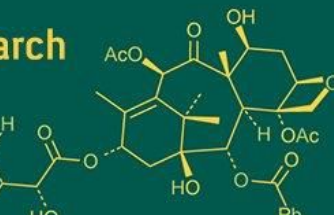
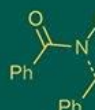
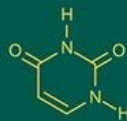
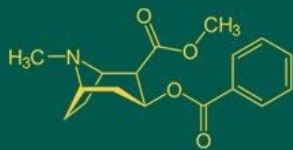


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## Effect of plant growth regulators on the shoot growth of black pepper (*Piper nigrum* L.) stem cuttings under shade net conditions

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### Abstract

The present investigation was undertaken to “Effect of Plant Growth Regulators on the Shoot Growth of Black Pepper (*Piper nigrum* L.) Stem Cuttings under Shade Net Conditions”, with effective treatment for producing high-quality planting material. The experiment was conducted during 2024-25 under a 50% shade-net structure using the black pepper variety ‘Panniyur-1’. The study was laid out in a Completely Randomized Design (CRD) comprising ten treatments, including three concentrations each of indole-3-acetic acid (IAA), naphthalene acetic acid (NAA), and indole-3-butyric acid (IBA), along with an untreated control, and replicated thrice. Observations on shoot growth parameters such as number of shoots per cutting, length of new shoot, number of leaves per shoot, leaf length, number of nodes per shoot, internodal length, and girth of new shoots were recorded at 30, 60, and 90 days after planting (DAS). The results revealed that application of plant growth regulators significantly influenced all shoot growth parameters compared to the control. Among the treatments, IBA at 1000 ppm consistently recorded superior performance by producing the maximum number of shoots per cutting, greater shoot length, higher leaf number, increased leaf size, more nodal formation, longer internodes, and thicker shoot girth at all stages of observation. This was followed by NAA at 1000 ppm and IAA at 1000 ppm, while the untreated control recorded the lowest values for most parameters. The enhanced shoot growth under auxin treatments may be attributed to improved root establishment, enhanced cell division and elongation, and efficient nutrient and water uptake under favorable shade-net microclimatic conditions. Overall, the study concludes that treatment of black pepper stem cuttings with IBA at 1000 ppm under shade net conditions is most effective for promoting vigorous shoot growth and producing quality planting material for sustainable black pepper cultivation.

**Keywords:** Black pepper, *Piper nigrum*, Plant growth regulators, IBA, NAA, IAA, Shoot growth, Shade net, Stem cuttings.

### 1. Introduction

Black pepper (*Piper nigrum* L.), a perennial climbing vine belonging to the family Piperaceae, is one of the most important spice crops cultivated in tropical regions of the world. India is recognized as the center of origin of black pepper, and the crop plays a crucial role in the national economy through domestic consumption and export earnings. Owing to its pungency, flavor, and medicinal properties attributed mainly to the alkaloid piperine, black pepper is widely used in food, pharmaceutical, and nutraceutical industries (Ahmad *et al.*, 2012 <sup>[2]</sup> and Ravindran, 2010) <sup>[18]</sup>. The increasing global demand for black pepper necessitates the production of large quantities of quality planting material for sustainable cultivation.

Vegetative propagation through stem cuttings is the most preferred method for black pepper multiplication, as seed propagation leads to genetic variability and poor field performance (Parthasarathy *et al.*, 2008; Kandianan *et al.*, 2015) <sup>[10, 14]</sup>. However, successful establishment of stem cuttings is often hindered by delayed sprouting, weak shoot growth, poor leaf development, and low survivability, particularly under nursery conditions. Early and vigorous shoot growth is essential for producing healthy seedlings capable of better root-shoot balance and successful field establishment.

Plant growth regulators (PGRs) play a pivotal role in regulating physiological processes such as cell division, elongation, and differentiation, thereby influencing sprouting and shoot growth in vegetatively propagated crops. Auxins such as indole-3-acetic acid (IAA), naphthalene acetic acid (NAA), and indole-3-butyric acid (IBA) have been widely reported to enhance rooting and also promote shoot elongation, leaf initiation, nodal development, and overall vegetative vigor in black pepper and other spice crops (Hartmann *et al.*, 2011; Akshay *et al.*, 2019) [9]. Among auxins, IBA is considered more stable and effective under nursery conditions, followed by NAA and IAA, depending on concentration and method of application (Davies, 2010 & Alexandre *et al.*, 2017) [5, 6].

