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Effects of Morphological Age and Indole-3-Butyric Acid Concentration on Rooting of Selected Robusta Coffee Varieties

Elijah Epedu[1,2], Godfrey H. Kagezi[2*], Jenipher Bisikwa[1], Ephraim Nuwamanya[1], Emmanuel Ejiet-Igolat[1], Jonath Manirakiza[1], Betty Magambo[2], and Geofrey Arinaitwe[2]

[1]College of Agricultural and Environmental Sciences (CAES), Makerere University,
P.O. Box 7062 University Road, Kampala, Uganda
[2]National Coffee Research Institute (NaCORI)/National Agricultural Research Organisation (NARO),
P.O. Box 185, Mukono, Uganda
[*]Corresponding author: gkagezi@gmail.com
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Abstract

In response to the outbreak of Coffee Wilt Disease (CWD) which wiped out almost 50% of Robusta coffee in Uganda, the National Coffee Research Institute (NaCORI) released 10 varieties (KR1-10) which are resistant to the disease. These varieties are being multiplied by stem cuttings for commercialization, although some of them present challenges in rooting. Research shows that rooting ability of stem cuttings is a function of the variety, their morphological status and rooting hormone used, among other factors. We therefore conducted an on-station study to determine the effect of morphological age of the stem cuttings and Indole-3-Butyric Acid (IBA) rooting hormone concentration on the rooting ability of varieties, KR1, KR3 and KR4. A factorial experiment with three stem segments with differing morphological age (softwood, semi-hardwood and hardwood) and six IBA concentration levels (0, 1, 2, 4, 7, and 10g/L) was set up for each variety in a completely randomized design and replicated five times. Results showed that the number of roots produced by stem cuttings varied significantly ($p \leq 0.05$) across varieties and IBA concentration level but not the morphological age of the cuttings. The highest number of roots was recorded on variety KR4, (35.3), 2 g/L of IBA (31.5) and softwood cuttings (29.1). Furthermore, the number of roots produced by stem cuttings varied significantly ($P<0.00001$) across combinations of factors. The highest number of roots was recorded on softwood treated with 10 g/L of IBA rooting hormone for KR1, hardwood cuttings treated with 2 g/L of IBA for KR3 and softwood cuttings treated with 2 g/L of IBA for KR4. For the three CWD-r Robusta coffee varieties evaluated, our findings provide a guide on variety-specific IBA rooting hormone concentrations for enhancing the rooting ability of stem cuttings of these CWD-r Robusta coffee varieties. We therefore recommend that similar studies be conducted on other CWD-r Robusta varieties such as KR8 which also has been recently reported for challenges of rooting of its stem cuttings.

Keywords: Coffee-Wilt-Disease, CWD-r, hardwood, KR, semi-hardwood, softwood

INTRODUCTION

Despite the fact that Robusta coffee, *Coffea canephora* (Pierre Ex A. Froehner) contributes >80% of the current coffee export volumes of Uganda as well as supporting millions of Ugandans along the value chain (MAAIF, 2025; NPA, 2024), its productivity of 0.5 t ha^{-1} (Nakyagaba *et al*., 2024) is far below the yields of >2.3 t ha^{-1} reported in other Robusta coffee growing countries such as Vietnam (ICO, 2019). This is due to a number of biotic and abiotic constraints, among other factors (Kyalo *et al*., 2025; Olango *et al*., 2024; Nakyagaba *et al*., 2024; Wang *et al*., 2015). Among the biotic factors, Coffee Wilt Disease (CWD), caused by the fungus *Fusarium xylarioides* which was first reported in 1993 in the western district of Bundibugyo and wiped out almost half of the Robusta coffee in Uganda causing an economic loss of more than US 100 million (Musoli *et al*., 2003; CABI, 2003) has been the most important (Peck & Boa, 2024).

