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Scientific Article

Effect of rooting hormones and media on vegetative propagation of Bougainvillea

Jebina Shrestha[1], Nirajan Bhandari[2*], Swastika Baral[1], Sharad Parasar Marahatta[3], Umed Pun[4]

[1] Gauradaha Agriculture Campus, Institute of Agriculture and Animal Science, Gauradaha, Jhapa, Nepal.
[2] Agriculture and Forestry University, College of Natural Resource Management, Pakhribas, Dhankuta, Nepal.
[3] University of Hawaii at Hilo, Hilo, Hawaii, USA.
[4] King Mongkut's Institute of Technology, Ladkrabang, Bangkok, Thailand.

Abstract

The propagation success of bougainvillea through hardwood stem cutting varied with rooting hormones and rooting media. This experiment was carried out to study the effect of rooting hormone and rooting media on hardwood cuttings of *Bougainvillea glabra* cv. Double Red during April-July, 2021. The treatments were combination of rooting hormones [Indole-3-Butyric Acid (500 mg L^{-1}), Indole-3-Butyric Acid (1,000 mg L^{-1}), Naphthalene Acetic Acid (1,500 mg L^{-1}), Naphthalene Acetic Acid (3,000 mg L^{-1}), Rootex C] and different rooting media (soil and farmyard manure, sand and farmyard manure, sand and cocopeat) in 1:1 ratio. Cuttings without rooting hormones served as control. We observed earliest sprouting (10.33 days) of cuttings treated with IBA (500 mg L^{-1}) and planted in sand and cocopeat. The highest sprouting percent (100%) and length of longest sprout (49 cm) were recorded when cuttings were treated with Rootex C and planted in sand and cocopeat. The highest shoot fresh weight (10.04 g), shoot dry weight (2.09 g), length of root (13.75 cm), number of roots (34.17), root fresh weight (2.33 g) and root dry weight (0.24 g) was observed in cuttings treated with IBA (1000 mg L^{-1}) and planted in sand and cocopeat. The effect of rooting hormone and rooting media on the diameter of sprouts, rooting percentage, and transplanting success percentage was non-significant. Considering economically important parameters (sprouting percentage and length of longest sprout), this study revealed that sand and cocopeat with Rootex C was the best combination for the propagation of bougainvillea.
Keywords: cocopeat, hardwood cuttings, media, sprouting.

Resumo

Efeito de hormônios e meios de enraizamento na propagação vegetativa de buganvília

O sucesso da propagação de buganvília por meio de estacas lenhosas variou com os hormônios de enraizamento e o meio de enraizamento. Este experimento foi conduzido para estudar o efeito do hormônio e do substrato no enraizamento de estacas lenhosas de *Bougainvillea glabra* cv. Double Red durante abril-julho de 2021. Os tratamentos foram a combinação de hormônios de enraizamento [Ácido indol-3-butírico (500 mg L^{-1}), ácido indol-3-butírico (1000 mg L^{-1}), ácido naftaleno acético (1500 mg L^{-1}), ácido Naftaleno Acético (3.000 mg L^{-1}), Rootex C] e diferentes meios de enraizamento (terra e esterco de curral, areia e esterco de curral, areia e fibra de coco) na proporção de 1:1. Estacas sem hormônios de enraizamento serviram como controle. Observou-se brotação precoce (10,33 dias) de estacas tratadas com AIB (500 mg L^{-1}) e plantadas em areia e fibra de coco. O maior percentual de brotação (100%) e comprimento do broto mais longo (49 cm) foram registrados quando as estacas foram tratadas com Rootex C e plantadas em areia e fibra de coco. Foi observada a maior massa fresca da parte aérea (10,04 g), massa seca da parte aérea (2,09 g), comprimento da raiz (13,75 cm), número de raízes (34,17), massa fresca da raiz (2,33 g) e massa seca da raiz (0,24 g) em estacas tratadas com AIB (1000 mg L^{-1}) e plantadas em areia e fibra de coco. O efeito do hormônio de enraizamento e do meio de enraizamento no diâmetro das brotações, porcentagem de enraizamento e porcentagem de sucesso do transplante não foi significativo. Considerando parâmetros economicamente importantes (porcentagem de brotação e comprimento do broto mais longo), este estudo revelou que areia e fibra de coco com Rootex C foi a melhor combinação para a propagação de buganvílias.
Palavras-chave: brotação, estacas lenhosas, fibra de coco, substrato.