Shade net cultivation provides a favorable microclimate by reducing light intensity, moderating temperature, and maintaining higher relative humidity, which closely resembles the natural understorey habitat of black pepper. Such protected conditions minimize moisture stress, reduce transplant shock, and enhance physiological activity in stem cuttings (Prasath *et al.*, 2014; Prajapati *et al.*, 2018) [17, 15]. The combined application of suitable plant growth regulators under shade net conditions has been shown to significantly improve shoot growth parameters such as number of shoots, shoot length, number of leaves, internodal length, and seedling vigor (Mustakim *et al.*, 2022; Prajwal *et al.*, 2024) [13, 16]. Therefore, the present investigation was undertaken to evaluate the effect of different plant growth regulators and their concentrations on the shoot growth of black pepper (*Piper nigrum* L.) stem cuttings under shade net conditions, with the aim of standardizing an efficient propagation protocol for quality seedling production.

## 2. Methodology

The effect of different plant growth regulators on shoot growth of black pepper (*Piper nigrum* L.) stem cuttings was assessed under shade net conditions using a Completely Randomized Design (CRD). Healthy, uniform stem cuttings of variety Panniyur-1 were treated with different concentrations of IAA, NAA, and IBA as per the treatment schedule, along with an untreated control. The treated cuttings were planted in polybags filled with a standardized potting mixture and maintained under a 50% shade-net structure with uniform irrigation and management practices. Observations related to shoot growth were recorded at 30, 60, and 90 days after planting (DAS).

The number of shoots per cutting was determined by counting all newly emerged shoots on each cutting at each observation stage. Shoot length was measured in centimeters using a measuring scale from the base of the shoot to the apical tip. The number of fully expanded leaves per shoot was recorded manually, while leaf length was measured from the base of the leaf blade to the tip. The number of nodes per shoot was counted visually along the main shoot, and internodal length was calculated by measuring the distance between two successive nodes and averaging the values for each treatment. All observations were recorded from randomly selected plants in each replication to ensure uniformity and accuracy.

The girth of new shoots was measured at approximately 2 cm above the base of the shoot using a vernier caliper and expressed in centimeters. Mean values for each parameter were computed treatment-wise and stage-wise. The data collected were subjected to statistical analysis following

standard procedures applicable to CRD, and treatment means were compared using the critical difference (CD) test at the 5% level of significance.

## 3. Result

### 3.1 No. of shoot per cuttings

The data pertaining to no. of shoot per cuttings as influenced of plant growth regulator on rooting, growth and survivability of Black Pepper (*Piper nigrum*) stem cutting under shade net condition has been recorded and presented in Table 1.

Among the treatments at 30 DAS, performance of treatments varied, with T<sub>8</sub> (IBA 1000 ppm) recording the highest no. of shoot per cuttings (1.59), while this was at par with the treatment T<sub>5</sub> (NAA 1000 ppm) and T<sub>2</sub> (IAA 1000 ppm) showed (1.55) and (1.53) respectively. The least performance (1.41) was noted in the treatment T<sub>0</sub> (Control) and at 60 DAS, performance of treatments varied, with T<sub>8</sub> (IBA 1000 ppm) recording the highest no. of shoot per cuttings (2.14), while this was at par with the treatment T<sub>5</sub> (NAA 1000 ppm) and T<sub>2</sub> (IAA 1000 ppm) showed (2.13) and (2.08) respectively. The least performance (1.87) was noted in the treatment T<sub>0</sub> (Control). Among the treatments at 90 DAS, performance of treatments varied, with T<sub>8</sub> (IBA 1000 ppm) recording the highest no. of shoot per cuttings (2.68), while this was at par with the treatment T<sub>5</sub> (NAA 1000 ppm) and T<sub>2</sub> (IAA 1000 ppm) showed (2.59) and (2.57) respectively. The least performance (2.28) was noted in the treatment T<sub>0</sub> (Control). The enhanced shoot proliferation in these treatments may be attributed to the ability of auxins to stimulate cell division and elongation in the nodal region, thereby encouraging multiple shoot initiation. Among the different regulators, IBA proved to be the most effective, followed closely by NAA and IAA, suggesting its superior role in promoting both rooting and shoot development simultaneously. The better root system induced by IBA likely facilitated improved nutrient and water uptake, which in turn supported vigorous shoot growth. These findings align with those of earlier researchers who reported that the application of auxin-based growth regulators enhances shoot multiplication and overall vegetative growth in black pepper and other spice crops propagated through stem cuttings. Similar results were also observed by Santoso *et al.*, (2016).

