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Efficacy of Plant Growth Regulator and Soil Media on Rooting, Growth and Survival of Stem Cuttings of Punjab Baramasi Lemon [*Citrus limon* (L.) Burm] in Sub-mountainous Zone of Punjab, India

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***Abstract*:** Lemon [*Citrus limon* (L.) burm] is one of the most popular fruit of the citrus group in India and around the world as well. Mostly, lemons are propagated through air layering and cutting methods of vegetative propagation. But the study on the effect of plant growth regulators and soil media on stem cuttings of Punjab Baramasi lemon, in particular, are scarce, especially under sub-mountainous agro-climatic conditions. Therefore, the present study was planned to find the efficacy of plant growth regulator and soil media on rooting, growth and survival of stem cuttings of Punjab Baramasi lemon [*Citrus limon* (L.) Burm] in the sub-mountainous zone of Punjab, India and to develop a protocol for the optimum rooting hormone concentration and growth media for faster multiplication and early production of true-to-type nursery plants to meet the increasing demand of fruit growers/farmers of the region**.** The healthy and disease-free hardwood stem cuttings were obtained from one-year-old shoots of 5-6-years-old mother plants of Punjab Baramasi lemon in the month of February. The basal portion of the cuttings was dipped for one minute in different doses (500ppm, 1000ppm, 1500ppm and control) of indole-3-butyric acid (IBA) plant growth regulator to induce rootings and planted in different growth media (garden soil, sand, farmyard manure, vermicompost, cocopeat) in polythene bags with different treatment combinations and control (without IBA+ garden soil). Stem cuttings of Punjab Baramasi lemon treated with IBA 1500ppm and planted in garden soil + sand+vermicompost+cocopeat (1:1:1:1) growth media in the month of February were found best for rooting, vegetative growth, and survival percentage in the Gurdaspur sub-mountainous zone of Punjab.

***Keywords*:** Growth media, Hardwood cutting, Indole-3-butyric acid, Punjab Baramasi lemon, Rooting, Survival, Vegetative growth.

1. INTRODUCTION

Lemon [*Citrus limon* (L.) Burm] is the most important citrus fruit of India and around the world as well, belongs to the family Rutaceae, sub-family Aurantioideae having chromosome number 2n=18 and is native to East Asia (Salaria, 2004). 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 (PAU, 2024). Its propagation through seeds cause problem of non-uniformity of progeny and high chance of viral disease contamination (Babu, 2001). So, it is not advisable to use seeds for commercial planting because these seeds do not produce true fruits. 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). To obtain ideal, true-to-type and good quality planting material through vegetative propagation, cutting is the cheapest, rapid and simplest method of multiplication to meet the demand of fruit growers. Such plants lead to uniform growth and a plant canopy which comes into bearing earlier than the seedling plants. The success of cuttings depend upon the many factors, associated with plants i.e. age of the mother plant, parts used of tree, time of planting, rainfall, humidity, temperature, rooting media and after care (Frey et al., 2006). 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 cuttings (Hartmann et al., 2002; Sharma et al., 2013; Verma, 2013). Similarly, rooting media also plays an important role in better root formation and development. The nature of roots arising from the cuttings is also influenced by the type of rooting medium, e.g., cuttings when planted in pure sand produce long, unbranched, coarse and brittle roots, but those

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planted in a mixture of sand, soil and peat produce well-developed branches (Chattopadhyay, 1994). Different growing media that are well aerated, loose, porous, create optimum conditions for respiration and maintain temperature, well-drained and with good water retention are used in establishing crop plantlets (Rymbai and Reddy, 2010; Bhosale et al., 2014). 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). Similarly, Kumar and Kumar (2022) reported that 800ppm IBA + garden soil + sand + vermicompost (1:1:1) gave significant results on rooting of stem cuttings and survival percentage of lemon cultivar Pant Lemon-1. 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 regulators and soil media on stem cuttings in citrus, especially in Punjab Baramasi lemon, in particular, are scarce, particularly under sub-mountainous agroclimatic conditions. Therefore, keeping in view the above points, the present study was undertaken to determine the optimum concentration of rooting hormone (IBA) and suitable growth/soil media for faster rooting and survival of Punjab Baramasi lemon cuttings in the sub-mountainous zone of Punjab.

2. MATERIALS AND METHODS

2.1. Experimental Site

The present investigation on "Efficacy of plant growth regulator and soil media on rooting, growth and survival of stem cuttings of Punjab Baramasi lemon [*Citrus limon* (L.) Burm] in sub-mountainous zone of Punjab, India" was conducted during the years 2022-23 and 2023-24 at Punjab Agricultural University, Regional Research Station, Gurdaspur in sub-mountainous 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. The submountain zone of Punjab (Kandi region) features hilly topography with Shiwalik foothills, undulating terrains, and deep, coarse- textured sandy loam to silt loam coarse-textured soils.

