication of nursery plants of sour lime.

**Keywords:** Growth media, hard wood cutting, indole-3-butyric acid, sour lime, rooting, survival, vegetative growth

### 1. Introduction

Citrus fruits are one of the major choicest fruit crop of the world having high consumer's preference both as fresh and as well as its processed juice. Important species of citrus group is acid lime (*Citrus aurantifolia* Swingle.) which is also known as sour lime or maxican lime or pati lime. Sour lime (*Citrus aurantifolia* Swingle.) belongs to family Rutaceae with sub-family Aurantioideae and originated in India. It is one of the most important citrus fruit as a major source of vitamin C with acidic taste (Souci *et al.*, 2000) <sup>[61]</sup> grown throughout the world (Babaie *et al.*, 2014) <sup>[10]</sup>. The major sour lime producing countries are China, Maxico, Brazil and India. It is commercially grown in tropical and sub-tropical region of India. Sour lime is the third most important fruit after mandarin and sweet orange and India ranks fifth among major lime producing countries (Anonymous, 2014) <sup>[6]</sup>. In India, citrus fruits are primarily grown in Maharashtra, Andhra Pradesh, Punjab, Karnataka, Uttaranchal, Bihar, Orissa, Assam and Gujarat. In Punjab, citrus is cultivated in 56492 hactare area with 1380867 metric tonnes production, among which lemon and lime contribute about 3252 hactare area with 26278 metric tonns production (Anonymous, 2024) <sup>[5]</sup>. Sour lime fruits are extensively used for squashes, pickles, syrups and cordials, manufacture of citric acid and for table purpose in daily life of Indians (Cheema *et al.*, 1954) <sup>[18]</sup>. It also makes delicious and refreshing cold drinks. Sour lime fruits are valued not only for its nutritional qualities but also medicinal purpose. Sour lime required a wide range of soil and climatic conditions and is hard enough to withstand considerable neglect as compared to other fruit crops. It is relatively a disease free crop subjected to only a few diseases and insects, and requires less

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plant protection and irrigation as compared to other important fruit crops. Generally, acid lime is regenerated through seeds, but there is a problem of nonuniformity of progeny and high chance of viral disease contamination by this method (Babaie *et al.*, 2014)<sup>[10]</sup>. Also, it is not advisable to use seeds for commercial planting because these seeds do not produce true fruits. Therefore, it is advisable to avoid seedlings for commercial plantation. For overcoming this problem, the vegetative propagation is vital to produce citrus plants having desirable characters as mother plant and they are propagated true to type from cuttings, budding, grafting, layering, etc. (Seran and Umadevi, 2011)<sup>[54]</sup>. However, vegetative multiplication through cutting is only cheap, practicable and widely used option for augmenting natural regeneration and for large scale cultivation programmes. Owing to high intensity of polyembryony and least chance of contamination of viral diseases in sour lime, the stem cutting appears as most suitable method for regeneration of the species (Babaie *et al.*, 2014)<sup>[10]</sup>. Further, it is reported that juvenile stage of plants can be decreased through stem cutting technique and the time of nursery development can also be reduced. It is inexpensive, rapid and simple and does not require the special techniques as required in other vegetative methods. The success of stem cutting depends on many factors associated with plants such as age of the mother plant, parts used of tree, time of planting, rainfall, humidity, temperature, rooting media and after care (Frey *et al.*, 2006)<sup>[22]</sup>. Plant growth regulators, such as indole-3-butyric acid (IBA), naphthalene acetic acid (NAA) and 6-Benzylaminopurine (BAP) are frequently used to promote shooting and rooting in plant cuttings (Hartmann *et al.*, 2002; Sharma *et al.*, 2013; Verma, 2013)<sup>[26, 55, 63]</sup>. Similarly, rooting media also play an important role for better root formation and development. The nature of roots arising from the cuttings is also influenced by the type of rooting medium e.g. cutting when planted in pure sand produce long, unbranched, coarse and brittle roots but those planted in a mixture of sand, soil and peat produce well developed branches (Chattopadhyaya, 1994)<sup>[16]</sup>. Different growing media that are well aerated, loose, porous, created optimum condition for respiration and maintains temperature, well drained and with good water retention are used in establishing crop plantlets (Bhosale *et al.*, 2014; Rymbai and Reddy, 2010)<sup>[12, 51]</sup>. Pomegranate cultivar 'Bhagwa' cuttings planted in the month of February after giving IBA 2000 ppm treatment and planted in the media combination of cocopeat, perlite and vermicompost in ratio of 4:1:1 resulted in minimum number of days taken for

