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Effect of type of cuttings and growth regulators on root and shoot biomass accumulation in passion fruit (*Passiflora edulis* Sims.) stem cuttings

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ABSTRACT

An experiment was carried out to study the effect of type of cuttings and growth regulators on root and shoot biomass accumulation in passion fruit (*Passiflora edulis*) stem cuttings under shade net conditions. The experiment comprised two types of cuttings, viz., softwood and semi-hardwood and seven growth regulator treatments, viz., control, IBA (Indole-3-butyric acid) at 500, 750 and 1000 ppm and NAA (α -Naphthalene acetic acid) at 500, 750 and 1000 ppm, arranged in a factorial completely randomized design with three replications. Among the types of cuttings, semi-hardwood cuttings recorded maximum fresh weight of root (2.32 g), dry weight of root (1.08 g), shoot fresh weight (18.17 g), shoot dry weight (5.39 g) and root-to-shoot ratio (0.20). Among growth regulators, cuttings treated with IBA 1000 ppm recorded 2.84 g, 1.34 g, 20.17 g, 5.96 g and 0.23, respectively, at 120 days after planting. In interaction effect, semi-hardwood cuttings with IBA 1000 ppm recorded the highest fresh root weight (3.42 g), dry root weight (1.52 g), fresh shoot weight (23.09 g), dry shoot weight (6.09 g) and root-to-shoot ratio (0.26) at 120 days after planting. Therefore, among the various treatments, semi-hardwood cuttings with IBA 1000 ppm are the best for propagation through cuttings.

Keywords: *Passiflora edulis*, Softwood, Semi-hardwood, Biomass accumulation, Root-to-shoot ratio

Introduction

Passion fruit (*Passiflora edulis* Sims) is a perennial woody vine with axillary tendrils that belongs to the family Passifloraceae. The majority of *Passiflora* species are indigenous to the tropical and subtropical regions of South America. Brazil is known as center of diversity of the Passifloraceae. Out of the 500 known species of *Passiflora*, about 50 or 60 bear edible fruits. The majority of these species are unknown outside their center of origin. There are mainly two types of passion fruit under cultivation. They are the yellow passion fruit (*Passiflora edulis* var. *flavicarpa*), suited to tropical conditions or the plains and the purple passion fruit (*Passiflora edulis* var. *edulis*) which grows best under subtropical conditions or high altitudes (Sivappa *et al.*, 2019; Weyya *et al.*, 2024) [1, 2]. The cultivation of *Passiflora* species has been for their edible fruits, ornamental flowers and pharmaceutical uses. Its fruits are used for fresh consumption and processing purpose. It has a soft to firm moist interior, filled with numerous seeds. Its commercial plantation is found in Australia, Hawaii, USA, India, New Guinea, Kenya, South Africa, Sri Lanka and Costa Rica and is considered as an important high-value fruit crop owing to its distinctive flavour, pleasant aroma, nutritional value and processing potential (Shivanna, 2012; Bakir *et al.*, 2023) [4, 3]. The fruit is consumed fresh and processed into juice, nectar, squash, syrup, concentrate, jam and jelly, which further enhances its commercial importance (He *et al.*, 2020) [5]. In India it is found to be growing wild in many parts of Western Ghats such as Nilgiris, Wayanad, Kodaikanal, Coorg and Malabar as well as Himachal Pradesh and North Eastern States viz., Meghalaya, Mizoram, Manipur, Nagaland and Sikkim. Peoples like this fruit due to its pleasant aroma, rich flavor, prolific bearer and highly remunerative even without much care and has capacity to suited in hill farming system. Area under passion fruit cultivation in India is 9,000 ha with an annual production and productivity of 34,000 MT and 3.78 MT/ha (Anonymous, 2025) [6], respectively. For further area expansion and commercial cultivation, the availability of healthy, vigorous and genetically uniform planting material is essential.