*Corresponding author: iaasnirajan@gmail.com

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Introduction

Bougainvillea is a high value ornamental shrub available in a variety of colors and textures of the flower. Bougainvillea can be multiplied through air layering, root cuttings and stem cuttings. Hardwood stem cuttings with pencil size thickness and 15-25 cm length have been commercially practiced (Eed et al., 2015; Datta et al., 2020; Singh et al., 2020a). However, the rooting response may vary with variety, physiological stage of the mother plant, time of planting of the cuttings, environmental conditions (temperature and humidity) of propagation chamber, type of growth regulators and type and quality of rooting media used (Hartmann et al., 2011). Among different factors associated with cutting success, the plant growth regulators and rooting media have been found to have remarkable effect (Bosila et al., 2010; Singh et al., 2011; Mehraj et al., 2013; Eed et al., 2015; Marasini and Khanal, 2018).

Various auxins such as indole-3-acetic acid (IAA), indole-3-butyric acid (IBA) and naphthalene acetic acid (NAA) have been reported to promote rooting in the cuttings of bougainvillea (Ibironke, 2019). Both concentration and combination of rooting hormones and rooting media have found a direct effect on the rooting success of the cuttings. IBA or NAA or a combination of both is recommended by different studies (Parmar et al., 2010; Dawa et al., 2013; Kumar et al., 2014; Hajano et al., 2015; Abbas et al., 2015; Grewal, 2018). In addition, rooting media is another important factor that affects the propagation of cuttings (Shadparvar et al., 2011; Eed et al., 2015; Singh et al., 2020b). The selection and preparation of the medium are extremely important for rooting response and plant growth (Chaudhari et al., 2018). The better growth of roots can be attributed to the physical (structure, texture, aeration, porosity and water holding capacity) and chemical properties (pH, nutrient status, electrical conductivity and cation exchange capacity) of rooting media (Riaz et al., 2008). For the propagation of bougainvillea, different rooting media [soil, sand, silt, farmyard manure (FYM), coco peat, peat moss, perlite] and their combination have experimented (Bosila et al., 2010; Eed et al., 2015; Marasini and Khanal 2018; Singh et al., 2020b). A good combination of rooting hormone and rooting media hasten root initiation (Shadparvar et al., 2011; Marasini and Khanal, 2018; Aparna et al., 2021).

Currently, most of the floriculture farms are in Bagmati province, the central part of Nepal, in which Kathmandu valley and Chitwan share about 2/3rd of the total floriculture business in the country (Pun, 2019). The propagation of bougainvillea in Kathmandu valley is limited to the summer season only due to unfavorable environmental conditions (too cold and low relative humidity) in the winter. The terai (lowland regions in southern Nepal that lies south of the outer foothills of the Himalayas) area of Nepal is suitable for the propagation of bougainvillea round the year due to favorable environmental conditions. However, in central terai, the propagation is restricted due to sandy soil, as the sandy soil cannot fulfill the evapotranspiration demand of new leaves with no or undeveloped roots. Besides, ornamental plant nurseries in Kathmandu valley have acute space constraints and they prefer fast growing annuals and import Bougainvillea from India to fulfill the domestic demand. This creates not only a financial burden but also the possibility of entry of bio-hazard due to the possibility of introducing invasive pathogens through the soil. In this scenario, eastern terai of Koshi province can be the potential area to produce bougainvillea plant in sufficient quantity to meet the national demand. Therefore, the present experiment was carried out to elucidate the best combination of rooting hormone and rooting media for the propagation of bougainvillea through stem cutting.

Materials and Methods

The present study was carried out in the greenhouse of Institute of Agriculture and Animal Science (IAAS), Gauradaha Agriculture Campus, Gauradaha, Jhapa from April to July 2021. The experiment was carried out in a two factor randomized complete block design (RCBD) with eighteen treatments and three replications. There were a total of 54 experimental plots, with 6 cuttings per replication.

Treatment details

The treatments consisted of a combination of rooting hormones and rooting media (Table 1).

Table 1. Treatment combination of rooting hormones and rooting media.