sprouting with highest sprouts per cutting, sprouted percentage, survival percentage, plant height, stem diameter, number of leaves, shoot fresh weight and shoot dry weight (Saini *et al.*, 2022)<sup>[52]</sup>. Maximum survival percentage of Assam lemon stem cuttings was recorded under IBA 800 ppm + soil + sand + vermicompost + cocopeat (1:1:1:1) treatment as reported by Lalhruaitluanga *et al.* (2022)<sup>[37]</sup>. Although the studies on the effect of plant growth regulators on rooting of stem cuttings in citrus have been investigated over the years, but the studies on the effect of plant growth regulator and soil media on stem cuttings in citrus especially in sour lime in particular is scarce. Therefore, keeping in view the above points, the present study was undertaken to find out the optimum concentration of rooting hormone or auxins (IBA) and suitable growth/soil media for faster rooting and survival of sour lime stem cutting.

## 2. Material and Methods

The present investigation on "Effect of indole-3-butyric acid (IBA) and growing media on shoot and root growth characteristics of sour lime (*Citrus aurantifolia* Swingle.) hardwood cuttings grown under submontaneous zone of Punjab" was conducted during the years 2023-24 and 2024-25 at Punjab Agricultural University, Regional Research Station, Gurdaspur in submontaneous region of Punjab which is situated between 32°3' N latitude, 75°22' E longitude and has an altitude of about 257 m from mean sea level having humid subtropical and dry winter climate. Sour lime (5-6 years old plants) grown in the orchard were selected for this experiment on the basis of their uniformity in appearance, growth habit, free from visual symptoms of pests and disease occurrence. Healthy and mature shoots preferably one year old having thickness of about 1.0 cm were selected in the month of February before sprouting from the central and basal part of the branch and cuttings were made of about 15-20 cm in length possessing 8-10 buds. Leaves were completely removed from the cuttings with the help of secateurs to reduce the transpiration loss. A slanting cut was given at the upper side and a slight slanting cut also was given at the lower end to provide a large surface area to encourage the rooting in cuttings. The basal parts (2-3 cm) of all the cuttings were dipped in different concentrations of IBA 1000, 2000 and 3000 ppm for one minute dip along with control Hartmann *et al.*, 2002)<sup>[26]</sup>. After this, these treated and un-treated cutting were planted in different growth/soil media with total sixteen treatments combination as following:

| Treatment number | Treatment detail                                                      |
|------------------|-----------------------------------------------------------------------|
| T <sub>1</sub>   | 1000 ppm IBA + garden soil + sand (1:1)                               |
| T <sub>2</sub>   | 1000 ppm IBA + garden soil + sand + FYM (1:1:1)                       |
| T <sub>3</sub>   | 1000 ppm IBA + garden soil + sand + vermicompost (1:1:1)              |
| T <sub>4</sub>   | 1000 ppm IBA + garden soil + sand + FYM + cocopeat(1:1:1:1)           |
| T <sub>5</sub>   | 1000 ppm IBA + garden soil + sand + vermicompost + cocopeat (1:1:1:1) |
| T <sub>6</sub>   | 2000 ppm IBA + garden soil + sand (1:1)                               |
| T <sub>7</sub>   | 2000 ppm IBA + garden soil + sand + FYM (1:1:1)                       |
| T <sub>8</sub>   | 2000 ppm IBA + garden soil + sand + vermicompost (1:1:1)              |
| T <sub>9</sub>   | 2000 ppm IBA + garden soil + sand + FYM + cocopeat((1:1:1:1)          |
| T <sub>10</sub>  | 2000 ppm IBA + garden soil + sand + vermicompost + cocopeat (1:1:1:1) |
| T <sub>11</sub>  | 3000 ppm IBA + garden soil + sand (1:1)                               |
| T <sub>12</sub>  | 3000 ppm IBA + garden soil + sand + FYM (1:1:1)                       |
| T <sub>13</sub>  | 3000 ppm IBA + garden soil + sand + vermicompost (1:1:1)              |
| T <sub>14</sub>  | 3000 ppm IBA + garden soil + sand + FYM + cocopeat(1:1:1:1)           |
| T <sub>15</sub>  | 3000 ppm IBA + garden soil + sand + vermicompost + cocopeat (1:1:1:1) |
| T <sub>16</sub>  | Control (without IBA + garden soil)                                   |