Passion fruit is a shallow-rooted, woody, perennial climbing vine that uses tendrils for support. The flowers are solitary and fragrant, while the fruits are nearly round to oval with a tough, smooth and waxy rind and aromatic orange-coloured pulp containing numerous dark-coloured seeds (Morton, 1987) [7]. The crop grows well in well-drained soils, particularly sandy loam soils, while poor drainage and waterlogging can adversely affect root health and favour root diseases. Passion fruit can be propagated by seeds, stem cuttings and grafting; however, seed propagation may result in considerable variability, whereas vegetative propagation

through stem cuttings enables rapid multiplication of elite plants while maintaining the desirable characteristics of the mother plant (Gurung *et al.*, 2015; Jesus *et al.*, 2020) [8, 9]. The success of rooting in stem cuttings depends on several factors, including genotype, physiological maturity of the cutting, carbohydrate reserves, endogenous hormonal balance, rooting medium and environmental conditions. With respect to type of cuttings, softwood and semi-hardwood cuttings differ in their physiological maturity, carbohydrate status and degree of lignification, which can influence adventitious root formation and subsequent plant establishment (Hartmann *et al.*, 2018) [10]. The auxin group of hormones IAA (indole-3-acetic acid), IBA (indole-3-butyric acid) and NAA (α -naphthalene acetic acid) had an apparent effect on the morphological characteristics of the newly generated plants, especially root generation (Sevik *et al.*, 2013) [11]. Despite the importance of passion fruit as a high-value fruit crop, limited information is available on the combined influence of type of cuttings and growth regulator concentration on root and shoot biomass accumulation under shade net conditions. Therefore, the present investigation was undertaken to study the effect of softwood and semi-hardwood cuttings and different concentrations of IBA and NAA on root and shoot biomass accumulation and root-to-shoot ratio in passion fruit stem cuttings under shade-net nursery conditions.

Materials and Methods

The experiment was carried out in nursery of Arecanut Research Centre from 2025 to 2026 under 50 per cent shade-net condition, Keladi Shivappa Nayaka University of Agricultural and Horticultural Sciences, Shivamogga, using purple passion fruit (*Passiflora edulis* Sims.) as a plant material. The experiment comprised two types of stem cuttings, viz., softwood and semi-hardwood, and seven growth regulator treatments, viz., control, IBA at 500, 750 and 1000 ppm and NAA at 500, 750 and 1000 ppm. The experiment was laid out in a factorial completely randomized design with three replications. Uniform cuttings of 15-20 cm length with four nodes from healthy and disease-free mother vines were selected. The basal 1-2 cm portion of the cuttings was dipped in the respective growth regulator solutions for 15 minutes following the long-dip method. The rooting medium consisted of soil, fine sand and well-decomposed farmyard manure in a ratio of 1:1:1 (v/v). The medium was drenched with carbendazim at 2 gL⁻¹ before planting. The treated cuttings were planted vertically in perforated polyethylene bags, keeping one node below the medium surface. Each replication contains 20 cuttings per treatment. Irrigation and other cultural practices were maintained uniformly throughout the experimental period. The observations recorded fresh are root weight, dry root weight, shoot fresh weight, shoot dry weight and root-shoot ratio. Roots and shoots were separated and their fresh weights were recorded separately. The samples were then dried in a hot-air oven at 60 °C until constant weight was attained and dry weights were recorded. Root-to-shoot ratio was calculated from the respective dry weights of roots and shoots. The data were analysed using analysis of variance appropriate for factorial CRD and treatment means were compared at the 5 per cent level of significance (Pansé *et al.*, 1967) [12].

Results and Discussion

Two types of cuttings, viz., softwood and semi-hardwood and different growth regulator treatments, viz., control, IBA 500, 750 and 1000 ppm and NAA 500, 750 and 1000 ppm, were used. The interaction effect between type of cuttings and growth regulators was found significant for all the biomass parameters, viz., fresh and dry weight of root, fresh and dry weight of shoot and root-to-shoot ratio at 60, 90 and 120 days after planting. Semi-hardwood cuttings performed better than softwood cuttings, while IBA 1000 ppm was the most effective treatment for biomass accumulation.

Fresh weight of root (g)

The results presented in Table 1 showed that the type of cuttings significantly influenced fresh root weight at all stages of observation. Semi-hardwood cuttings recorded 1.28, 1.64 and 2.32 g at 60, 90 and 120 days after planting, respectively, compared with 0.99, 1.37 and 1.66 g in softwood cuttings. This may be attributed to the relatively mature tissues also favoured better establishment of the developing root system, resulting in greater water uptake and tissue hydration which may have further contributed to greater fresh root biomass. Similar findings were reported by Desai *et al.* (2022) [13] in fig. Among the growth regulator treatments, IBA 1000 ppm (T₄) recorded 1.65, 1.96 and 2.84 g at 60, 90 and 120 days after planting, respectively, while the control recorded 0.55, 0.97 and 1.22 g. The increase in fresh root weight with IBA application may be associated with enhanced adventitious root development and greater root tissue formation. Exogenous IBA may enhance cell division and elongation and facilitate the mobilization of stored nutritional reserves towards the rooting region, thereby promoting root growth and fresh biomass accumulation. Similar responses to IBA application were reported by Rajangam *et al.* (2022) [14] in acid lime and Harika *et al.* (2024) [15] in pomegranate.