**Table 1:** No. of shoot per cuttings of Black Pepper (*Piper nigrum*).

| Tr. no         | Treatment Combination | No. of shoot per cuttings |        |        |
|----------------|-----------------------|---------------------------|--------|--------|
|                |                       | 30 DAS                    | 60 DAS | 90 DAS |
| T <sub>0</sub> | Control               | 1.41                      | 1.87   | 2.28   |
| T <sub>1</sub> | IAA 500 ppm           | 1.42                      | 1.93   | 2.36   |
| T <sub>2</sub> | IAA 1000 ppm          | 1.53                      | 2.08   | 2.57   |
| T <sub>3</sub> | IAA 1500 ppm          | 1.48                      | 1.98   | 2.47   |
| T <sub>4</sub> | NAA 500 ppm           | 1.43                      | 1.95   | 2.39   |
| T <sub>5</sub> | NAA 1000 ppm          | 1.55                      | 2.13   | 2.59   |
| T <sub>6</sub> | NAA 1500 ppm          | 1.50                      | 2.00   | 2.49   |
| T <sub>7</sub> | IBA 500 ppm           | 1.51                      | 2.04   | 2.51   |
| T <sub>8</sub> | IBA 1000 ppm          | 1.59                      | 2.14   | 2.68   |
| T <sub>9</sub> | IBA 1500 ppm          | 1.47                      | 1.95   | 2.43   |
| Sem (±)        |                       | 0.02                      | 0.03   | 0.04   |
| CD (5%)        |                       | 0.06                      | 0.08   | 0.12   |

### 3.2 Length of new shoot (cm)

The data pertaining to length of new shoot (cm) as influenced of plant growth regulator on rooting, growth and

survivability of Black Pepper (*Piper nigrum*) stem cutting under shade net condition has been recorded and presented in Table 2

In treatment T<sub>8</sub> (IBA 1000 ppm), the length of new shoot (cm) at (4.64 cm), emerging as the significantly superior value across treatments at 30 DAS. A nearly equivalent length of new shoot (cm) was at par with the treatment T<sub>5</sub> (NAA 1000 ppm) (4.52 cm) and the treatment T<sub>2</sub> (IAA 1000 ppm) (4.44 cm). At the other end, T<sub>0</sub> (Control) exhibited the poorest length of new shoot (cm) (3.56 cm) and treatment T<sub>8</sub> (IBA 1000 ppm), the length of new shoot (cm) at (11.52 cm), emerging as the significantly superior value across treatments at 60 DAS. A nearly equivalent length of new shoot (cm) was at par with the treatment T<sub>5</sub> (NAA 1000 ppm) (11.19 cm) and the treatment T<sub>2</sub> (IAA 1000 ppm) (10.93 cm). At the other end, T<sub>0</sub> (Control) exhibited the poorest length of new shoot (cm) (8.67 cm).

In treatment T<sub>8</sub> (IBA 1000 ppm), the length of new shoot (cm) at (21.18 cm), emerging as the significantly superior value across treatments at 90 DAS. A nearly equivalent length of new shoot (cm) was at par with the treatment T<sub>5</sub> (NAA 1000 ppm) (20.04 cm). At the other end, T<sub>0</sub> (Control) exhibited the poorest length of new shoot (cm) (15.76 cm). The data indicated that the application of plant growth regulators had a significant effect on the length of new shoots in black pepper cuttings under shade-net conditions. Treatments involving auxins such as IBA, NAA, and IAA promoted greater shoot elongation at all stages of observation compared to the untreated control. The superior performance of IBA-treated cuttings suggests that this regulator effectively stimulates cell elongation and apical dominance, leading to increased shoot growth. The enhanced shoot length observed under auxin treatments can be attributed to improved root activity, which facilitates better absorption of water and nutrients, thereby supporting vigorous vegetative growth. The gradual increase in shoot length from 30 to 90 days after planting reflects the sustained physiological response of the cuttings to auxin treatment. These results are consistent with the findings of earlier researchers who reported that IBA and NAA treatments enhance shoot elongation by promoting meristematic activity and hormonal balance in vegetatively propagated spice crops such as black pepper. These outcomes are consistent with findings of Akshay *et al.*, (2018) [4] and Nikita Prajapati *et al.*, (2018) [15].