The experiment was performed in a completely randomized block design with 3 replicates with a unit of 100 cuttings comprised of one replication. The treated cuttings were planted in the polythene bags by incorporating a different media mixture and kept under the shade of a tree. The medium was prepared well and drenched with chloropyriphos solution to avoid the attack of termites. The holes for planting the cuttings were made in the poly bags with the help of iron rod so as to avoid any damage to cuttings. While planting, about 2/3<sup>rd</sup> portion of the cuttings were buried in the rooting medium, leaving 1/3<sup>rd</sup> portion exposed to the environment. The various observation i.e. days to first sprout, number of sprouts, sprouting percentage, plant height (cm), number of shoot, shoot length (cm), shoot diameter (mm), number of leaves, leaf length, leaf breadth, rooting (%), number of primary roots, longest root length (cm), thick root diameter (mm), fresh root weight (gm), dry root weight(gm), fresh shoot weight(gm), dry shoot weight(gm), root spread (cm) and survival percentage were recorded after planting of cutting. The recorded data were statistically analyzed by using Completely Randomized Design (CRBD) as suggested by (Gomez and Gomez, 2010) [25]. Experimental data was statistically analyzed by using SPSS software.

### 3. Results and Discussion

#### 3.1 Number of days taken for sprouting

Sour lime stem cuttings treated with IBA 3000 ppm and planted in garden soil + sand + vermicompost: cocopeat (1:1:1:1) medium recorded the minimum days for sprouting (10.15 days) (Table1). The longest days for sprouting (38.18 days) were observed in control treatment. The speed and success rate of sprouting in cuttings are largely determined by the efficient downward movement of carbohydrates and the localized concentration of auxin at the base of the cutting, which fuels necessary physiological transitions. Research supports the idea that specialized media, specifically a blend of soil, sand and vermicompost create an ideal environment for these processes (Kasim *et al.*, 2009; Priya *et al.*, 2008) [31, 49]. This combination provides the structural aeration and nutrient density required to trigger early sprouting and improve the overall percentage of successful cuttings. Likewise (Saini *et al.*, 2022) [52] noted that pomegranate cultivar 'Bhagwa' stem cuttings treated with IBA 2000 ppm and planted in the media combination of cocopeat, perlite and vermicompost growth media in ratio of 4:1:1 resulted in minimum number of days taken for sprouting. Similarly Amrutha and Patel (2025) [3] also noted that exogenous application of IBA 1500 ppm to dragon fruit cuttings with growth media combination of soil + sand + cocopeat significantly taken minimum days for initiation of sprouts. Likewise Anand and Ajay (2025) [4] also reported minimum number of days taken to sprouting in lemon cuttings treated with 1500 ppm IBA and planted in garden soil + sand + FYM(1:1:1) growth media.

#### 3.2 Number of sprouts per cutting and percent sproutings

Sour lime cuttings treated with IBA 3000 ppm and planted in garden soil + sand + vermicompost: cocopeat (1:1:1:1) medium recorded maximum number of sprouts per cuttings (26.52) & sprouting percentage (92.51) and control treatment was recorded minimum sprouts per cuttings (5.21) & sprouting percentage (25.13) (Table1). This may also be

due to higher net assimilation rate on account of better growth leading to the production of endogenous metabolites earlier in optimum level enabling early bud initiation and thereby better survival. Further, vermicompost in comparison to FYM used for polybag mixture contained higher level of nutrients. Increase in sprouting percentage may be due to better utilization of stored carbohydrate, nitrogen and other factor with the aid of growth regulator. Similarly Kumar and Kumar (2022) [33] reported that Pant lemon cuttings treated with 1800 ppm IBA and grown in garden soil + sand + vermicompost (1:1:1) produced maximum percentage of sprouting. Amrutha and Patel (2025) [3] also noted maximum sprouting percentage with exogenous application of IBA 1500 ppm to dragon fruit cuttings with growth media combination of soil + sand + cocopeat. Tanwar *et al.* (2020) [62] also reported IBA 2000 ppm treated cuttings of pomegranate cultivar 'Bhagwa' and grown in cocopeat + perlite + vermiculite mixture recorded highest number of sprouts per cutting.