2.2. Planting Material

Punjab Baramasi lemon (5-6 years old plants) plants grown in the orchard of Punjab Agricultural University, Regional Research Station, Gurdaspur, were selected for this experiment on the basis of their uniformity in appearance, growth habit, and being free from visual symptoms of pests and disease occurrence.

2.3. Experimental Design

The experiment was performed in a two-way analysis of variance in Completely Randomised Block Design (CRBD) with three replications.

2.4. Preparation of Stem Cuttings and Growth Media

Healthy and mature shoots, preferably one year old, having a thickness of about 1.0 cm, were selected in the month of February before sprouting from the central and basal part of the branch of the Baramasi lemon plant, and cuttings were made of about 15-20 cm in length, possessing 6-8 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 was also given at the lower end to provide a large surface area to encourage rooting in cuttings**.** The basal parts (2-3cm) of all the cuttings were dipped in different concentrations of IBA 500ppm (dissolve 500mg IBA in one litre of water), 1000ppm (dissolve 1000mg IBA in one litre of water), and 1500 ppm (dissolve 1500mg IBA in one litre of water) for one minute dip along with control (Hartmann et al., 2002) . After this, these treated and un-treated cutting were planted in different growth/soil media with a total of sixteen treatment combinations as follows:

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 chlorpyriphos 20EC 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 2/3rd portion of the cuttings were buried in the rooting medium, leaving 1/3rd portion exposed to the environment.

2.5. Observations Recorded

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(cm), leaf breadth(cm), 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 (%) were recorded after planting of cutting.

Treatment number	Treatment detail
T_1	500ppm IBA + garden soil + sand (1:1)
T_2	500ppm IBA + garden soil + sand + FYM (1:1:1)
T_3	500ppm IBA +garden soil + sand + vermicompost (1:1:1)
T_4	500ppm IBA + garden soil + sand+ FYM+cocopeat (1:1:1:1)
T_5	500ppm IBA + garden soil + sand+ vermicompost +cocopeat (1:1:1:1)
T_6	1000ppm IBA + garden soil + sand (1:1)
T_7	1000ppm IBA + garden soil + sand + FYM (1:1:1)
T_8	1000ppm IBA +garden soil + sand + vermicompost (1:1:1)
T_9	1000ppm IBA + garden soil + sand + FYM+cocopeat((1:1:1:1)
T_{10}	1000ppm IBA + garden soil + sand +vermicompost +cocopeat (1:1:1:1)
T_{11}	1500ppm IBA + garden soil + sand (1:1)
T_{12}	1500ppm IBA + garden soil + sand + FYM (1:1:1)
T_{13}	1500ppm IBA +garden soil + sand + vermicompost (1:1:1)
T_{14}	1500ppm IBA + garden soil + sand +FYM+cocopeat (1:1:1:1)
T_{15}	1500ppm IBA + garden soil + sand+ vermicompost +cocopeat (1:1:1:1)
T_{16}	Control (without IBA+garden soil)

2.6. Statistical Analysis

The recorded data were statistically analysed by using two-way analysis of variance (ANOVA) with a Completely Randomised Design (CRBD) as suggested by Gomez and Gomez (2010). Experimental data were statistically analysed using SPSS-30 software.

3. RESULTS AND DISCUSSION

3.1. Number of Days Taken for Sprouting

Punjab Baramasi lemon cuttings treated with IBA 1500 ppm and planted in garden soil+sand+vermicompost :cocopeat (1:1:1:1) medium recorded the minimum days for sprouting (5.02 days) (Table1). The longest days for sprouting (28.50 days) were observed in control treatment. Rajangam et al. (2022) also reported that acid lime cutting treated with IBA 2000 ppm recorded early sprouting as compared to untreated ones. It might be due to wood maturity of cutting which probably reserves high starch and sugar (Singh et al., 2013). Lalhruaitluanga et al. (2022) also reported the minimum number of days taken to sprout in Assam lemon stem cuttings under IBA 800ppm+soil + sand + vermicompost+ cocopeat (1:1:1:1) treatment. This might be due to presence of endogenous auxins in cuttings might have brought early breakage of bud dormancy and results in early bud sprouting (Iqbal et al., 1999). Chandramouli (2001) observed that the increase in the concentration of IBA significantly decreased the number of days to first sprouting of cuttings and earliness in sprouting might be due to better utilization of stored carbohydrates, nitrogen and other factors with the help of growth regulators. The earliest number of days taken to first bud sprouting may be caused by the downward transfer of carbohydrates and auxin build-up inside of cuttings for the completion of physiological processes. Similar findings were also reported by Patel et al. (2018), Malakar et al. (2019), Kumar and Singh (2020) and Patel et al. (2021). Kumar et al. (2015) also reported minimum days were taken to sprouting in lemon cultivar Pant Lemon-1 cuttings treated with 800ppm IBA and planted in garden soil + sand + vermicompost (1:1:1). Likewise, Saini et al. (2022) noted that pomegranate cultivar Bhagwa stem cuttings treated with IBA 2000 ppm and planted in the combination of cocopeat, perlite and vermicompost growth media in ratio of 4:1:1 resulted in minimum number of days taken for sprouting. Amrutha and Patel (2025) also noted that exogenous application of IBA1500 ppm to dragon fruit stem cuttings with a media combination of soil + sand + cocopeat significantly reduced the minimum days for initiation of sprouts. Likewise, Mehra et al. (2019) also noted that persimmon cultivar Fuyu cuttings treated with IBA 6000ppm and planted in soil+FYM(1:2) rooting media taken minimum number of days to sprouting with maximum number of sprouts.