The interaction between type of cuttings and growth regulator was significant. Semi-hardwood cuttings treated with IBA 1000 ppm (C₂T₄) recorded the highest fresh root weight of 1.88, 2.12 and 3.42 g at 60, 90 and 120 days after planting, respectively, whereas softwood cuttings without growth regulator recorded the lowest values of 0.52, 0.89 and 1.18 g. This response may be due to the favourable physiological condition of semi-hardwood cuttings and the stimulatory effect of IBA, resulting in greater root tissue formation and fresh biomass accumulation. Similar findings were reported by Desai *et al.* (2022) [13] in fig and Harika *et al.* (2024) [15] in pomegranate.

Dry weight of root (g)

Significantly higher dry root weight of 0.36, 0.71 and 1.08 g at 60, 90 and 120 days after planting (DAP), respectively, was observed in semi-hardwood cuttings, while softwood cuttings recorded 0.26, 0.55 and 0.83 g. The higher dry matter accumulation in semi-hardwood cuttings may be associated with their greater physiological maturity and reserve food availability, which supported root development and translocation of photosynthates towards the developing roots. Similar observations were reported by Desai *et al.* (2022) [13] in fig.

Dry root weight was significantly affected by plant growth regulator treatments. IBA 1000 ppm (T₄) recorded the maximum dry root weight of 0.48, 0.88 and 1.34 g at 60, 90 and 120 days after planting, respectively, whereas the control recorded the minimum (0.17, 0.34 and 0.54 g). The increased dry root weight under IBA treatment may be attributed to enhanced root initiation and development, which increased the sink strength of the developing root system. Greater root growth would have facilitated the accumulation and translocation of photosynthates into root tissues, resulting in increased dry matter accumulation. Similar findings were reported by Parse *et al.* (2018) [16] in passion fruit.

The data presented in Table 2 showed that the interaction between type of cuttings and growth regulator was significant. The highest dry root weight of 0.59, 1.02 and 1.52 g was recorded in semi-hardwood cuttings treated with IBA 1000 ppm at 60, 90 and 120 days after planting, respectively, whereas softwood cuttings without growth regulator (C₁T₁) recorded the lowest values of 0.16, 0.32 and 0.51 g. This may be attributed to the greater rooting capacity and endogenous food reserves of semi-hardwood cuttings, together with the stimulatory effect of IBA on root development. The development of a well-established root system would have enhanced the translocation of nutrients and photosynthates, thereby promoting greater dry matter accumulation. Similar findings were reported by Desai *et al.* (2022) [13] in fig.

Fresh weight of shoot (g)

The type of cutting significantly influenced fresh shoot weight. Semi-hardwood cuttings recorded 10.76, 15.57 and 18.17 g at 60, 90 and 120 days after planting, respectively, compared with 8.15, 12.74 and 14.65 g in softwood cuttings. The higher shoot biomass may be attributed to the greater physiological maturity and reserve carbohydrate content of semi-hardwood cuttings, which supported shoot development during establishment. Similar results were reported by Malakar *et al.* (2019) [17] in acid lime and Desai *et al.* (2022) [13] in fig.

Among the growth regulators, IBA 1000 ppm (T₄) recorded the highest fresh shoot weight of 12.79, 18.04 and 20.17 g at 60, 90 and 120 days after planting, respectively, whereas the control recorded the lowest values of 6.22, 9.36 and 11.45 g. The increase in fresh shoot weight may be associated with improved root development under IBA treatment, which enhanced water and nutrient uptake and supported shoot biomass production. Similar findings were reported by Deb *et al.* (2009) [18] in lemon and Parse *et al.* (2018) [16] in passion fruit.

The interaction between type of cutting and growth regulator was significant (Table 3). Semi-hardwood cuttings treated with IBA 1000 ppm (C₂T₄) recorded the highest fresh shoot weight of 14.19, 20.19 and 23.09 g at 60, 90 and 120 days after planting, respectively, whereas softwood cuttings without growth regulator (C₁T₁) recorded the lowest values of 6.07, 9.09 and 11.09 g. This response may be attributed to the combined effect of adequate reserves in semi-hardwood cuttings and improved root establishment induced by IBA, which supported greater water and nutrient uptake, supporting photosynthetic activity and subsequent shoot growth. Similar observations were reported by Desai *et al.* (2022) [13] in fig and Malakar *et al.* (2019) [17] in acid lime.