**Table 2:** Length of new shoot (cm) of Black Pepper (*Piper nigrum*).

| Tr. no  | Treatment Combination | Length of new shoot (cm) |        |        |
|---------|-----------------------|--------------------------|--------|--------|
|         |                       | 30 DAS                   | 60 DAS | 90 DAS |
| T0      | Control               | 3.56                     | 8.67   | 15.76  |
| T1      | IAA 500 ppm           | 3.76                     | 9.21   | 16.30  |
| T2      | IAA 1000 ppm          | 4.44                     | 10.93  | 19.36  |
| T3      | IAA 1500 ppm          | 4.18                     | 9.86   | 17.65  |
| T4      | NAA 500 ppm           | 3.93                     | 9.42   | 16.78  |
| T5      | NAA 1000 ppm          | 4.52                     | 11.19  | 20.04  |
| T6      | NAA 1500 ppm          | 4.24                     | 10.05  | 18.15  |
| T7      | IBA 500 ppm           | 4.34                     | 10.58  | 18.59  |
| T8      | IBA 1000 ppm          | 4.64                     | 11.52  | 21.18  |
| T9      | IBA 1500 ppm          | 3.99                     | 9.60   | 17.13  |
| Sem (±) |                       | 0.10                     | 0.14   | 0.23   |
| CD (5%) |                       | 0.31                     | 0.43   | 0.69   |

### 3.3 No. of leaves per shoot

The data pertaining to no. of leaves per shoot as influenced of plant growth regulator on rooting, growth and survivability of Black Pepper (*Piper nigrum*) stem cutting under shade net condition has been recorded and presented in Table 3

Data analysis revealed that T<sub>8</sub> (IBA 1000 ppm) produced the significantly highest no. of leaves per shoot at 30 DAS (4.33), which was followed by the treatment T<sub>5</sub> (NAA 1000 ppm) (4.19) and the treatment T<sub>2</sub> (IAA 1000 ppm) (4.10). Conversely, T<sub>0</sub> (Control) exhibited the lowest no. of leaves per shoot (3.75).

Data analysis revealed that T<sub>8</sub> (IBA 1000 ppm) produced the significantly highest no. of leaves per shoot at 60 DAS (7.41), which was followed by the treatment T<sub>5</sub> (NAA 1000 ppm) (7.25) and the treatment T<sub>2</sub> (IAA 1000 ppm) (7.16). Conversely, T<sub>0</sub> (Control) exhibited the lowest no. of leaves per shoot (6.67).

Data analysis revealed that T<sub>8</sub> (IBA 1000 ppm) produced the significantly highest no. of leaves per shoot at 90 DAS (10.58), which was at par with the treatment T<sub>5</sub> (NAA 1000 ppm) (10.46) and the treatment T<sub>2</sub> (IAA 1000 ppm) (10.31). Conversely, T<sub>0</sub> (Control) exhibited the lowest no. of leaves per shoot (9.26). The results showed that plant growth regulators had a pronounced effect on the number of leaves per shoot in black pepper cuttings under shade-net conditions. Cuttings treated with auxins, particularly IBA, NAA, and IAA, consistently produced a higher number of leaves at all growth stages compared to the untreated control. The improved leaf production under auxin treatments may be attributed to enhanced root development, which supports greater nutrient and water uptake, leading to vigorous shoot growth and increased leaf initiation. Auxins also promote cell division and expansion in the shoot meristem, resulting in better canopy development. The progressive increase in the number of leaves from 30 to 90 days indicates sustained vegetative growth and efficient physiological activity induced by the treatments. These findings are in agreement with previous studies reporting that auxin application encourages higher leaf formation and overall vegetative vigor in black pepper and other spice crops propagated through stem cuttings. The finding of present study is in accordance with those of Nikita Prajapati *et al.*, (2018) [17].

**Table 3:** No. of leaves per shoot of Black Pepper (*Piper nigrum*).

| Tr. no  | Treatment Combination | No. of leaves per shoot |        |        |
|---------|-----------------------|-------------------------|--------|--------|
|         |                       | 30 DAS                  | 60 DAS | 90 DAS |
| T0      | Control               | 3.75                    | 6.67   | 9.26   |
| T1      | IAA 500 ppm           | 3.85                    | 6.76   | 9.55   |
| T2      | IAA 1000 ppm          | 4.10                    | 7.16   | 10.31  |
| T3      | IAA 1500 ppm          | 4.02                    | 6.95   | 9.91   |
| T4      | NAA 500 ppm           | 3.91                    | 6.78   | 9.58   |
| T5      | NAA 1000 ppm          | 4.19                    | 7.25   | 10.46  |
| T6      | NAA 1500 ppm          | 4.04                    | 7.04   | 9.98   |
| T7      | IBA 500 ppm           | 4.06                    | 7.14   | 10.12  |
| T8      | IBA 1000 ppm          | 4.33                    | 7.41   | 10.58  |
| T9      | IBA 1500 ppm          | 3.98                    | 6.84   | 9.85   |
| Sem (±) |                       | 0.05                    | 0.07   | 0.10   |
| CD (5%) |                       | 0.13                    | 0.20   | 0.30   |

### 4.2.4 Leaf length (cm)

The data pertaining to leaf length (cm) as influenced of plant

growth regulator on rooting, growth and survivability of Black Pepper (*Piper nigrum*) stem cutting under shade net condition has been recorded and presented in Table 4.