#### 3.3 Plant height

Maximum plant height (65.21 cm) was recorded in sour lime cuttings treated with IBA 3000 ppm and planted in soil + sand + vermicompost: cocopeat (1:1:1:1) medium and minimum plant height (25.12 cm) was noted in control treatment (Table1). Optimum dose of IBA on plant height might be attributed to the fact that cuttings treated with this concentration had improved root system thus absorbed more amount of nutrients which helped in better stem growth and plant height, similar explanation had been suggested by Chauhan and Maheshwari (1970) [17]. According to the current study, the strong root development and more roots per cutting may be the reason for the increase in shoot length in terminal cuttings caused by IBA. This improves the absorption of nutrients and water as a result, also promotes protein synthesis, cell division, and elongation, which might have resulted in stronger and more vigorous vegetative growth in jasmine (Kumaresan *et al.*, 2019) [36]. Likewise plant height was highest in IBA 2000 ppm treated stem cuttings of pomegranate cultivar 'Bhagwa' planted in cocopeat, perlite and vermicompost (4:1:1) as noted by (Saini *et al.*, 2022) [52]. Lalhrualtuanga *et al.*, (2022) [37] also reported maximum plant height of assam lemon stem cuttings in IBA 800 ppm + soil + sand + vermicompost + cocopeat (1:1:1:1) treatment.

#### 3.4 Number of shoots

It has been showed that sour lime stem cutting treated with 3000 IBA and planted in soil + sand + vermicompost: cocopeat (1:1:1:1) medium produced maximum (12.52) number of shoots per plant and the minimum(2.05) number of shoots per plant were recorded in control treatment (Table 1). This enhancement in aerial growth is attributed to the activation of Indole-3-butyric acid (IBA) within the vegetative tissues, which stimulates cell division and axillary bud outgrowth. Furthermore, the inclusion of nutrient enrich media components like farmyard manure (FYM) and leaf mould provides the essential macro and micro-nutrients required to sustain rapid shoot and leaf development. These results align with previous observations by (Kumar *et al.*, 2004; Murkute *et al.*, 2009) [35, 44], confirming that the synergy between hormonal application and a fertile rooting medium accelerates the transition from root initiation to vigorous canopy growth. Likewise Anand

and Ajay (2025) <sup>[4]</sup> observed highest number of shoots per lemon cutting in IBA 1500 ppm and garden soil + sand + FYM (1:1:1) treatment. Similarly Jaiwal *et al.* (2021) <sup>[28]</sup> also observed highest number of shoots in pomegranate cuttings treated with IBA 4500 ppm and planted in cocopeat + FYM growth media.

### 3.5 Shoot length

From the Table 1, It has been observed that sour lime stem cutting treated with IBA 3000 ppm and planted in soil + sand + vermicompost: cocopeat (1:1:1:1) medium produced longest shoot length (30.61 cm) and the control treatment cuttings retained shortest shoot length (10.02 cm). The probable cause of increased shoot length might be the better utilization of carbohydrates, nitrogen and other nutrients from media, which had been aided by growth regulators (Babaie *et al.*, 2014) <sup>[10]</sup>. Similarly, maximum shoot length was reported in IBA 800 ppm treated cuttings of Assam lemon and planted in soil + sand + vermicompost + cocopeat (1:1:1:1) growing media (Lalhruaitluanga *et al.*, 2022) <sup>[37]</sup>. Likewise (Anand and Ajay, 2025) <sup>[4]</sup> reported maximum shoot length in lemon cuttings treated with IBA 1500 ppm and planted in garden soil + sand + FYM (1:1:1). Kumar *et al.* (2025) <sup>[32]</sup> also reported maximum shoot length in pomegranate cultivar 'Bhagwa' cuttings treated with IBA 2000 ppm and planted in sand and vermiculite growth media.