3.2. Number of Sprouts per Cutting and Percent Sprouting

Punjab Baramasi lemon cuttings treated with IBA 1500ppm and planted in garden soil+sand+vermicompost: cocopeat(1:1:1:1) medium recorded maximum number of sprouts per cutting (30.52) & sprouting percentage (95.56), and the control treatment was recorded minimum sprouts(10.10) & sprouting percentage (30.54) per cutting (Table 1). Moisture holding capacity of cocopeat might have improved the sprouting of shoots and might be due to better aeration, nutrient availability, enzymatic activity and moisture retention capacity of substrate. This might be attributed to auxin-stimulated cell division at sprout union initiation (Seiar, 2017). Hydrolysis and translocation of carbohydrates and nitrogenous substances result in the accelerated cell growth and division, which might be

Table 1. Effect of plant growth regulator and soil media on shoot growth parameters of Punjab Baramasi lemon [*Citrus limon* (L.) Burm]

Indole-3-butyric acid (IBA)		Soil media combinations				
		Garden soil+ sand (1:1)	Garden soil+ sand+farmyard manure (1:1:1)	Garden soil + sand + vermicompost (1:1:1)	Garden soil+sand+ farmyard manure + cocopeat (1:1:1:1)	Garden soil +sand+ vermicompost+ cocopeat (1:1:1:1)
Days taken to sprout						
500ppm	-	19.65	18.35	17.48	15.56	14.42
1000ppm	-	13.05	12.35	11.26	10.75	9.62
1500ppm	-	9.10	8.50	8.02	7.52	5.02
Control	28.50	-	-	-	-	-
CD (5%)		Plant growth regulator (A): 0.97		Soil media (B): 1.08		(A x B) :0.01
Number of sprouts						
500ppm	-	17.50	18.30	18.74	17.35	17.82
1000ppm	-	18.10	19.21	20.16	21.35	22.12
1500ppm	-	22.75	23.52	24.70	26.25	30.52
Control	10.10	-	-	-	-	-
CD (5%)		Plant growth regulator (A): 0.76		Soil media (B): 0.85		(A x B) :1.70
Sprouting (%)						
500ppm	-	50.32	52.18	53.10	55.52	58.45
1000ppm	-	60.15	62.36	65.28	68.05	71.56
1500ppm	-	75.10	78.65	82.15	85.62	95.56
Control	30.54	-	-	-	-	-
CD (5%)		Plant growth regulator (A): 1.46		Soil media (B): 1.63		(A x B) :3.25
Plant height(cm)						
500ppm	-	50.52	52.45	53.30	54.52	55.12
1000ppm	-	56.06	58.10	58.85	59.12	59.56
1500ppm	-	60.36	62.28	63.65	65.42	70.72
Control	45.52	-	-	-	-	-
CD (5%)		Plant growth regulator (A): 1.44		Soil media (B): 1.61		(A x B) :3.22
Number of shoots						
500ppm	-	6.32	7.85	8.42	8.91	9.54
1000ppm	-	10.10	10.52	11.16	11.41	11.66
1500ppm	-	12.28	12.65	13.16	13.72	16.85
Control	3.50	-	-	-	-	-
CD (5%)		Plant growth regulator (A): 0.75		Soil media (B): 0.34		(A x B) :1.67
Shoot length(cm)						
500ppm	-	19.50	20.21	20.60	21.10	21.56
1000ppm	-	22.22	22.75	23.35	25.36	26.15
1500ppm	-	27.02	27.65	29.06	31.10	36.52
Control	15.02	-	-	-	-	-
CD (5%)		Plant growth regulator (A): 1.17		Soil media (B): 1.31		(A x B) :2.62
Shoot diameter (mm)						
500ppm	-	4.12	4.51	4.86	5.24	5.61
1000ppm	-	6.02	6.30	6.65	7.21	7.40
1500ppm	-	7.82	8.35	8.60	10.25	14.05
Control	2.50	-	-	-	-	-
CD (5%)		Plant growth regulator (A): 0.63		Soil media (B): 0.71		(A x B) :1.42