Shoot dry weight (g)

The results presented in Table 4 showed that semi-hardwood cuttings recorded higher dry shoot weight (3.05, 4.30 and 5.39 g) at 60, 90 and 120 days after planting, respectively, while softwood cuttings recorded 2.60, 3.81 and 4.95 g. The greater dry matter may be associated with their higher reserve carbohydrate content and better establishment, which provided sufficient assimilates for continued shoot development and dry matter production.

Among growth regulators, IBA 1000 ppm (T₄) recorded the highest dry shoot weight of 3.57, 4.62 and 5.96 g at 60, 90 and 120 days after planting, respectively, whereas the control recorded the lowest values of 2.00, 3.15 and 4.04 g. The increase in dry shoot weight with IBA application may be attributed to improved root development and consequent enhancement in water and nutrient absorption. The greater

availability of nutrients, together with auxin-mediated cell division and elongation, would have supported shoot growth and dry matter accumulation. Similar findings were reported by Wadhekar *et al.* (2022) [19] in dragon fruit and Parse *et al.* (2018) [16] in passion fruit.

The interaction between type of cuttings and growth regulator was significant. Semi-hardwood cuttings treated with IBA 1000 ppm (C₂T₄) recorded the highest dry shoot weight of 3.85, 4.85 and 6.09 g at 60, 90 and 120 days after planting, respectively, whereas softwood cuttings without growth regulator (C₁T₁) recorded the lowest (1.95, 3.02 and 4.01 g). This may be due to the favourable endogenous food reserves of semi-hardwood cuttings combined with improved root establishment under IBA treatment. Enhanced nutrient uptake and translocation of assimilates towards the developing shoot system would have contributed to greater dry matter accumulation. Similar trends were reported by Malakar *et al.* (2019) [17].

Root-to-shoot ratio

The type of cuttings significantly affected the root-to-shoot ratio (Fig. 1). Semi-hardwood cuttings recorded root to shoot ratio (0.11, 0.16 and 0.20) at 60, 90 and 120 days after planting, respectively, whereas softwood cuttings recorded 0.10, 0.14 and 0.17. The comparatively higher root-to-shoot ratio in semi-hardwood cuttings may be attributed to their greater physiological maturity, thickness and stored carbohydrate reserves, which favoured better root development and dry matter accumulation during establishment.

Among different growth regulators, IBA 1000 ppm (T₄) recorded the highest root-to-shoot ratio of 0.13, 0.18 and 0.23 at 60, 90 and 120 days after planting, respectively, whereas the control recorded the lowest values of 0.08, 0.11 and 0.13. The higher root-to-shoot ratio with IBA treatment may be attributed to the stimulatory effect of auxin on root regeneration, which promotes the mobilization and utilization of stored nutritional reserves towards the rooting region, thereby favouring root development relative to shoot growth. Similar findings were reported by Tanwar *et al.* (2020) [20] in pomegranate.

The interaction effect between type of cutting and growth regulator was significant at all three stages of observation. Semi-hardwood cuttings treated with IBA 1000 ppm (C₂T₄) recorded the highest root-to-shoot ratio of 0.15, 0.21 and 0.26 at 60, 90 and 120 days after planting, respectively, whereas softwood cuttings without growth regulator (C₁T₁) recorded the lowest values of 0.08, 0.11 and 0.13. This may be attributed to the greater maturity and stored reserves of semi-hardwood cuttings combined with the stimulatory effect of IBA on root regeneration. This favoured greater root biomass accumulation relative to shoot biomass, resulting in a higher root-to-shoot ratio. Similar observations were reported by Desai *et al.* (2022) [13] in fig.

Table 1. Effect of type of cuttings and growth regulators on fresh root weight (g) at different intervals of Passion fruit