### 3.6 Shoot diameter

It has been noted that different treatments of growth regulator and soil media significantly affect the shoot diameter (Table1). Sour lime cuttings treated with IBA 3000 ppm and planted in soil + sand + vermicompost: cocopeat (1:1:1:1) growth media had highest shoot diameter (15.32 mm) and untreated garden soil grown cuttings had lowest shoot diameter (4.15 mm). This might be due to the frequency at which the vascular bundles absorb water and nutrients is closely correlated with the increase in plant height and diameter. The greater rooting percentage in IBA treated plants enable the plant to absorb more nutrients, increasing plant height and shoot diameter (Kasim *et al.*, 2009; Siddiqui and Hussain, 2007) <sup>[30, 57]</sup>. Increased shoot diameter in lime cuttings might be due to more number of leaves and vigorous root system as a consequence of better carbohydrates production and assimilation with the application of rooting hormone and growth media. Also increase in shoot diameter might be due to higher cell activity and the synthesis of more food material through a process of photosynthesis (Kamboj *et al.*, 2017) <sup>[29]</sup>. Similarly maximum stem diameter was reported in IBA 800 ppm treated cuttings of Assam Lemon and planted in soil + sand + vermicompost + cocopeat (1:1:1:1) growing media (Lalhruaitluanga *et al.*, 2022) <sup>[37]</sup>. Similar results were also recorded in IBA treated fig cuttings by (Singh, and Rattanpal, 2017) <sup>[59]</sup>. Similarly shoot diameter was highest in IBA 2000 ppm treated stem cuttings of pomegranate cultivar 'Bhagwa' planted in cocopeat, perlite and vermicompost (4:1:1) growth media as observed by (Saini *et al.*, 2022) <sup>[52]</sup>.

### 3.7 Number of leaves

Maximum number of leaves (122.60) were observed in sour lime cuttings treated with IBA 3000 ppm and grown in soil + sand + vermicompost: cocopeat (1:1:1:1) media as compared to rest of treatments (Table1). This enhancement

in aerial growth is attributed to the activation of Indole-3-butyric acid (IBA) within the vegetative tissues, which stimulates cell division and axillary bud outgrowth. Furthermore, the inclusion of nutrient dense media components like farmyard manure (FYM) and leaf mould provides the essential macro and micro nutrients required to sustain rapid shoot and leaf development. These results align with previous observations by (Kumar *et al.*, 2004; Murkute *et al.*, 2009) <sup>[35, 44]</sup>, confirming that the synergy between hormonal application and a fertile rooting medium accelerates the transition from root initiation to vigorous canopy growth. Indole-3-butyric acid treated cuttings resulted in longer, healthier roots that aid in the absorption of water and nutrients, significantly impacting the cuttings ability to produce more leaves. There may be more roots, branches and plant height with IBA treatment which results in more leaves per cutting (Bowden *et al.*, 2022) <sup>[13]</sup>. Similarly Anand and Ajay (2025) <sup>[4]</sup> reported that lemon treated with IBA1500 ppm and grown in garden soil + sand + FYM (1:1:1) produced highest number of leaves per shoot. Likewise Kumar and Kumar (2022) <sup>[34]</sup> reported that Pant lemon-1 stem cuttings treated with 1800 ppm IBA and grown in garden soil + sand + vermicompost (1:1:1) growth media recorded highest number of leaves per cutting. Jaiwal *et al.* (2021) <sup>[28]</sup> also observed that pomegranate cutting treated with IBA 4500 ppm and grown in cocopeat + FYM media recorded highest number of leaves per cutting.

### 3.8 Leaf length and breadth

It has been noted that leaf length and breadth of sour lime were varied significantly among different IBA and soil media treatments (Table1). Maximum mean leaf length and breadth (9.15 cm and 6.02 cm respectively) were recorded in treatment IBA 3000 ppm + soil + sand + vermicompost: cocopeat (1:1:1:1) and minimum in control. This may be due to stem cuttings treated with IBA and growth media produced healthier lengthy roots and hence absorbed more nutrients and water contents lead to the synthesis of more carbohydrates in the leaves which might have resulted in elongation of leaves through cell division and cell elongation which resulted in more leaf area per cutting when compared to all other treatments. Similar results were undertaken by Ghosh *et al.* (2017) <sup>[24]</sup> in phalsa and Abhinav Burman *et al.* (2016) <sup>[1]</sup> in grapes. Mehra *et al.* (2019) <sup>[42]</sup> also noted that persimmon cultivar 'Fuyu' cuttings treated with IBA 6000 ppm and planted in soil + FYM(1:2) rooting media resulted highest leaf area.