triggered by the use of auxins. It also tends to promote the histological features like formation of callus and tissues and then further differentiation of vascular tissues (Singh, 2017). Similarly, Rajangam et al. (2022) observed highest number of sprouts in acid lime stem cuttings cultivar PKM1 treated with IBA 2000 ppm and the lowest number of sprouts was found in control. It might be due to a high accumulation of callus formation in cuttings with an optimum dose of auxin, resulting in the highest percentage of sprouted cuttings and leading to an increased percentage of branches per shoot. It is a fact that IBA directly affects the number of root and root growth and indirectly affects shoot length, which may result in a high number of branches per shoot (Stefancic et al., 2005). The more number of sprout formation with the growth regulator might be due to the vigorous root system which increased nutrient uptake under the combined influence of IBA application. Similarly, highest number of sprouts were reported in IBA 500 ppm treated cuttings of acid lime cultivar Kagzi (Malakar et al.,2019). Kumar et al. (2015) also reported maximum percentage of sprouting in Pant Lemon-1 cuttings with 800ppm IBA + garden soil + sand + vermicompost (1:1:1) treatment. Similarly, shoot parameters like number of sprouts and sprouted percentage were significantly highest in IBA 2000ppm 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). Amrutha and Patel (2025) also noted that exogenous application of IBA 1500 ppm to dragon fruit stem cuttings with a media combination of soil + sand + cocopeat significantly increased sprout length and number of sprouts per cutting.

3.3. Plant Height

From Table 1, it has been noted that the maximum plant height (70.72cm) was recorded in Punjab Baramasi lemon cuttings treated with 1500ppm IBA and planted in soil+sand+vermicompost:cocopeat (1:1:1:1) medium and the minimum plant height(45.52cm) was noted in the control treatment. Optimum dose of IBA on plant height might be attributed to the fact that cuttings treated with this concentration had an improved root system, thus absorbed more nutrients, which helped in better stem growth and plant height. A similar explanation had been suggested by Chauhan and Maheshwari (1970). Likewise, plant height was highest in IBA 2000ppm treated stem cuttings of pomegranate cultivar Bhagwa planted in cocopeat, perlite and vermicompost (4:1:1) as noted by Saini et al. (2022). Similarly, Rajangam et al. (2022) observed that in acid lime cultivar PKM1 stem cuttings, the highest plant height was recorded in the IBA 2000 ppm treatment and the lowest plant height was noticed in the control. Singh and Rattanpal (2017) also reported that IBA is the active inhibitor of axillary bud break on developing shoots, and it stimulates shoot initiation. Indole-3-butyric acid treatment enhanced rooting, plant growth and produced taller and healthy plants (Umrao, 1999). Lalhruaitluanga et al. (2022) also reported maximum plant height of assam lemon stem cuttings in IBA 800ppm + soil + sand+ vermicompost + cocopeat (1:1:1:1) treatment. Similar results of effect of IBA and growing media in lemon stem cuttings were also observed by Patel et al. (2018).

3.4. Number of Shoots

It has been observed that Punjab Baramasi lemon stem cutting treated with 1500ppm IBA and planted in soil+sand+vermicompost:cocopeat (1:1:1:1) medium produced maximum(16.85) number of shoots per plant, and the minimum (3.50) number of shoots per plant was recorded in the control treatment (Table 1). Similarly, Lalramhluna and Prasad (2016) reported the maximum number of branches in air-layered IBA 2000 ppm-treated assam lemon and the minimum number of branches in the control treatment. Likewise, Lalhruaitluanga et al. (2022) noted maximum number of branches in IBA 800ppm treated assam lemon cuttings planted in soil + sand + vermicompost+ cocopeat (1:1:1:1). The maximum number of branches due to higher number of roots, if there will be more number of food materials and other necessary minerals will be higher, in this way plant will take higher growth which results more number of branches. These findings are in accordance with the results reported in IBA treatment in air-layered guava by Maurya et al. (2022). An increase in the number of shoots per plant might be due to the activation of auxin in vegetative parts by using auxin. Similar results were reported earlier in IBA-treated Kagzi lime by Kumar and Singh (2020). Kumar et al. (2015) also reported that stem cutting of lemon treated with 1800ppm IBA and planted in garden soil + sand + vermicompost (1:1:1) produced maximum number of shoots per cutting, while minimum number of shoots were recorded per cutting was recorded under control treatment. Likewise, ficus cuttings treated with 2000 mg/litre IBA and planted in growing media of sand + cocopeat + vermicompost (1:1:1) recorded a significantly maximum number of shoots (Zala and Masu, 2025).