Treatment	60 DAP			90 DAP			120 DAP		
	C ₁	C ₂	Mean	C ₁	C ₂	Mean	C ₁	C ₂	Mean
T ₁ – Control	0.52	0.58	0.55	0.89	1.05	0.97	1.18	1.25	1.22
T ₂ – IBA 500 ppm	0.72	1.04	0.88	1.27	1.37	1.32	1.46	1.55	1.51
T ₃ – IBA 750 ppm	1.29	1.64	1.47	1.54	1.99	1.77	1.98	2.96	2.47
T ₄ – IBA 1000 ppm	1.42	1.88	1.65	1.80	2.12	1.96	2.26	3.42	2.84
T ₅ – NAA 500 ppm	0.68	0.85	0.77	1.17	1.33	1.25	1.35	1.49	1.42
T ₆ – NAA 750 ppm	1.10	1.36	1.23	1.43	1.74	1.59	1.64	2.17	1.91
T ₇ – NAA 1000 ppm	1.18	1.59	1.39	1.49	1.90	1.70	1.73	2.87	2.30
Mean	0.99	1.28	1.13	1.37	1.64	1.51	1.66	2.32	1.99
	C	T	C×T	C	T	C×T	C	T	C×T
S. Em ±	0.01	0.02	0.03	0.01	0.03	0.04	0.02	0.04	0.06
CD (P = 0.05)	0.04	0.07	0.10	0.04	0.08	0.11	0.06	0.11	0.16

C₁: Softwood; C₂: Semi-hardwood; DAP: Days after planting

(continued on next page)

Table 2. Effect of type of cuttings and growth regulators on dry root weight (g) at different intervals of Passion fruit

Treatment	60 DAP			90 DAP			120 DAP		
	C ₁	C ₂	Mean	C ₁	C ₂	Mean	C ₁	C ₂	Mean
T ₁ – Control	0.16	0.18	0.17	0.32	0.36	0.34	0.51	0.56	0.54
T ₂ – IBA 500 ppm	0.22	0.25	0.24	0.46	0.53	0.50	0.71	0.81	0.76
T ₃ – IBA 750 ppm	0.33	0.43	0.38	0.67	0.92	0.79	1.01	1.36	1.19
T ₄ – IBA 1000 ppm	0.37	0.59	0.48	0.75	1.02	0.88	1.16	1.52	1.34
T ₅ – NAA 500 ppm	0.20	0.23	0.22	0.42	0.50	0.46	0.63	0.75	0.69
T ₆ – NAA 750 ppm	0.27	0.39	0.33	0.59	0.81	0.70	0.87	1.25	1.06
T ₇ – NAA 1000 ppm	0.31	0.42	0.37	0.63	0.86	0.74	0.95	1.32	1.14
Mean	0.26	0.36	0.31	0.55	0.71	0.63	0.83	1.08	0.96
	C	T	C×T	C	T	C×T	C	T	C×T
S. Em ±	0.005	0.009	0.013	0.006	0.011	0.016	0.007	0.013	0.018
CD (<i>P</i> = 0.05)	0.013	0.025	0.036	0.018	0.033	0.047	0.019	0.036	0.051

C₁: Softwood; C₂: Semi-hardwood; DAP: Days after planting**Table 3.** Influence of type of cuttings and growth regulators on fresh shoot weight (g) at different intervals of Passion fruit

Treatments	60 DAP			90 DAP			120 DAP		
	C ₁	C ₂	Mean	C ₁	C ₂	Mean	C ₁	C ₂	Mean
T ₁ – Control	6.07	6.36	6.22	9.09	9.62	9.36	11.09	11.81	11.45
T ₂ – IBA 500 ppm	6.91	8.02	7.46	10.92	12.97	11.95	12.81	15.13	13.97
T ₃ – IBA 750 ppm	9.46	13.90	11.68	15.09	18.56	16.83	16.65	21.77	19.21
T ₄ – IBA 1000 ppm	10.67	14.19	12.79	15.89	20.19	18.04	17.26	23.09	20.17
T ₅ – NAA 500 ppm	6.57	7.43	7.00	10.31	12.14	11.23	12.57	14.23	13.40
T ₆ – NAA 750 ppm	8.44	11.89	10.16	13.66	17.45	15.55	15.78	20.10	17.94
T ₇ – NAA 1000 ppm	8.96	12.80	10.88	14.21	18.05	16.13	16.39	21.07	18.73
Mean	8.15	10.76	9.46	12.74	15.57	14.15	14.65	18.17	16.41
	C	T	C×T	C	T	C×T	C	T	C×T
S. Em ±	0.06	0.10	0.15	0.08	0.16	0.22	0.11	0.21	0.29
CD (<i>P</i> = 0.05)	0.16	0.30	0.42	0.24	0.45	0.64	0.32	0.60	0.85

C₁: Softwood; C₂: Semi-hardwood; DAP: Days after planting**Table 4.** Effect of type of cuttings and growth regulators on dry shoot weight (g) at different intervals of Passion fruit