S.N.	Treatments	Rooting hormones	Rooting media	Combination
1	T_1	Control (H_0)	Soil and FYM (M_1)	$H_0 \times M_1$
2	T_2	IBA (500 ppm) (H_1)	Soil and FYM (M_1)	$H_1 \times M_1$
3	T_3	IBA (1000 ppm) (H_2)	Soil and FYM (M_1)	$H_2 \times M_1$
4	T_4	NAA (1500 ppm) (H_3)	Soil and FYM (M_1)	$H_3 \times M_1$
5	T_5	NAA (3000 ppm) (H_4)	Soil and FYM (M_1)	$H_4 \times M_1$
6	T_6	Rootex C (H_5)	Soil and FYM (M_1)	$H_5 \times M_1$
7	T_7	Control (H_0)	Sand and FYM (M_2)	$H_0 \times M_2$
8	T_8	IBA (500 ppm) (H_1)	Sand and FYM (M_2)	$H_1 \times M_2$
9	T_9	IBA (1000 ppm) (H_2)	Sand and FYM (M_2)	$H_2 \times M_2$
10	T_{10}	NAA (1500 ppm) (H_3)	Sand and FYM (M_2)	$H_3 \times M_2$
11	T_{11}	NAA (3000 ppm) (H_4)	Sand and FYM (M_2)	$H_4 \times M_2$
12	T_{12}	Rootex C (H_5)	Sand and FYM (M_2)	$H_5 \times M_2$
13	T_{13}	Control (H_0)	Sand and Cocopeat (M_3)	$H_0 \times M_3$
14	T_{14}	IBA (500 ppm) (H_1)	Sand and Cocopeat (M_3)	$H_1 \times M_3$
15	T_{15}	IBA (1000 ppm) (H_2)	Sand and Cocopeat (M_3)	$H_2 \times M_3$
16	T_{16}	NAA (1500 ppm) (H_3)	Sand and Cocopeat (M_3)	$H_3 \times M_3$
17	T_{17}	NAA (3000 ppm) (H_4)	Sand and Cocopeat (M_3)	$H_4 \times M_3$
18	T_{18}	Rootex C (H_5)	Sand and Cocopeat (M_3)	$H_5 \times M_3$

”H” and “M” are rooting hormone and rooting media respectively. Rootex C (Manufacturer: Indo-Holland Gardening) is commercially available rooting hormone which do not require formulation. FYM (farm yard manure) is a type of cattle compost collected from local livestock farms.

Specification of greenhouse

The greenhouse had a top vent and was naturally ventilated. Its center was 5 meters tall and its sides were 3 meters. The roof was made of UV-stabilized plastic (200 micron), and a supplementary layer of white plastic shade net was employed. The insect net of 40 mesh was used on both sides of the greenhouse. The temperature and relative humidity of the greenhouse was partially controlled with the opening and closing of side roiling plastic.

Preparation of different concentration of rooting hormones

NAA and IBA were commercially available in powder form and their solutions were prepared first. To prepare stock solution of 1000 mg L^{-1} IBA, 1.0 g of IBA was first dissolved in 20 mL of 50% ethyl alcohol and final volume was made 1.0 L by adding distilled water. A similar procedure was followed to prepare the respective concentrations of IBA and NAA.

Preparation of cuttings

A healthy and well-grown 2-year-old bougainvillea plant of the local double red variety was selected and hardwood cuttings were prepared on 1st April, 2021. Each cutting was pencil-sized thick (1.0-1.5 cm diameter), 25-30 cm long and prepared with 3 nodes. The cuttings were given a slanting cut on the proximal end just below the lower node and a smooth cut on the distal end. The slanting end of prepared cuttings were immersed in distilled water before treatment with rooting hormones.

Preparation of rooting media

The media was prepared by mixing the respective constituents in a 1:1 ratio (v:v). The sand used in the media was sterilized before being mixed with cocopeat. The physiochemical properties of rooting substrates were also analyzed based on the procedure of Zheng et al. (2020) (Table 2).

Table 2. Physiochemical properties of different rooting substrate.

Media	pH	EC (dS m^{-1})	Bulk density (Kg m^{-3})
Soil and FYM	6	0.24	965
Sand and FYM	7.4	0.16	1015
Sand and Cocopeat	6.9	0.12	840

FYM (farm yard manure) is a type of cattle compost collected from local livestock farms, EC is the Electrical Conductivity.

Treatment of cuttings and planting

After giving a slanting cut at the proximal end, the proximal sides of the cuttings were treated by dipping them in rooting hormones for 1 hour and planted in the prepared rooting media on the planting tray at a depth of 3-4 cm.

Intercultural operation

Watering was done according to the moisture availability in the rooting media. Daily watering was done with a fine mist. The humidity of greenhouse was increased with the intermittent misting and periodic wetting of the floor. Manual weeding was done at 15 day intervals. Plant protection measures were followed for insect control.

Data collection

Data collection was started after the planting of cuttings. Phenological and climatic data (temperature and relative humidity) were recorded regularly. Phenological data were measured by using a measuring scale and digital Vernier caliper. The number of sprouted cuttings per plot was recorded daily after planting of cuttings and the average number of days taken for sprouting was calculated. The data on shoot parameters (total sprouted plants, sprout length/cutting, number of leaves/cutting, number of sprouts/cutting, sprout diameter and dry matter of sprout) and root parameters (root length/cutting, rooting percentage and dry matter of root) were recorded at 60 days of planting of cuttings. The shoot dry weight (SDW) and root dry weight (RDW) were measured by taking the weight of oven-dried samples at 72 ^{o}C for 72 hours. The transplanting success percentage was recorded at 20 days after planting rooted cuttings in a polybag. The sprouting percentage, rooting percentage and transplanting success percentage were calculated by using the following formula:

$$\text{Sprouting \%} = \frac{\text{number of sprouted cuttings}}{\text{total cuttings planted}} \times 100\%$$

$$\text{Rooting \%} = \frac{\text{number of rooted cuttings}}{\text{total number of cuttings planted}} \times 100\%$$

$$\text{Transplanting success (TS)\%} = \frac{\text{number of successfully transplanted plants}}{\text{total rooted cuttings transplanted}} \times 100\%$$