3.5. Shoot Length and Shoot Diameter

From Table 1, Punjab Baramasi lemon stem cuttings treated with 1500ppm IBA and planted in soil+sand

+vermicompost:cocopeat (1:1:1:1) medium produced the longest shoot length (36.52cm) with highest shoot diameter (14.05mm) and the control treatment cuttings retained the shortest shoot length(15.02cm) with the lowest shoot diameter(2.50mm). Rajangam et al. (2022) also reported that IBA 2000ppm treated acid lime stem cuttings cultivar PKM1 showed the highest shoot length, while the minimum shoot length was recorded in the control . Similarly, maximum shoot length was reported in IBA 800ppm treated cuttings of assam lemon and planted in soil + sand + vermicompost + cocopeat (1:1:1:1) growing media (Lalhruaitluanga et al., 2022). Likewise, Lalramhluna and Prasad (2016) observed the maximum length of branches in the IBA 2000ppm treated air-layered assam lemon, which was statistically superior to the control. As a growth promoter IBA promotes cell division, which results in early rooting leading towards efficient absorption of mineral nutrients and hence maximizes shoot length. This might be due to increased concentrations and activity of IBA, which causes hydrolysis and translocation of carbohydrates and nitrogenous substances at the cellular level at the base of cuttings, resulting in accelerated cell elongation and cell division, causing extension in shoot length under favourable environmental conditions (Singh and Singh, 2011). Mehra et al. (2019) also reported that persimmon cultivar Fuyu cuttings treated with IBA 6000ppm and planted in soil+FYM (1:2) rooting media resulted in the highest length and diameter of sprouts. Likewise, ficus cuttings treated with IBA 2000 mg/litre and planted in growing media of sand + cocopeat + vermicompost (1:1:1) recorded a significantly maximum length of the longest shoot (Zala and Masu, 2025). It has been noted that different treatments of growth regulator and soil media significantly affect the shoot diameter (Table1). Punjab Baramasi lemon cuttings treated with IBA 1500 ppm and planted in soil+sand+ vermicompost:cocopeat (1:1:1:1) growth media had the highest shoot diameter(14.05mm), and control treatment cuttings had the lowest shoot diameter(2.50mm). 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 (Siddiqui and Hussain, 2007 ; Kasim et al., 2009). This finding is also accordance with Maniriho et al. (2021) that reported thicker stems in peach by hard wood cuttings treated with IBA. Similarly, Kumar et al. (2024) reported that maximum shoot diameter in fig cuttings treated with IBA 2000ppm. 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). The girth of the plants was also much bigger in the stem cuttings of peach treated with IBA 2400 ppm (Pathlan et al., 2022). Similar results were also recorded in IBA treated fig cuttings by Singh and Rattanpal (2017). Similarly, shoot diameter was highest in IBA 2000ppm 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).

3.6. Number of Leaves, Leaf Length and Leaf Breadth

The maximum number of leaves (143.65) was observed in Punjab Baramasi lemon cuttings treated with IBA 1500ppm grown in soil+sand+vermicompost:cocopeat (1:1:1:1) media as compared to the rest of the treatments (Table 2). Similarly, the maximum number of leaves per cutting was observed in the IBA 1000 ppm treatment in the pomegranate cultivar Bhagwa, as reported by Satnam et al. (2022). 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). Similarly, stem cuttings treated with IBA produced more number of leaves in lemon (Maurya et al., 2022) and pomegranate (Kaushik et al., 2020). Similarly, the maximum number of leaves 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). Number of leaves was also highest in IBA 2000ppm 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). Mehra et al. (2019) also noted that persimmon cultivar fuyu cuttings treated with IBA 6000ppm and planted in soil+FYM(1:2) growth media resulted highest number of leaves. Likewise, ficus cuttings treated with IBA 2000 mg/litre and planted in growing media of sand + cocopeat + vermicompost (1:1:1) recorded a significantly maximum number of leaves (Zala and Masu, 2025). It has been noted that leaf length and breadth of Punjab Baramasi lemon were varied significantly among different IBA and soil media treatments (Table2). Maximum mean leaf length and

Table 2. Effect of plant growth regulator and soil media on leaf and root growth parameters of Punjab Baramasi lemon [*Citrus limon* (L.) Burm]