The treatments showed clear variation in performance at 30 DAS, with T<sub>8</sub> (IBA 1000 ppm) achieving the highest leaf length (cm) (3.55 cm). This was followed by the treatment T<sub>5</sub> (NAA 1000 ppm) (3.40 cm) and T<sub>2</sub> (IAA 1000 ppm) at (3.32 cm). In contrast, the lowest leaf length (cm) value (2.97 cm) was recorded in T<sub>0</sub> (Control).

The treatments showed clear variation in performance at 60 DAS, with T<sub>8</sub> (IBA 1000 ppm) achieving the highest leaf length (cm) (7.34 cm). This was at par with the treatment T<sub>5</sub> (NAA 1000 ppm) (7.28 cm) and T<sub>2</sub> (IAA 1000 ppm) at (7.12 cm). In contrast, the lowest leaf length (cm) value (6.32 cm) was recorded in T<sub>0</sub> (Control).

The treatments showed clear variation in performance at 90 DAS, with T<sub>8</sub> (IBA 1000 ppm) achieving the highest leaf length (cm) (10.86 cm). This was followed by the treatment T<sub>5</sub> (NAA 1000 ppm) (10.50 cm) and T<sub>2</sub> (IAA 1000 ppm) at (10.32 cm). In contrast, the lowest leaf length (cm) value (9.22 cm) was recorded in T<sub>0</sub> (Control). The results demonstrated that the application of plant growth regulators significantly influenced the leaf length of black pepper cuttings under shade-net conditions. Treatments involving auxins such as IBA, NAA, and IAA produced longer leaves compared to the untreated control across all stages of observation. The increase in leaf length under these treatments may be attributed to the stimulatory role of auxins in promoting cell division and elongation within leaf tissues, resulting in enhanced leaf expansion. Among the different regulators, IBA consistently proved most effective, suggesting its superior role in promoting vigorous vegetative growth through better root establishment and improved nutrient translocation to the developing shoots. The gradual and steady increase in leaf length from 30 to 90 days further reflects the sustained physiological activity and growth efficiency induced by auxin treatments. These findings are in accordance with previous research indicating that auxin-based plant growth regulators enhance leaf development and photosynthetic area, thereby improving overall plant vigor in black pepper and similar spice crops propagated through stem cuttings. The results obtained in the present study are supported by the works of Ganesh *et al.*, (2022).

**Table 4:** Leaf length (cm) of Black Pepper (*Piper nigrum*).

| Tr. no         | Treatment Combination | Leaf length (cm) |        |        |
|----------------|-----------------------|------------------|--------|--------|
|                |                       | 30 DAS           | 60 DAS | 90 DAS |
| T <sub>0</sub> | Control               | 2.97             | 6.32   | 9.22   |
| T <sub>1</sub> | IAA 500 ppm           | 3.06             | 6.48   | 9.57   |
| T <sub>2</sub> | IAA 1000 ppm          | 3.32             | 7.12   | 10.32  |
| T <sub>3</sub> | IAA 1500 ppm          | 3.16             | 6.77   | 9.88   |
| T <sub>4</sub> | NAA 500 ppm           | 3.08             | 6.67   | 9.65   |
| T <sub>5</sub> | NAA 1000 ppm          | 3.40             | 7.28   | 10.50  |
| T <sub>6</sub> | NAA 1500 ppm          | 3.19             | 6.85   | 10.14  |
| T <sub>7</sub> | IBA 500 ppm           | 3.25             | 7.04   | 10.22  |
| T <sub>8</sub> | IBA 1000 ppm          | 3.55             | 7.34   | 10.86  |
| T <sub>9</sub> | IBA 1500 ppm          | 3.14             | 6.73   | 9.83   |
| Sem (±)        |                       | 0.05             | 0.09   | 0.10   |
| CD (5%)        |                       | 0.14             | 0.26   | 0.29   |

### 3.5 No. of nodes per shoot

The data pertaining to no. of nodes per shoot as influenced of plant growth regulator on rooting, growth and

survivability of Black Pepper (*Piper nigrum*) stem cutting under shade net condition has been recorded and presented in Table 5.