The temperature and relative humidity of the greenhouse were recorded by using a digital thermohygrometer (USB Data Logger, LASCAR, Kwun Tong, Kowloon, Hong Kong) throughout the research period (Table 3).

Statistical analysis

The data were entered into Microsoft Excel 2016 and analyzed using the SAS software (version 9.4). Mean separation was carried out using Fisher's least significant difference (LDS) at 0.05 level of significance ($p < 0.05$).

Table 3. Average temperature and relative humidity of the greenhouse.

Period	Temperature (^{o}C)	Relative humidity (%)
27th April-11th May, 2021	27.21	83.91
12th May-26th May, 2021	28.78	90.82
27th May-10th June, 2021	28.72	90.95
11th June-25th June, 2021	28.71	92.24
26th June-15th July, 2021	29.08	93.11

Results

Effect of rooting hormones and rooting media on sprouting of bougainvillea cuttings

A synergistic interaction effect of rooting hormones and rooting media on the sprouting of cuttings of bougainvillea was found (Table 4). The lowest number of days (10.33 days) taken for sprouting was observed in sand and cocopeat with IBA (500 mg L^{-1}), which was statistically similar to sand and cocopeat with IBA (1000 mg L^{-1}) and sand and cocopeat with NAA (3000 mg L^{-1}). The maximum number of days (32.33 days) to sprouting was observed in sand and FYM with IBA (500 mg L^{-1}), which was statistically at par with soil and FYM with IBA (500 mg L^{-1}) and soil and FYM with IBA (1000 mg L^{-1}). The highest sprouting percentage (100%) was recorded in sand and cocopeat with Rootex C. The least sprouting percentage (22.22%) was recorded in soil and FYM with IBA (1000 mg L^{-1}) followed by sand and FYM with NAA (3000 mg L^{-1}). Maximum numbers of sprouts (4.00) were observed in soil and FYM with NAA (1500 mg L^{-1}) which was statistically at par with sand and cocopeat with Rootex C and sand and cocopeat with control. Minimum sprouts (1.22) were observed in sand and cocopeat with NAA (3000 mg L^{-1}) followed by sand and FYM with IBA (500 mg L^{-1}) (Table 5).

Table 4. Analysis of variance of rooting hormones and media on sprouting of bougainvillea cuttings.

		Sprouting					
		No of days to sprouting		Sprouting percent		No. of sprouts	
Source of variation	df	MS	F	MS	F	MS	F
Replication	2	130.86	1.88	185.15	0.28	0.90	1.29
Treatment (H×M)	17	178.48**	2.56	1379.06*	2.17	1.84**	2.64
Error	34	69.75		642.68		0.70	

** Significant at $p \leq 0.01$, * Significant at $p \leq 0.05$, MS = Mean square, F = Value of F

Table 5. Effect of rooting hormones and media on sprouting of bougainvillea cuttings.

Treatment	No of days to sprouting	Sprouting percent	No of sprouts
Control × Soil and FYM	15.39^{bc}	77.78^{abc}	2.33^{bcde}
IBA (500 ppm) × Soil and FYM	31.00^{a}	50.00^{bcdef}	2.11^{cde}
IBA (1000 ppm) × Soil and FYM	31.00^{a}	22.22^{f}	2.67^{abcd}
NAA (1500 ppm) × Soil and FYM	13.83^{bc}	66.67^{abcde}	4.00^{a}
NAA (3000 ppm) × Soil and FYM	13.00^{bc}	72.22^{abcd}	3.22^{abc}
Rootex C × Soil and FYM	12.10^{bc}	61.11^{abcdef}	3.33^{abc}
Control × Sand and FYM	23.42^{abc}	44.44^{cdef}	2.67^{abcd}
IBA (500 ppm) × Sand and FYM	32.33^{a}	33.33^{def}	1.67^{de}
IBA (1000 ppm) × Sand and FYM	16.00^{bc}	33.34^{def}	2.00^{cde}
NAA (1500 ppm) × Sand and FYM	13.92^{bc}	50.00^{bcdef}	2.67^{abcd}
NAA (3000 ppm) × Sand and FYM	25.67^{ab}	27.78^{ef}	2.67^{abcd}
Rootex C × Sand and FYM	12.77^{bc}	44.44 ^{cdef}	3.00^{abcd}
Control × Sand and Cocopeat	12.22^{bc}	77.78^{abc}	3.89^{a}
IBA (500 ppm) × Sand and Cocopeat	10.33^{c}	66.67^{abcde}	2.89^{abcd}
IBA (1000 ppm) × Sand and Cocopeat	10.37^{c}	88.89^{ab}	3.66^{ab}
NAA (1500 ppm) × Sand and Cocopeat	12.50^{bc}	66.67^{abcde}	2.33^{bcde}
NAA (3000 ppm) × Sand and Cocopeat	11.25^{c}	66.67^{abcde}	1.22^{e}
Rootex C × Sand and Cocopeat	12.22^{bc}	100.00^{a}	3.89^{a}
LSD	13.85**	42.06*	1.38**
CV	48.60	43.45	29.95