Indole-3-butyric acid (IBA)		Soil media combinations				
		Garden soil+ sand (1:1)	Garden soil+ sand+farmyard manure (1:1:1)	Garden soil + sand + vermicompost (1:1:1)	Garden soil+sand+ farmyard manure + cocopeat (1:1:1:1)	Garden soil +sand+ vermicompost+ cocopeat (1:1:1:1)
Number of leaves						
500ppm	-	80.48	83.11	85.08	88.28	90.42
1000ppm	-	92.18	95.21	101.62	105.16	110.11
1500ppm	-	117.28	123.05	128.32	133.12	143.65
Control	65.10	-	-	-	-	-
CD (5%)		Plant growth regulator (A): 1.49		Soil media (B): 1.67	(A x B) : 3.33	
Leaf length (cm)						
500ppm	-	9.05	9.30	9.48	9.71	10.05
1000ppm	-	10.60	11.05	11.31	11.50	11.76
1500ppm	-	12.15	12.40	12.72	13.25	16.56
Control	7.02	-	-	-	-	-
CD (5%)		Plant growth regulator (A): 0.70		Soil media (B): 0.78	(A x B) : 1.55	
Leaf breadth (cm)						
500ppm	-	5.50	5.72	6.05	6.41	6.65
1000ppm	-	6.81	6.96	7.35	7.48	7.61
1500ppm	-	7.83	8.05	8.36	8.51	10.46
Control	4.50	-	-	-	-	-
CD (5%)		Plant growth regulator (A): 0.78		Soil media (B): 0.01	(A x B) :0.01	
Rooting (%)						
500ppm	-	51.18	53.10	56.13	58.45	60.25
1000ppm	-	63.38	65.05	67.51	70.22	74.52
1500ppm	-	77.76	82.65	86.06	90.52	96.10
Control	35.25	-	-	-	-	-
CD (5%)		Plant growth regulator (A): 1.76		Soil media (B): 1.97	(A x B) : 3.94	
Number of primary roots						
500ppm	-	20.36	22.22	23.62	25.58	26.08
1000ppm	-	28.62	30.38	32.35	35.20	38.45
1500ppm	-	40.56	43.10	45.18	47.51	55.16
Control	13.52	-	-	-	-	-
CD (5%)		Plant growth regulator (A): 1.75		Soil media (B): 1.95	(A x B) :3.91	
Longest root length (cm)						
500ppm	-	18.36	19.10	19.50	20.08	20.74
1000ppm	-	21.28	23.45	24.23	26.68	27.05
1500ppm	-	29.10	31.65	33.42	34.65	40.56
Control	13.02	-	-	-	-	-
CD (5%)		Plant growth regulator (A): 1.15		Soil media (B): 1.29	(A x B) :2.58	
Thick root diameter (mm)						
500ppm	-	0.65	0.82	1.05	1.42	1.73
1000ppm	-	1.95	2.16	2.41	2.70	3.02
1500ppm	-	3.32	3.55	3.86	4.05	6.15
Control	0.30	-	-	-	-	-
CD (5%)		Plant growth regulator (A): 0.20		Soil media (B): 0.22	(A x B) :0.45	

breadth (16.56cm & 10.46cm respectively) were recorded in treatment IBA 1500 ppm+ soil+sand+vermicompost: cocopeat (1:1:1:1) and lowest leaf length and breadth (7.02cm & 4.50cm respectively) were obsrved in control. Similarly, Singh and Rattanpal (2017) noted maximum leaf length and breadth in fig cuttings treated with IBA 1250 ppm as compared to control. Likewise, Ausari et al. (2023) reported maximum leaf area in grape cultivar Pusa Navrang cuttings treated with IBA 6000 ppm .Likewise , highest leaf length and leaf breadth were reported in IBA 3000 ppm treated Flordaguard peach cuttings (Kaur, 2017). This may be due to IBA, which produced healthier, longer roots and hence absorbed more nutrients and water content, which has a great influence on leaf growth. Treatment of IBA 1000 ppm to grape cuttings had a maximum mean leaf area; however, a minimum mean leaf area was noticed in the control(Ghangale et al., 2021).The relative humidity and optimum light intensity, which are the important factors in the development of leaves, coupled with auxin content, activated the synthesis of more carbohydrates in the leaves, which might have resulted in the elongation of leaves through cell division and cell elongation, resulting in more leaf area per cutting when compared to all other treatments. Similar results were reported by Shao et al. (2018) in Chinese jujube and by Abhinav et al. (2016) in grapes. Mehra et al. (2019) also noted that persimmon cultivar fuyu cuttings treated with IBA 6000ppm and planted in soil+FYM (1:2) rooting media resulted highest leaf area.