In response, the National Coffee Research Institute (NaCORI) of the National Agricultural Research Organization (NARO), developed and released ten Coffee Wilt Disease-resistant Robusta coffee varieties (Kituza Robusta, KR1–KR10) that were developed and officially released as varieties through recurrent selection and evaluation of diverse Robusta germplasm in Uganda (Musoli *et al*., 2008, 2013, 2017). Kituza Robusta (KR) are varieties because they originated from genetically distinct populations that consistently expressed resistance to CWD under evaluation across multiple environments (Musoli *et al*., 2017). However, Robusta coffee (*Coffea canephora*) being an obligate outcrosser with a high degree of heterozygosity, seed propagation does not guarantee genetic fidelity in terms of uniformity, resistance, and yield traits (Espindula *et al*., 2022). While seed gardens can be used to generate planting material of the KR's, progenies derived from seeds of these KR's would segregate genetically, leading to variability and possible loss of the resistance trait (Musoli *et al*., 2008). To address this challenge therefore, vegetative propagation using either tissue culture or rooting of stem cuttings approaches which maintain the genetic identity of the propagated clones are usually employed (Espindula *et al*., 2022; Simanjuntak & Wardani, 2021; UCDA, 2019). These approaches ensure that farmers receive uniform and genetically identical plants that retain the CWD resistance identified in the original selections (UCDA, 2019; Travis *et al*., 2018).

Research shows that the rooting ability of these stem cuttings is a function of the variety (Vallejos-Torres *et al.,* 2020; Magesa *et al*., 2020), physiological and morphological status of the cutting (Simanjuntak & Wardani, 2021; Magesa *et al*., 2020; Giuriatto *et al*., 2020), rooting hormone (Chichipe Oyarce *et al*., 2021; Marques Cavalcanti Filho *et al*., 2018), growth medium (Salinas-Ruiz *et al*., 2021; Magesa *et al*., 2018) and rooting environment (Oliveira *et al*., 2011), among others. The rooting ability of cuttings from woody or perennial plants has been reported to decline with an increase in the mother plant's physiological and morphological age (Santoso & Parwata, 2014), whereas, Bijalwan & Thakur, (2010) stated that the position of cutting and the age of the mother plant played a significant role in rooting and sprouting. Depending on their maturity or juvenility, stem cuttings can therefore be categorized as hardwood, semi-hardwood, or softwood (Mehta *et al*., 2018). According to Simanjuntak & Wardani (2021), and Mehta *et al*. (2018), softwood cuttings are taken from upper most young, actively growing shoots that are tender and not fully lignified whereas, semi-hardwood are from middle positions along the sucker with partially matured shoots that have begun to lignify but still retain some flexibility. On the other hand, hardwood cuttings are obtained from basal positions along a sucker with fully mature, lignified stems. Semi-hardwood cuttings have been reported to form better roots than hardwood and softwood cuttings (Simanjuntak & Wardani, 2021). The Coffee Department of the Ministry of Agriculture, Animal Industry and Fisheries (MAAIF) of Uganda therefore recommends that nursery operators should use semi-hard wood tissue for raising coffee seedlings from cuttings (UCDA, 2019).

Furthermore, hormones are often used in the commercial propagation of cuttings so as to guarantee faster and more uniform rooting (Hunt *et al*., 2010). Treating the basal portions of stem cuttings with synthetic auxins improves rooting success rate, speed of rooting and quantity of adventitious roots which reduces exposure to stress and improves uniformity (Caplan *et al*., 2009). The most common synthetic auxins used in plant propagation, Indole-3-Butyric Acid (IBA), Indole Acetic Acid (IAA) and Naphthalene Acetic Acid (NAA), are among the recommended rooting hormones for woody species of stem cuttings (Sourati *et al*., 2022; Ullah *et al*., 2013). In Uganda, powdered IBA is the most widely utilized rooting hormone for propagation of stem cuttings of coffee (UCDA, 2019). However, there is a need to conduct detailed research studies to establish the best-bet IBA rooting hormone concentrations for enhancing roots of stem segments of different morphological and physiological status of these newly released CWD-r Robusta coffee varieties.

Basing on this backdrop, we therefore conducted an on-station study to determine the effect of the status (morphological and physiological) of the stem cutting and concentration levels of Indole-3-Butyric Acid (IBA) rooting hormone on the rooting ability of three selected CWD-r Robusta coffee varieties. Specifically, we hypothesized that: i) rooting ability of cuttings depends on the CWD-r Robusta coffee variety in question, ii) the rooting ability of stem cuttings derived from the CWD-r Robusta coffee varieties depending on their status (morphological and physiological), iii) increasing the concentration of IBA hormone enhances the rooting ability of stem cuttings of CWD-r Robusta coffee varieties, and, iv) the combined effect of the morphological status of the stem cuttings and the IBA concentration increases the rooting ability of the stem cuttings derived from the three selected CWD-r Robusta coffee varieties.