Evaluation of no. of nodes per shoot at 30 DAS showed that treatment T<sub>8</sub> (IBA 1000 ppm) attained the significantly maximum value (3.16), which was at par with the treatment T<sub>5</sub> (NAA 1000 ppm) and T<sub>2</sub> (IAA 1000 ppm) registering (3.13) and (3.12) respectively. The significantly, treatment T<sub>0</sub> (Control) recorded the minimum no. of nodes per shoot (2.76).

Evaluation of no. of nodes per shoot at 60 DAS showed that treatment T<sub>8</sub> (IBA 1000 ppm) attained the significantly maximum value (5.30), which was at par with the treatment T<sub>5</sub> (NAA 1000 ppm) and T<sub>2</sub> (IAA 1000 ppm) registering (5.22) and (5.12) respectively. The significantly, treatment T<sub>0</sub> (Control) recorded the minimum no. of nodes per shoot (4.59).

Evaluation of no. of nodes per shoot at 90 DAS showed that treatment T<sub>8</sub> (IBA 1000 ppm) attained the significantly maximum value (7.59), which was at par with the treatment T<sub>5</sub> (NAA 1000 ppm) and T<sub>2</sub> (IAA 1000 ppm) registering (7.41) and (7.27) respectively. The significantly, treatment T<sub>0</sub> (Control) recorded the minimum no. of nodes per shoot (6.74). The observations revealed that plant growth regulators exerted a significant influence on the number of nodes per shoot in black pepper cuttings under shade-net conditions. Treatments with auxins, particularly IBA, NAA, and IAA, consistently produced a higher number of nodes at all observation stages compared to the untreated control. The increased node formation under these treatments may be attributed to the role of auxins in promoting cell division and elongation along the stem axis, thereby encouraging the development of more nodal points. A greater number of nodes indicate enhanced vegetative growth potential, as nodes are critical for leaf emergence and further shoot proliferation. The superior performance of IBA-treated cuttings could be linked to its efficiency in root stimulation and nutrient mobilization, which supports vigorous shoot growth. These findings are in agreement with previous research suggesting that auxin-based plant growth regulators significantly improve nodal development and overall vegetative performance in black pepper and other perennial spice crops propagated through stem cuttings. The results obtained in the present study is in accordance with the results.

**Table 5:** No. of nodes per shoot of Black Pepper (*Piper nigrum*).

| Tr. no         | Treatment Combination | No. of nodes per shoot |        |        |
|----------------|-----------------------|------------------------|--------|--------|
|                |                       | 30 DAS                 | 60 DAS | 90 DAS |
| T <sub>0</sub> | Control               | 2.76                   | 4.59   | 6.74   |
| T <sub>1</sub> | IAA 500 ppm           | 2.83                   | 4.74   | 6.79   |
| T <sub>2</sub> | IAA 1000 ppm          | 3.12                   | 5.12   | 7.27   |
| T <sub>3</sub> | IAA 1500 ppm          | 3.02                   | 4.93   | 7.02   |
| T <sub>4</sub> | NAA 500 ppm           | 2.91                   | 4.80   | 6.89   |
| T <sub>5</sub> | NAA 1000 ppm          | 3.13                   | 5.22   | 7.41   |
| T <sub>6</sub> | NAA 1500 ppm          | 3.04                   | 5.01   | 7.06   |
| T <sub>7</sub> | IBA 500 ppm           | 3.08                   | 5.09   | 7.17   |
| T <sub>8</sub> | IBA 1000 ppm          | 3.16                   | 5.30   | 7.59   |
| T <sub>9</sub> | IBA 1500 ppm          | 2.93                   | 4.86   | 6.97   |
| Sem (±)        |                       | 0.03                   | 0.07   | 0.09   |
| CD (5%)        |                       | 0.10                   | 0.22   | 0.28   |

### 3.6 Length of internodes (cm)

The data pertaining to length of internodes (cm) as influenced of plant growth regulator on rooting, growth and survivability of Black Pepper (*Piper nigrum*) stem cutting under shade net condition has been recorded and presented in Table 6

It was observed that the treatments differed significantly in length of internodes (cm) at 30 DAS, with treatment T<sub>8</sub> (IBA 1000 ppm) attaining the maximum value of (1.47 cm). This was at par with the treatment T<sub>5</sub> (NAA 1000 ppm) (1.44 cm) and T<sub>2</sub> (IAA 1000 ppm) (1.42 cm). Conversely, T<sub>0</sub> (Control) displayed the lowest length of internodes (cm) (1.29 cm).