3.7. Dry and Fresh Weight of Shoot

Maximum shoot fresh weight (33.10gm) and dry weight (21.65gm) were reported in the Punjab Baramasi lemon cuttings treated with IBA 1500 ppm and planted in soil+sand+vermicompost:cocopeat (1:1:1:1) growth media as compared to other treatments(Table 2). Samim et al. (2018) observed that IBA 5000 ppm treated stem cuttings of barbados cherry showed maximum fresh and dry weight of shoot. Indole-3-butyric acid treatment might have increased the number of shoots, resulting in increased accumulation of fresh and dry weight in shoots. Likewise, shoot fresh weight and shoot dry weight were highest in IBA 2000ppm 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). Ficus cuttings treated with IBA 2000 mg/litre and planted in growing media of sand + cocopeat + vermicompost (1:1:1) recorded the highest fresh and dry weight of shoot (Zala and Masu, 2025).

3.8. Rooting Percentage, Number of Primary Roots, Longest Root Length, Thick Root Diameter, Fresh Root Weight, Dry Root Weight and Root Spread

From Table 2 and 3, it was observed that maximum rooting (96.10%), number of primary roots (55.16), longest root length (40.56cm), thick root diameter (6.15mm), fresh root weight (16.45gm), dry root weight (11.56gm) and root spread(32.65cm) were noted in Punjab Baramasi lemon cuttings treated with IBA 1500 ppm and planted in soil+sand+vermicompost:cocopeat (1:1:1:1) growth media as compared to rest of treatments. Similarly, Kaur and Singh (2022) observed that per cent rooting, number of roots per cutting, root length, fresh weight of roots and dry weight of roots were significantly highest in pomegranate cultivar Bhagwa cuttings treated with 1000 ppm IBA. The improved rooting in cuttings treated with auxin might be due to enhanced hydrolytic activity, which favours the formation of high carbohydrate levels and low nitrogen levels, leading to increased root formation (Narula, 2018). The production of a good amount of roots in auxin-treated cuttings pertains to the fact that the auxins promoted cell division and their elongation which led to differentiation of cambial initials into root primordia and in the mobilization of reserve food material to sites of root initiation, thereby giving a higher number of roots per cutting (Sharma, 1999). Auxins might have helped in amplifying rooting and boosting the length of roots, as the root elongation stage is very responsive to auxin concentrations (Hartmann et al., 2002). The availability of carbohydrates is often considered solely as an energy source and a carbon skeleton for driving root development (Correa et al., 2005).The increase in root weight might be due to the reserved food materials in the cuttings; the translocation of reserved carbohydrates may have also helped in better root growth and weight. Maximum root formation zone and rooting percentage, which might have been due to increased cell division and their differentiation under the influence of rooting chemicals, enhanced hydrolysis of nutritional reserves resulting into increased root formation zone (Singh, 2014). Likewise, Lalhruaitluanga et al. (2022) reported that IBA 800ppm treated cuttings of assam lemon and planted in soil + sand + vermicompost + cocopeat (1:1:1:1) growing media showed maximum values of length of tap root, root spread, fresh and dry weight of root. Samim et al. (2018) also reported that IBA 5000 ppm treated stem cuttings of barbados cherry showed maximum values of percentage of rooting, number of root, average root length, length of longest root , number

Table 3. Effect of plant growth regulator and soil media on root and shoot growth parameters of Punjab Baramasi lemon [*Citrus limon* (L.) Burm]