### 3.9 Dry and fresh weight of shoot

Maximum shoot fresh weight(29.16 gm) and dry weight(20.15 gm) were reported in the sour lime stem cuttings treated with IBA 3000 ppm and planted in soil + sand + vermicompost: cocopeat (1:1:1:1) growth media as compared to others treatments(Table 2). Indole-3-butyric acid treatment might have increased the number of shoots resulting in increased higher accumulation of fresh and dry weight in shoots. Likewise shoot fresh weight and shoot dry weight were highest in IBA 2000 ppm treated stem cuttings of pomegranate cultivar 'Bhagwa' planted in cocopeat, perlite and vermicompost (4:1:1) growth media as noted by Saini *et al.* (2022) <sup>[52]</sup>. Ficus cuttings treated with IBA 2000 mg/litre and planted in growing media of sand + cocopeat + vermicompost (1:1:1) was recorded highest fresh and dry weight of shoot (Zala and Masu, 2025) <sup>[64]</sup>. This may be

related to the use of growth regulators to improve the mobilization of primary metabolites for enhanced root and shoot formation. Indole-3-butyric acid increases the number of leaves and roots in the cuttings, resulting in a higher fresh weight accumulation. This could also possibly be attributed to the hydrolysis and transfer of carbohydrates and nitrogenous compounds near the base of cuttings, which led to increased cell proliferation and elongation (Satpal *et al.*, 2014) [53]. It also promotes the formation of callus and tissues, as well as vascular tissue differentiation. Similarly Maurya *et al.* (2022) [41] also reported that lemon cuttings treated with IBA 2000 ppm and planted in soil + peat moss + sand resulted into maximum fresh and dry weight of cuttings.

### 3.10 Rooting percentage, number of primary roots, longest root length, thick root diameter, fresh root weight, dry root weight and root spread

From Table 2, it has been noted that maximum rooting percentage (93.16), number of primary roots (50.18), longest root length (38.21), thick root diameter (6.85 mm), fresh root weight (12.52 gm), dry root weight (7.32 gm) and root spread (28.16 cm) were noted in sour lime cuttings treated with IBA 3000 ppm and planted in soil + sand + vermicompost: cocopeat (1:1:1:1) growth media as compared to rest of treatments. Maurya *et al.* (2022) [41] also reported that lemon cuttings treated with IBA 2000 ppm + soil + peat moss + sand resulted into highest number of roots with longest root length per cutting. Similarly Kumar *et al.* (2025) [32] reported that pomegranate cultivar 'Bhagwa' stem cuttings treated with IBA 2000 ppm and planted in mixture of sand and vermiculite with 2000 ppm IBA resulted highest rooting percentage with maximum root length. Auxins initiate synthesis of structural enzyme protein in the formation of adventitious roots, thus increasing the root length through the process of acidification (Audus, 1963) [8]. The various aspects of root development are influenced by IBA such as the formation of adventitious roots, regulation of root apical meristem size, root hair elongation and lateral root development Frick *et al.* (2018) [23]. The enhanced root length in treatments involving cocopeat and higher IBA concentration may be attributed to the physical and chemical properties of cocopeat. Its low particle density and high specific surface area promote water and nutrient retention, which supports better root elongation. Additionally, the presence of auxins (such as IBA) stimulates cell elongation and root growth. These findings are in close agreement with the results of Porghorban *et al.* (2014) [47] in olive and Araujo *et al.* (2010) [7] in Passiflora, who reported that improved substrate texture and porosity facilitated enhanced root growth through better aeration and nutrient mobility. The enhanced rooting observed in the higher IBA concentration and cocopeat containing media may be attributed to rapid hydrolysis of stored polysaccharides in stem cuttings into physiologically active sugars. These sugars provide energy to meristematic tissues, stimulating root primordia initiation (Chander and Kumar, 2023; Singh *et al.*, 2025) [15, 58]. Additionally, cocopeat has been reported to release phenolic compounds (Lokesha *et al.*, 1988) [38] and its beneficial physical properties such as high aeration and water holding capacity further support root development (Smith, 1995) [60]. It might be due to that the rich source of essential nutrients like N, P, K and trace elements provided by the vermicompost and these nutrients