Means are an average of three replications. Means in a column followed by the same letter do not differ according to Fisher's least significant difference (LSD) at 0.05 level ($p < 0.05$). Where, * represents significant ($p \leq 0.05$), ** represents highly significant ($p \leq 0.01$), CV is the coefficient of variation (%).

Effect of rooting hormones and rooting media on shoot parameters of bougainvillea cuttings

The effect of rooting hormones and media was significant for most of the shoot parameters except for diameter of sprouts as shown by Analysis of variance (Table 6). The length of the longest sprout was found in sand and cocopeat with Rootex C (49 cm), while the shortest length was recorded in sand and FYM with IBA (500 mg L^{-1}) (9.50 cm). The maximum length of sprouts (24.71 cm) was observed in sand and cocopeat with NAA (3000 mg L^{-1}), followed by sand and cocopeat with Rootex C and sand and cocopeat with control. The minimum length of sprout (4.03 cm) was observed in sand and FYM with Rootex C, followed by soil and FYM with control and soil and FYM with IBA (500 mg L^{-1}). The maximum number of leaves (18.67) was recorded in sand and cocopeat with NAA (3000 mg L^{-1}), which was at par with sand and FYM with IBA (1000 mg L^{-1}. The minimum number of leaves per cutting (7.14) was recorded in soil and FYM with control, followed by sand and FYM with Rootex C. The highest shoot fresh weight (10.04 gm) was observed in sand and cocopeat with IBA (1000 mg L^{-1}) while the least shoot fresh weight (0.06 gm) was observed in sand and FYM with IBA (1000 mg L^{-1}). The highest shoot dry weight (2.09 gm) was observed in sand and cocopeat with IBA (1000 mg L^{-1}) which was statistically at par with sand and cocopeat with Rootex C. The least shoot dry weight (0.01 gm) was recorded in sand and FYM with IBA (1000 mg L^{-1}), which was statistically at par with sand and FYM with IBA (500 mg L^{-1}) (Table 7).

Table 6. Analysis of variance of rooting hormones and media on shoot parameters of bougainvillea cuttings.

		Shoot parameters									
		Length of longest sprout		Diameter of sprouts		Number of leaves		Shoot fresh weight		Shoot dry weight	
Source of variation	df	MS	F	MS	F	MS	F	MS	F	MS	F
Replication	2	79.37	0.44	0.008	1.22	12.86	1.32	0.37	0.05	0.007	0.02
Treatment (H×M)	17	479.59**	2.65	0.012^{ns}	1.86	33.77**	3.47	22.56**	3.71	1.48**	4.74
Error	34	181.05		0.007		9.74		6.89		0.31	

** Significant at $p \leq 0.01$, ns-non significant ($p > 0.05$), MS = Mean square, F = Value of F.

Table 7. Effect of rooting hormones and media on shoot parameters of bougainvillea cuttings.