Treatments	60 DAP			90 DAP			120 DAP		
	C ₁	C ₂	Mean	C ₁	C ₂	Mean	C ₁	C ₂	Mean
T ₁ – Control	1.95	2.04	2.00	3.02	3.29	3.15	4.01	4.08	4.04
T ₂ – IBA 500 ppm	2.22	2.56	2.39	3.49	3.85	3.67	4.49	4.96	4.73
T ₃ – IBA 750 ppm	3.04	3.64	3.34	4.25	4.84	4.55	5.57	6.03	5.80
T ₄ – IBA 1000 ppm	3.30	3.85	3.57	4.39	4.85	4.62	5.83	6.09	5.96
T ₅ – NAA 500 ppm	2.12	2.44	2.28	3.33	3.65	3.49	4.28	4.71	4.50
T ₆ – NAA 750 ppm	2.72	3.34	3.03	4.05	4.87	4.46	5.16	5.89	5.53
T ₇ – NAA 1000 ppm	2.87	3.48	3.18	4.15	4.75	4.45	5.32	5.95	5.64
Mean	2.60	3.05	2.83	3.81	4.30	4.06	4.95	5.39	5.17
	C	T	C×T	C	T	C×T	C	T	C×T
S. Em ±	0.02	0.04	0.06	0.03	0.06	0.09	0.03	0.06	0.08
CD (<i>P</i> = 0.05)	0.07	0.12	0.17	0.09	0.17	0.23	0.09	0.16	0.23

C₁: Softwood; C₂: Semi-hardwood; DAP: Days after planting

Conclusion

The investigation revealed that type of cuttings and growth regulator application caused significant variation in biomass accumulation of passion fruit propagation under nursery conditions. Overall, semi-hardwood cuttings treated with IBA 1000 ppm (C₂T₄) recorded the highest root and shoot biomass and root-to-shoot ratio at all three stages of observation. The results indicate that the combination of suitable cutting maturity and IBA 1000 ppm was effective in promot-

ing biomass accumulation and establishment of passion fruit stem cuttings under nursery conditions.

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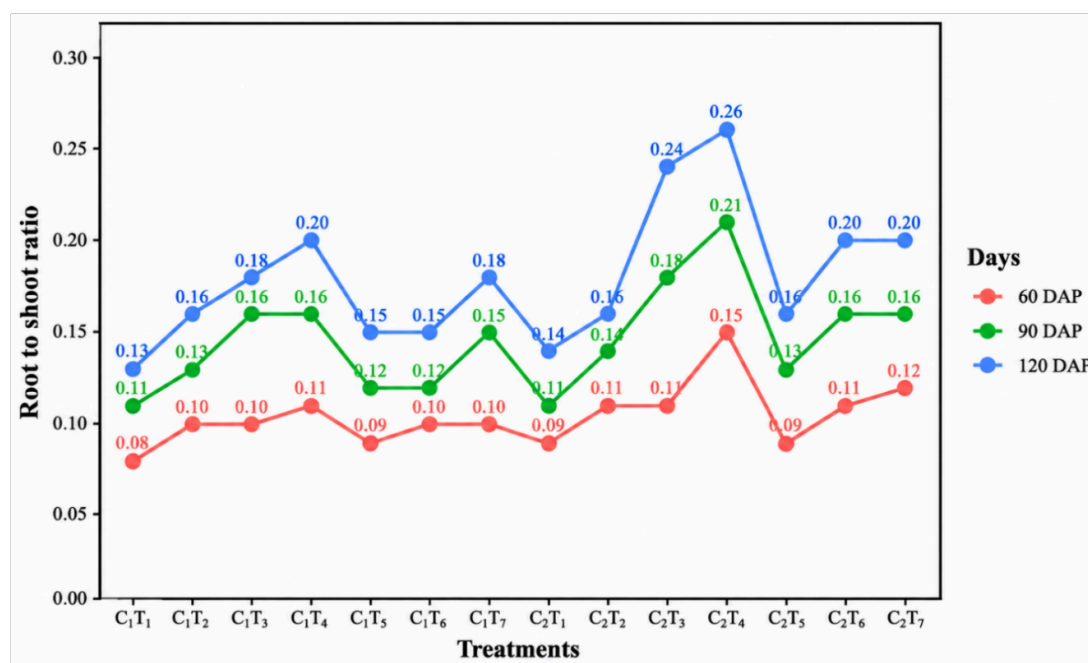


Figure 1. Effect of type of cuttings and growth regulators on root to shoot ratio in passion fruit cuttings

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