were in a readily available form, that was helpful in promoting better root development. The present findings are in accordance with the findings of (Ingole *et al.*, 2024; Misra *et al.*, 2024) [27, 43] in dragon fruit. Malik *et al.* (2022) [40] also noted that snapdragon cultivar 'Rocket Pink' stem cuttings treated with IBA 1500 ppm and planted in sand + perlite + cocopeat growth media significantly increased number of roots with root length per cuttings. Shrestha *et al.* (2023) [56] also reported highest root length, number of roots, root fresh weight and root dry weight in hardwood cuttings of bougainvillea cultivar 'Double red' treated with IBA (1000 mg L<sup>-1</sup>) and planted in sand + cocopeat. The degree of root formation per cutting steadily increases with increased concentration of IBA, there is a correlation between primordia division in root initiation and endogenous or exogenous auxin. The induction of maximum number of roots in treated cuttings may be due to the fact that cambial activity and metabolic activity involved in root initiation is stimulated by growth regulators as reported by (Ali *et al.*, 2022; Pandey *et al.*, 2022) [2, 46] in dragon fruit. The vermicompost recorded best and this might be due to the presence of nutrients and trace elements. Polysaccharides stored in the cuttings undergo hydrolysis and converted into physiologically active sugars, then supplies the energy through respiratory activity to the root primordia and helps in enlargement of root meristematic cells and thereby obtained maximum root length. The results obtained were in similar with the findings of (Ingole *et al.*, 2024; Prasad *et al.*, 2022) [27, 48] in dragon fruit. Auxin application has been found to enhance the histological features like differentiation of vascular tissue and increased the plasticity of cell wall which in turn resulted in cell enlargement and better nutrients uptake and causing more growth of roots. Vermicompost has an extensive surface area, enabling it to absorb and hold nutrients effectively. This allows it to retain a higher quantity of nutrients over extended periods and this helps to establish and increase the length of the roots. The above results are similar with the findings of Ingole *et al.* (2024) [27] in dragon fruit and Deshmukh *et al.*, 2019 [21] in pomegranate. The growth regulator IBA 3000 ppm recorded best when compared to other IBA concentration. This might be the result of the polysaccharides in cuttings hydrolysing quickly into physiologically active sugars. These sugars give off energy through respiratory activity, assisting in the meristematic tissues to quick elongation, which in turn caused the longest roots to form. Similar results were reported by Ayesha *et al.* (2018) [9] in dragon fruit and Nale *et al.* (2024) [45] in fig. Vermicompost contains plant growth regulators, nutrients and humic acids, which stimulate root growth. This hormonal influence can lead to increased root biomass and fresh weight. The microbes in vermicompost helps in nutrient cycling and suppress soil borne diseases, allowing the roots to grow more freely and increase in weight. Similar results were reported in dragon fruit (Chahal *et al.*, 2020) [14] and pomegranate (Deshmukh *et al.*, 2019) [21]. Indole-3-butyric acid accelerates cell division and elongation and can interact synergistically with other plant hormones and growth regulators, further enhancing root biomass and increasing the fresh weight of roots. This might be attributed due to higher fresh weight of roots and ultimately led into higher dry weight of roots of cuttings. Vermicompost's physiochemical properties enhanced the nutrient absorption, promoted the root growth and stimulated the vascular cambium, leading to the increased

root diameter and thickness. The results are in consonance with findings of Misra *et al.* (2024) <sup>[43]</sup>. Indole-3-butyric acid increased the root thickness and this might be due to the quick survival of rooted cuttings in dragon fruit is further aided by the supply of photo assimilates produced in new shoots that are directed towards the root system. Similarly, Amrutha *et al.* (2025) <sup>[3]</sup> also reported that exogenous application of IBA 1500 ppm with media combination of soil + sand + cocopeat to dragon fruit significantly increased the rooting percentage and root length. Likewise Madhuri *et al.* (2024) <sup>[39]</sup> observed that treatment combination (IBA 3000 ppm + red earth + vermicompost) to dragon fruit stem cuttings recorded highest number of roots, root length, fresh weight of the roots, dry weight of the roots and root thickness. Tanwar *et al.* (2020) <sup>[62]</sup> also reported treatment combination comprising IBA 2000 ppm + cocopeat + perlite + vermiculite to pomegranate 'Bhagwa' recorded highest values in term of percentage of rooted cuttings, survival of rooted cuttings, number of roots per cutting and length of longest roots per cutting.