Treatment	Length of longest sprouts (cm)	Diameter of sprouts (cm)	Number of leaves	SFW (gm)	SDW (gm)
Control × Soil and FYM	14.17^{f}	0.17	7.14^{g}	1.26^{def}	0.33^{def}
IBA (500 ppm) × Soil and FYM	14.17^{f}	0.18	8.40^{efg}	1.59^{def}	0.39^{def}
IBA (1000 ppm) × Soil and FYM	25.83^{bcdef}	0.30	13.53^{abcde}	2.57^{cdef}	0.50^{def}
NAA (1500 ppm) × Soil and FYM	48.00^{ab}	0.38	12.98^{bcde}	5.42^{bcd}	1.08^{bcd}
NAA (3000 ppm) × Soil and FYM	29.83^{abcdef}	0.27	9.88^{cdefg}	3.23^{cdef}	0.69^{def}
Rootex C × Soil and FYM	30.00^{abcdef}	0.27	9.18^{cdefg}	2.77^{cdef}	0.52^{def}
Control × Sand and FYM	15.83^{ef}	0.24	9.00^{cdefg}	0.63^{ef}	0.13^{ef}
IBA (500 ppm) × Sand and FYM	9.50^{f}	0.20	8.89^{defg}	0.13^{f}	0.03^{f}
IBA (1000 ppm) × Sand and FYM	22.00^{cdef}	0.32	18.00^{ab}	0.06^{f}	0.01^{f}
NAA (1500 ppm) × Sand and FYM	23.67^{cdef}	0.28	11.72^{cdefg}	1.84^{ef}	0.37^{def}
NAA (3000 ppm) × Sand and FYM	19.67^{def}	0.26	10.55^{cdefg}	1.23^{def}	0.25^{def}
Rootex C × Sand and FYM	13.50^{f}	0.18	7.35^{fg}	4.58^{bcde}	0.96^{cde}
Control × Sand and Cocopeat	42.33^{abc}	0.32	14.16^{abc}	7.76^{ab}	1.94^{ab}
IBA (500 ppm) × Sand and Cocopeat	43.33^{abc}	0.34	13.96^{abcd}	6.53^{abc}	1.81^{abc}
IBA (1000 ppm) × Sand and Cocopeat	39.67^{abcd}	0.37	13.79^{abcd}	10.04^{a}	2.09^{a}
NAA (1500 ppm) × Sand and Cocopeat	25.67^{cdef}	0.25	12.33^{cdef}	2.10^{def}	0.31^{def}
NAA (3000 ppm) × Sand and Cocopeat	36.67^{abcde}	0.31	18.67^{a}	2.96^{cdef}	0.56^{def}
Rootex C × Sand and Cocopeat	49.00^{a}	0.32	14.16^{abc}	7.76^{ab}	1.94^{ab}
LSD	22.32*	0.13^{ns}	5.17**	4.35**	0.92**
CV	48.16	29.32	26.28	75.64	72.39

Means are an average of three replications. Means in a column followed by the same letter do not differ according to Fisher's least significant difference (LSD) at 0.05 level ($p < 0.05$). Where, * represents significant ($p \leq 0.05$), ** represents highly significant ($p \leq 0.01$), ns represents non significant ($p > 0.05$), CV is the coefficient of variation (%), SFW is Shoot Fresh Weight, SDW is Shoot Dry Weight.

Effect of rooting hormones and rooting media on root parameters of bougainvillea cuttings

Analysis of variance showed that effect of rooting hormones and rooting media was significant for length of root, number of roots, root fresh weight and root dry weight and non-significant for rooting percentage and transplanting success percentage (Table 8). The highest root length (13.75 cm) was reported in sand and cocopeat with IBA (1000 mg L^{-1}) while the lowest root length (1.50 cm) was reported in sand and FYM without rooting hormone. The highest number of roots (34.17) was observed in sand and cocopeat with IBA (1000 mg L^{-1}), which was statistically at par with all other treatments belonging to sand and cocopeat. Meanwhile, the lowest number of roots (1.17) was observed in sand and FYM with control. Maximum root fresh weight (2.33 gm) and dry weight (0.24 gm) were recorded in sand and cocopeat with IBA (1000 mg L^{-1}). The minimum root fresh weight (0.02 gm) was observed in soil and FYM with IBA (1000 mg L^{-1}) and sand and FYM with control, while the minimum root dry weight was observed in sand and FYM with IBA (1000 mg L^{-1}) (Table 9).

Table 8. Analysis of variance of rooting hormones and media on root parameters of bougainvillea cuttings.

		Root parameters											
		Length of root		Number of roots		Root fresh weight		Root dry weight		Rooting percentage		Transplanting success	
Source of variation	df	MS	F	MS	F	MS	F	MS	F	MS	F	MS	F
Replica-tion	2	12.70	0.73	1.89	0.03	0.39	1.58	0.002	0.53	1255.15	0.79	2638.89	1.80
Treatment (H×M)	17	35.61*	2.05	455.69**	6.66	1.15**	4.60	0.012**	2.92	2453.42^{ns}	1.55	1593.14^{ns}	1.09
Error	34	17.33		68.37		0.25		0.004		1581.94		1462.42	

** Significant at $p \leq 0.01$; * Significant at $p \leq 0.05$; ns-not significant, MS = Mean square, F = Value of F.

Table 9. Effect of rooting hormones and media on root parameters of bougainvillea cuttings.