It was observed that the treatments differed significantly in length of internodes (cm) at 60 DAS, with treatment T<sub>8</sub> (IBA 1000 ppm) attaining the maximum value of (2.17 cm). This was at par with the treatment T<sub>5</sub> (NAA 1000 ppm) (2.14 cm) and T<sub>2</sub> (IAA 1000 ppm) (2.13 cm). Conversely, T<sub>0</sub> (Control) displayed the lowest length of internodes (cm) (1.89 cm).

It was observed that the treatments differed significantly in length of internodes (cm) at 90 DAS, with treatment T<sub>8</sub> (IBA 1000 ppm) attaining the maximum value of (2.79 cm). This was at par with the treatment T<sub>5</sub> (NAA 1000 ppm) (2.71 cm). Conversely, T<sub>0</sub> (Control) displayed the lowest length of internodes (cm) (2.34 cm). The results showed that the application of plant growth regulators significantly influenced the internodal length of black pepper cuttings under shade-net conditions. Treatments involving auxins, particularly IBA, NAA, and IAA, resulted in greater internodal elongation compared to the untreated control across all observation periods. The increase in internode length may be attributed to the role of auxins in promoting cell elongation and division within stem tissues, thereby facilitating enhanced vegetative growth. Among the different PGRs, IBA proved most effective, likely due to its strong influence on root establishment and the subsequent improvement in nutrient and water uptake, which supports better shoot elongation. Longer internodes indicate more active meristematic growth and improved hormonal balance, leading to vigorous and healthy plant development. These results are consistent with previous studies reporting that auxin-based treatments, particularly IBA, enhance internodal elongation and overall shoot growth in black pepper and other vegetatively propagated spice crops. Similar results were also observed by Freire *et al.*, (2017)<sup>[7]</sup> and Adsure (2021)<sup>[1]</sup>.

**Table 6:** Length of internodes (cm) of Black Pepper (*Piper nigrum*).

| Tr. no         | Treatment Combination | Length of internodes (cm) |        |        |
|----------------|-----------------------|---------------------------|--------|--------|
|                |                       | 30 DAS                    | 60 DAS | 90 DAS |
| T <sub>0</sub> | Control               | 1.29                      | 1.89   | 2.34   |
| T <sub>1</sub> | IAA 500 ppm           | 1.33                      | 1.94   | 2.40   |
| T <sub>2</sub> | IAA 1000 ppm          | 1.42                      | 2.13   | 2.66   |
| T <sub>3</sub> | IAA 1500 ppm          | 1.39                      | 2.00   | 2.51   |
| T <sub>4</sub> | NAA 500 ppm           | 1.35                      | 1.96   | 2.43   |
| T <sub>5</sub> | NAA 1000 ppm          | 1.44                      | 2.14   | 2.71   |
| T <sub>6</sub> | NAA 1500 ppm          | 1.39                      | 2.01   | 2.57   |
| T <sub>7</sub> | IBA 500 ppm           | 1.41                      | 2.08   | 2.59   |
| T <sub>8</sub> | IBA 1000 ppm          | 1.47                      | 2.17   | 2.79   |
| T <sub>9</sub> | IBA 1500 ppm          | 1.36                      | 1.97   | 2.46   |
| Sem (±)        |                       | 0.03                      | 0.02   | 0.04   |
| CD (5%)        |                       | 0.09                      | 0.06   | 0.11   |

### 3.7 Girth of new shoots (cm)

The data pertaining to girth of new shoots (cm) as influenced of plant growth regulator on rooting, growth and survivability of Black Pepper (*Piper nigrum*) stem cutting under shade net condition has been recorded and presented in Table 7.

The results indicated significant variation in the girth of new shoots (cm) at 30 DAS. The maximum value (0.25 cm) was recorded in T<sub>8</sub> (IBA 1000 ppm), which was at par with the treatment T<sub>5</sub> (NAA 1000 ppm) with (0.25 cm) and T<sub>2</sub> (IAA 1000 ppm) with (0.25 cm). The minimum girth of new shoots (cm) (0.23 cm) was recorded In the treatment T<sub>0</sub> (Control).

The results indicated significant variation in the girth of new shoots (cm) at 60 DAS. The maximum value (0.37 cm) was recorded in T<sub>8</sub> (IBA 1000 ppm), which was at par with the treatment T<sub>5</sub> (NAA 1000 ppm) with (0.36 cm) and T<sub>2</sub> (IAA 1000 ppm) with (0.36 cm). The minimum girth of new shoots (cm) (0.32 cm) was recorded in the treatment T<sub>0</sub> (Control).