Indole-3-butyric acid (IBA)		**Soil media combinations**				
		Garden soil+ sand (1:1)	**Garden soil+ sand+farmyard manure (1:1:1)**	**Garden soil + sand + vermicompost (1:1:1)**	**Garden soil+sand+ farmyard manure + cocopeat (1:1:1:1)**	**Garden soil +sand+ vermicompost+ cocopeat (1:1:1:1)**
				Root spread (cm)		
500ppm	-	20.38	20.73	21.14	21.38	21.72
1000ppm	-	22.10	22.31	23.42	24.10	24.62
1500ppm	-	25.15	25.52	25.86	27.22	32.65
Control	15.20	-	-	-	-	-
CD (5%)		Plant growth regulator (A): 0.93		Soil media (B): 1.03		(A x B) :2.07
				Fresh weight of roots (gm)		
500ppm	-	8.18	9.10	9.32	9.65	10.12
1000ppm	-	10.56	11.02	11.25	11.76	12.25
1500ppm	-	12.76	13.10	13.34	13.70	16.45
Control	5.53	-	-	-	-	-
CD (5%)		Plant growth regulator (A):0.79		Soil media (B): 0.89		(A x B) :0.01
				Dry weight of roots (gm)		
500ppm	-	3.50	3.76	4.05	4.30	4.60
1000ppm	-	5.10	5.55	5.82	6.12	6.34
1500ppm	-	6.60	6.86	7.60	8.71	11.56
Control	1.50	-	-	-	-	-
CD (5%)		Plant growth regulator (A): 0.60		Soil media (B): 0.70		(A x B) :1.40
				Fresh weight of shoot(gm)		
500ppm	-	19.10	19.64	20.35	21.45	22.11
1000ppm	-	22.65	23.08	23.40	23.85	24.46
1500ppm	-	24.95	25.61	27.12	29.05	33.10
Control	14.21	-	-	-	-	-
CD (5%)		Plant growth regulator (A): 0.81		Soil media (B): 0.91		(A x B) :1.82
				Dry weight of shoot (gm)		
500ppm	-	11.12	12.18	12.45	13.76	14.28
1000ppm	-	14.60	15.06	15.36	15.68	16.04
1500ppm	-	16.46	16.72	17.26	18.71	21.65
Control	7.10	-	-	-	-	-
CD (5%)		Plant growth regulator (A): 0.68		Soil media (B): 0.76		(A x B) :1.52
				Survival (%)		
500ppm	-	40.12	43.14	45.65	47.56	50.22
1000ppm	-	52.10	55.62	60.46	63.05	67.15
1500ppm	-	71.05	75.12	80.18	86.30	97.25
Control	25.10	-	-	-	-	-
CD (5%)		Plant growth regulator (A): 1.67		Soil media (B): 1.87		(A x B) :3.74

of primary and secondary roots , fresh and dry weight of root and root volume. Kumar and Kumar (2022) also reported that the significantly maximum length and diameter of primary root were recorded with the treatment of 800 ppm IBA + garden soil + sand + vermicompost (1:1:1) in stem cutting of lemon cultivar Pant Lemon-1. Likewise, Amrutha and Patel (2025) also noted that exogenous application of IBA1500 ppm to dragon fruit stem cuttings with media combination of soil + sand + cocopeat significantly increased the length of roots and rooting percentage. Mehra et al. (2019) also noted that persimmon cultivar Fuyu cuttings treated with IBA 6000 ppm and planted in soil +FYM(1:2) rooting media resulted in maximum values of number of rooted cuttings, root length and survival of cuttings. Likewise, ficus cuttings treated with IBA 2000 mg/litre and planted in growing media of sand + cocopeat + vermicompost (1:1:1) was recorded significantly maximum length of longest root as well as fresh and dry weight of root(Zala and Masu, 2025).

3.9. 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. The highest survival percentage (97.25) of cuttings of Punjab Baramasi lemon was found in the cuttings treated with 1500 ppm IBA and planted in garden soil+sand+vermicompost+cocopeat(1:1:1:1) growth medium, while the minimum survival percentage (25.10) of cuttings was observed in the cuttings planted under 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 the IBA 800 ppm + soil + sand + vermicompost + cocopeat (1:1:1:1) treatment, as reported by Lalhruaitluanga et al. (2022). In addition to that, when using growth regulators, boosting the rooting can be attributed to the favourable environmental conditions 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). Auxin may have induced favourable environment for root and shoot development and enhanced survival (Constanzi et al., 1988). Similarly, the survival percentage was highest in IBA 2000 ppm-treated stem cuttings of the Pomegranate cultivar Bhagwa planted in cocopeat, perlite and vermicompost (4:1:1) growth media, as reported by Saini et al. (2022). This could be due to the availability of good amount of nutrients in vermicompost growth media. Amrutha and Patel (2025) also noted that exogenous application of IBA1500 ppm to dragon fruit stem cuttings and planted in media combination of soil + sand + cocopeat significantly increased the survival percentage.

4. CONCLUSION

The treatment combination of 1500 ppm IBA + garden soil + sand + vermicompost + cocopeat (1:1:1:1) for stem cuttings of Punjab Baramasi lemon the month of February was found to be best for rooting, growth, and survival percentage in the Gurdaspur sub-mountainous zone of Punjab. This treatment combination gave the significant response with respect to all the shoot and root growth parameters. Moreover, the above mentioned treatment combination promoted faster multiplication and early production of nursery plants and also provides true-to-type and elite planting material of Punjab Baramasi lemon to the fruit growers of the sub-mountainous regions of Punjab.

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Author's Contributions

Sukhjit Kaur: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation Visualization, Writing – original draft, Writing - review and editing

Conflict of Interest

The authors declare that they have no conflict of interest.

Declaration of Generative AI and AI-assisted technologies

Authors declare that they have not used any generative AI and AI-assisted technologies in the writing process, figures/ images and artwork.

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