Treatment	Length of root (cm)	Number of roots	RFW (gm)	RDW (gm)	Rooting percent	TS percent
Control × Soil and FYM	2.65^{cd}	1.83^{c}	0.04^{e}	0.01^{e}	27.78	100.00
IBA (500 ppm) × Soil and FYM	3.18^{cd}	4.17^{c}	0.09^{de}	0.03^{bcde}	50.00	66.67
IBA (1000 ppm) × Soil and FYM	5.47^{bcd}	8.00^{c}	0.02^{e}	0.04^{bcde}	33.33	33.33
NAA (1500 ppm) × Soil and FYM	7.78^{abcd}	13.17^{bc}	0.32^{bcde}	0.07^{bcde}	83.33	100.00
NAA (3000 ppm) × Soil and FYM	4.32^{cd}	7.00^{c}	0.17^{cde}	0.04^{bcde}	50.00	100.00
Rootex C × Soil and FYM	5.30^{bcd}	8.67^{c}	0.19^{cde}	0.04^{bcde}	50.00	66.67
Control × Sand and FYM	1.50^{d}	1.17^{c}	0.02^{e}	0.01^{e}	33.33	66.67
IBA (500 ppm) × Sand and FYM	6.00^{bcd}	4.00^{c}	0.07^{de}	0.01^{e}	66.67	66.67
IBA (1000 ppm) × Sand and FYM	3.00^{cd}	2.00^{c}	0.04^{e}	0.00^{e}	33.33	33.33
NAA (1500 ppm) × Sand and FYM	4.50^{cd}	3.50^{c}	0.06^{e}	0.02^{cde}	100.00	100.00
NAA (3000 ppm) × Sand and FYM	3.00^{cd}	2.33^{c}	0.04^{e}	0.01^{de}	66.67	66.67
Rootex C × Sand and FYM	3.52^{cd}	11.50^{c}	0.99^{c}	0.12^{bcd}	50.00	66.67
Control × Sand and Cocopeat	9.48^{abc}	30.83^{a}	0.98^{bc}	0.12^{bc}	100.00	83.33
IBA (500 ppm) × Sand and Cocopeat	8.20^{abcd}	31.00^{a}	1.10^{b}	0.09^{bcde}	100.00	100.00
IBA (1000 ppm) × Sand and Cocopeat	13.75^{a}	34.17^{a}	2.33^{a}	0.24^{a}	100.00	100.00
NAA (1500 ppm) × Sand and Cocopeat	11.78^{ab}	27.00^{a}	0.62^{bcde}	0.12^{bcd}	100.00	100.00
NAA (3000 ppm) × Sand and Cocopeat	8.70^{abc}	25.50^{ab}	0.90^{bcd}	0.13^{b}	100.00	100.00
Rootex C × Sand and Cocopeat	9.48^{abc}	30.80^{a}	0.98^{bc}	0.12^{bc}	100.00	100.00
LSD	6.90*	13.73^{**}	0.82^{**}	0.10^{**}	65.9^{ns}	63.45^{ns}
CV	67.14	60.34	99.9	95.83	57.52	47.47

Means are an average of three replications. Means in a column followed by the same letter do not differ according to Fisher's least significant difference (LDS) at 0.05 level ($p < 0.05$). Where, * represents significant ($p \leq 0.05$), ** represents highly significant ($p < 0.01$), ns represents non significant ($p > 0.05$), CV is the coefficient of variation (%), RFW is Root Fresh Weight, RDW is Root Dry Weight, TS is Transplanting Success.

Discussion

Studies have shown that exogenous application of rooting hormones stimulates the formation of adventitious roots and enhances the rooting percentage and quality of stem cuttings (Hartmann et al., 2002; Dirr and Heuser, 2006). IBA and NAA have been the choices of horticulturists for the commercial propagation of bougainvillea through hardwood stem cuttings (Parmar et al., 2010; Grewal, 2018). Soil and FYM are popularly used as conventional rooting media, but nowadays, commercial nurseries mostly prefer the cocopeat medium due to its desirable physical and chemical properties (high water holding capacity, high porosity, high cation exchange capacity, cost effective, easy to use, organic and ecofriendly) (Datta et al., 2022). The present study clearly indicated that the number of days taken to sprouting has been governed by the rooting media rather than rooting hormone because a statistically similar result was recorded within the sand and cocopeat media with or without rooting hormones. Contrary to the findings of Marasini and Khanal (2018), the present result revealed that sand and cocopeat media produced sprouts earlier as compared to sand and FYM and sand and soil. The appropriate texture of sand and cocopeat media holds water, prevents compaction and allows enough space for root growth, allowing plants to sprout and grow earlier (Fagge and Manga, 2011). Though, the result of the effect of rooting hormone on the number of days to sprouting was like the findings of Marasini and Khanal (2018), our data indicated a slightly better result in IBA at concentration of 500 mg L^{-1} and 1000 mg L^{-1}. Rootex C is a broad-spectrum commercial plant growth regulator which contains vitamins, minerals, sucrose and stabilizers in addition to the rooting hormone and thus promotes sprouting and survivability. The proper growth of shoots and roots under suitable hormones and rooting media could produced the maximum sprouted plants per plot, which might be the reason for the highest sprouting percentage in sand and cocopeat media with Rootex C. The effect of Rootex on the rooting ability, sprouting and survival of different plants was reported by Tiwari et al. (2015) and Siddique et al. (2009). This combination of sand and cocopeat media with Rootex C could be the propagation protocol for Bougainvillea producers in Nepal thereby increasing domestic production and decreasing imports.