The results indicated significant variation in the girth of new shoots (cm) at 90 DAS. The maximum value (0.54 cm) was recorded in T<sub>8</sub> (IBA 1000 ppm), which was at par with the treatment T<sub>5</sub> (NAA 1000 ppm) with (0.54 cm) and T<sub>2</sub> (IAA 1000 ppm) with (0.53 cm). The minimum girth of new shoots (cm) (0.43 cm) was recorded in the treatment T<sub>0</sub> (Control). The data clearly indicated that the girth of new shoots in black pepper cuttings was significantly influenced by the application of plant growth regulators under shade-net conditions. Treatments with auxins such as IBA, NAA, and IAA consistently resulted in thicker shoot girth compared to the untreated control across all growth stages. The increase in shoot girth under these treatments may be attributed to the role of auxins in enhancing cambial activity, promoting cell enlargement, and improving the translocation of nutrients and assimilates towards the developing shoot tissues. A well-developed root system induced by auxin treatments likely supported better water and nutrient uptake, which contributed to stronger and more robust shoot growth. Among the tested regulators, IBA was observed to be the most effective, indicating its superior ability to stimulate both root and shoot vigor. These findings are in agreement with earlier reports stating that auxin-based plant growth regulators enhance stem thickening and overall vegetative growth in black pepper and other spice crops propagated through stem cuttings. Also, similar results were reported by Nikita Prajapati *et al.*, (2018)<sup>[15]</sup>.

**Table 7:** Girth of new shoots (cm) of Black Pepper (*Piper nigrum*).

| Tr. no         | Treatment Combination | Girth of new shoots (cm) |        |        |
|----------------|-----------------------|--------------------------|--------|--------|
|                |                       | 30 DAS                   | 60 DAS | 90 DAS |
| T <sub>0</sub> | Control               | 0.23                     | 0.32   | 0.43   |
| T <sub>1</sub> | IAA 500 ppm           | 0.23                     | 0.32   | 0.45   |
| T <sub>2</sub> | IAA 1000 ppm          | 0.25                     | 0.36   | 0.53   |
| T <sub>3</sub> | IAA 1500 ppm          | 0.24                     | 0.35   | 0.48   |
| T <sub>4</sub> | NAA 500 ppm           | 0.23                     | 0.34   | 0.46   |
| T <sub>5</sub> | NAA 1000 ppm          | 0.25                     | 0.36   | 0.54   |
| T <sub>6</sub> | NAA 1500 ppm          | 0.24                     | 0.35   | 0.48   |
| T <sub>7</sub> | IBA 500 ppm           | 0.24                     | 0.36   | 0.50   |
| T <sub>8</sub> | IBA 1000 ppm          | 0.25                     | 0.37   | 0.54   |
| T <sub>9</sub> | IBA 1500 ppm          | 0.23                     | 0.34   | 0.46   |
| Sem (±)        |                       | 0.005                    | 0.004  | 0.006  |
| CD (5%)        |                       | 0.014                    | 0.012  | 0.019  |

#### 4. Conclusion

The present investigation clearly demonstrated that the application of plant growth regulators had a significant and positive influence on shoot growth of black pepper (*Piper nigrum* L.) stem cuttings under shade net conditions. Among the different treatments, IBA at 1000 ppm consistently proved superior by recording the highest number of shoots per cutting, maximum shoot length, greater number of leaves, increased leaf size, higher nodal formation, longer internodes, and improved shoot girth at all stages of observation, followed by NAA at 1000 ppm and IAA at 1000 ppm. The enhanced shoot growth under auxin treatments may be attributed to improved root establishment, efficient nutrient and water uptake, and balanced hormonal regulation, which together promoted vigorous vegetative development. The shade net environment further supported uniform growth by providing a favorable microclimate for physiological activity. Overall, the study suggests that treatment of black pepper stem cuttings with IBA at 1000 ppm under shade net conditions is an effective and reliable practice for producing high-quality planting material with superior shoot vigor, which can contribute to better field establishment and sustainable black pepper cultivation.

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#### 6. Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of this research.

#### 7. Future Suggestions

1. Long-term field evaluation of seedlings raised under different plant growth regulator treatments should be conducted to assess their performance, yield, and survivability under open field conditions.
2. Studies may be undertaken to evaluate the combined effect of plant growth regulators with biofertilizers or microbial inoculants for sustainable and eco-friendly propagation of black pepper.
3. Optimization of PGR concentrations for different black pepper varieties and agro-climatic zones should be explored to develop location-specific propagation protocols.
4. Comparative studies involving natural growth stimulants and organic alternatives in combination with

shade net conditions may be carried out to reduce dependency on synthetic chemicals.

5. Further research on the physiological, biochemical, and molecular mechanisms underlying auxin-induced shoot growth in black pepper stem cuttings would help in better understanding and refinement of propagation techniques.

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