### 3.11 Survival percentage

It is evident from the data shown in Table 2 that growth regulator and soil media had significant effect on survival percentage of cuttings. Highest survival percentage (95.13) of sour lime was found in the cuttings treated with 3000 ppm IBA and planted in garden soil + sand + vermicompost: cocopeat (1:1:1:1) growth medium while minimum survival percentage (22.18) of cuttings was observed in the control treatment. Significant effect of growth regulators on survival percentage was due to root induction capacity of auxin and better root growth in rooting media which help in production of adventitious roots and thereby increase in the survival of plants. It also might be probably due to root and root length at this concentration which could have caused the absorption of nutrients and the fact that rooting co-factors and their balance with auxin and nutritive substances. Likewise the maximum survival percentage of Assam lemon stem cuttings was recorded under IBA 800 ppm + soil + sand + vermicompost + cocopeat (1:1:1:1) treatment as reported by Lalhruaitluanga *et al.* (2022) <sup>[37]</sup>. In addition to that when using growth regulator boosting the rooting can be attributed to the favorable environmental condition with higher photosynthetic activity which promoted better rooting in cutting and survival percentage. The facilitated absorption of nutrients and moisture from soil and better growth might have developed capacity to withstand for a longer period Ram *et al.* (2005) <sup>[50]</sup>. This could be due to the availability of good amount of nutrients in vermicompost growth media. Auxin may have induced favourable environment for root and shoot development and enhanced survival Constanzi *et al.* (1988) <sup>[20]</sup>. Similarly survival percentage was highest in IBA 2000 ppm treated stem cuttings of pomegranate cultivar 'Bhagwa' planted in cocopeat, perlite and vermicompost (4:1:1) growth media as reported by (Saini *et al.*, 2022) <sup>[52]</sup>. Anand and Ajay (2025) <sup>[4]</sup> also noted that exogenous application of IBA 1500 ppm to dragon fruit stem cuttings and planted in media combination of soil + sand + cocopeat significantly increased the survival percentage. Likewise treatment of IBA 7500 ppm + sphagnum moss + cocopeat + vermicompost resulted into highest survival percentage in guava cultivar 'L-49' air layers (Chhabra *et al.*, 2022) <sup>[19]</sup>. Kumar and Kumar (2022) <sup>[34]</sup> also reported highest survival

percentage of Pant lemon stem cuttings treated with 1800 ppm IBA and grown in garden soil + sand + vermicompost growth media. Similarly Jaiwal *et al.* (2021) <sup>[28]</sup> observed that maximum survival percentage of rooted cutting of pomegranate in 4500 ppm IBA + coco peat + FYM treatment. Likewise Kumar *et al.* (2025) <sup>[32]</sup> also reported that combination of IBA 2000 ppm, sand and vermiculite to pomegranate cultivar 'Bhagwa' stem cuttings produced highest survival percentage of rooted cuttings. Malik *et al.* (2022) <sup>[40]</sup> also reported that snapdragon cultivar 'Rocket Pink' stem cuttings treated with 1500 ppm IBA and grown in sand + perlite + cocopeat media recorded the highest survival percentage. Amrutha and Patel (2025) <sup>[3]</sup> also noted that exogenous application of 1500 ppm IBA with growth media combination of soil + sand + cocopeat to dragon fruit stem cuttings resulted highest survival percentage. Similarly Tanwar *et al.* (2020) <sup>[62]</sup> reported that treatment combination comprising IBA 2000 ppm + cocopeat + perlite + vermiculite recorded highest survival percentage in pomegranate cultivar 'Bhagwa'.

### 4. Conclusion

Based on the findings of the present investigation, it can be concluded that plant growth regulator IBA 3000 ppm + garden soil + sand + vermicompost + cocopeat (1:1:1:1) was found superior in maximizing rooting, growth and survival percentage of stem cuttings of sour lime (*Citrus aurantifolia* Swingle.) in the month of february. This treatment combination gave the significant response in respect to all the shooting and root growth parameters. Moreover, the above mentioned treatment combination also provides true to type and elite planting material of sour lime to the fruit growers of the region. This treatment promoted the faster multiplication and early production of nursery plants of sour lime.

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