Rootex C enriched with sucrose, vitamins and minerals triggered the growth of sprouted plants, which in turn produced the maximum height of sprouts. The effectiveness of Rootone was similar to IBA and NAA for shoot length as reported by Yoon et al. (2021). In our experiment, the performance of cuttings was better in sand and cocopeat media irrespective of rooting hormones implying the importance of moisture and aeration in the media for the root growth. The cuttings with better root growth sustains the moisture loss from the sprouts and consequently increases survival percentage as has been exhibited in sand and cocopeat. A better result recorded in sand and cocopeat media for shoot parameters (length of sprouts, number of leaves, shoot dry weight and shoot fresh weight) might be due to the superior properties of sand and cocopeat as compared to other media for rooting and subsequent growth of cuttings. A good water holding capacity of cocopeat and ample aeration ability of sand combined with suitable rooting hormones are attributed to significantly better growth of cuttings. The aeration encourages aerobic root respiration which generates ATP in the form of energy, thus promoting root and shoot growth of cuttings. The present result was in line with the Singh et al. (2020b), who reported the good result of shoot growth in sand and cocopeat media next to sand:cocopeat:perlite media. The result shows that sand and cocopeat with NAA 3000 mg L^{-1} was efficient for leaf production as compared to other rooting hormones which might be due to the higher average length of sprouts. The highest shoot fresh weight and shoot dry weight were attributed to the highest number of sprouts per cutting, average length of sprouts and growth of sprouts. Yeshiwas et al. (2015) also reported maximum shoot fresh weight and shoot dry weight in IBA 1000 mg L^{-1}. The present result was similar to the findings of Marasini and Khanal (2018), who reported an non--significant result in the diameter of sprouts.

This study revealed that root parameters were better in sand and cocopeat with IBA (1000 mg L^{-1}). The various aspects of root development are influenced by IBA such as the formation of adventitious roots, regulation of root apical meristem size, root hair elongation and lateral root development (Frick and Strader, 2018). The better performance of roots in sand and cocopeat media with IBA (1000 mg L^{-1}) might be due to apical meristematic activities and cambial division. The present result was similar to the finding of Gupta et al. (2002) who reported the maximum number of roots and rooting percentage in IBA 1000 mg L^{-1} in bougainvillea. Susaj et al. (2012) also recorded the maximum number of roots by using IBA 1000 mg L^{-1} in rose. Mehraj et al. (2013) reported similar results in bougainvillea cuttings. The highest root fresh weight in sand and cocopeat media with IBA (1000 mg L^{-1}) was attributed to the number of roots per cutting. The present finding was similar to that of Baldotto et al. (2012), who reported the highest accumulation of root dry matter of hibiscus at 970 mg L^{-1} IBA. The present finding was similar to Yeshiwas et al. (2015) for the number of roots and dry weight of roots. However, many previous studies conducted on different species of bougainvillea have shown that significantly better results were observed for root and shoot parameters at higher concentrations of IBA than in the present experiment (Parmar et al., 2010; Singh et al., 2011; Asl et al., 2012; Kuldeep et al., 2013). The strong shoot and root inducing capacity of Rootex C and IBA (1000 mg L^{-1}) combining with acceptable pH, electrical conductivity and other physical (lower bulk density, good aeration, good water holding capacity) and chemical properties of sand and cocopeat media (Krishnapillai et al., 2020; Singh et al., 2022) hastened the overall performance of bougainvillea cuttings.

Conclusions

We conclude that sand and cocopeat media with Rootex C was the most effective for the vegetative propagation of bougainvillea through hardwood cuttings. Most of the shoot and root parameters were superior in sand and cocopeat media but among rooting hormones, IBA (1000 mg L^{-1}) is seen as a good alternative to Rootex C. However, for the commercial propagation, a higher concentration of IBA and a combination of suitable medium with cocopeat needs to be evaluated.

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Authors contribution

JS and SB: Conducted field work, obtained results and compiled the data; **NB:** designed the experiment and drafted the manuscript; **SPM:** analyzed the data and edited the manuscript; **UP:** provided research idea, supervised the experiment and edited the manuscript.

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