MATERIALS AND METHODS

Study Area

The study was conducted at the National Agricultural Coffee Research Institute (NaCORI) station. The Institute is located about 37 km east of Kampala (Latitude: 0.25718; Longitude: 32.79036) and at an altitude of 1,205 meters above sea level (asl.) in Kituza village, Ntenjeru sub-county, Mukono district, central Uganda (Figure 1) (Epedu, 2025). The area has a tropical climate with a bi-modal rainfall pattern, the mean annual rainfall is 1,100 mm distributed over 106 rain days, with peaks in March-May and September–November and the temperatures ranges between 16 and 28^{O}C throughout the year (Kobusinge *et al*., 2023). The topography of the area consists of sloping land with many undulations dominated by sandy loam soil and the vegetation cover is of the forest/savannah which are characterized by patches of dense forest (Mukono District, 2016).

Experimental Design

Uniform orthotropic suckers of selected three CWD-r Robusta coffee varieties (KR1, KR3, and KR4) that have difficulty with rooting (UCDA, 2017) were used in this

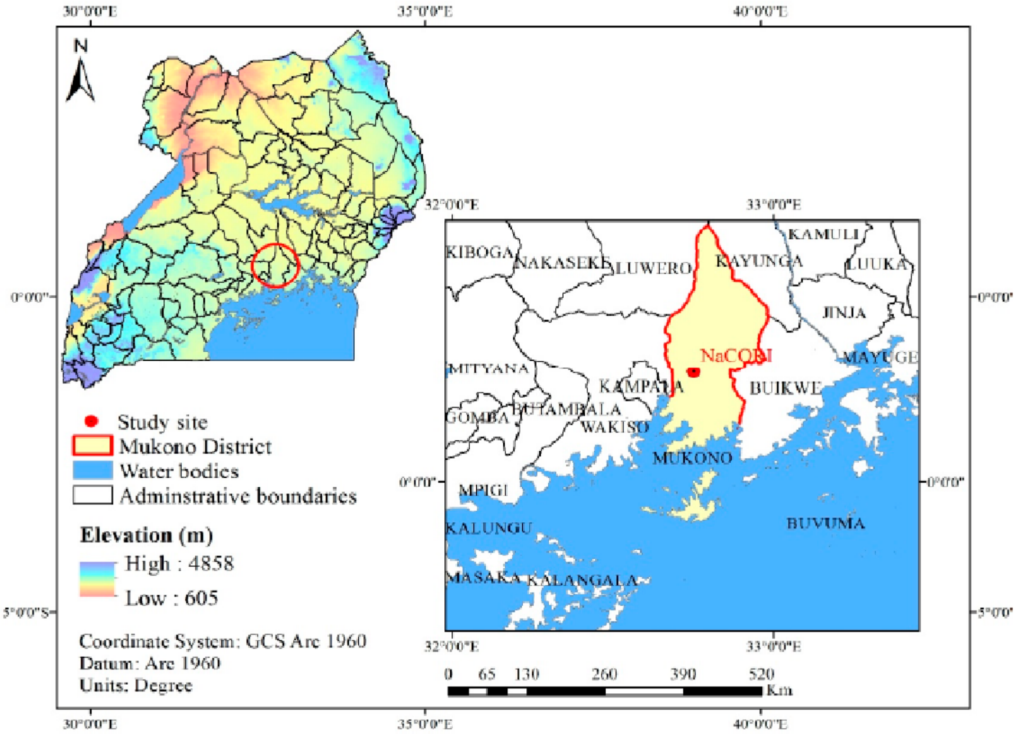

Figure 1. Location of the study area in Mukono District, Central Uganda
(Source: Kobusinge *et al*., 2023).

study. Due to the fact that the response of the three CWD-r Robusta coffee varieties to the IBA hormone differs (Magesa *et al*., 2018), a separate experiment was conducted for each variety using a factorial completely randomized design (CRD), replicated five (5) times. Factor A consisted of three (3) stem segments of different morphological and physiological status; softwood, semi-hardwood and hardwood cuttings (Mehta *et al*., 2018) while, factor B consisted of five (5) concentration levels of Indole-3- Butyric Acid (IBA) rooting hormone (0, 1, 2, 4, 7, and 10g/L). For each variety, the 0g/L acted as the control for each stem segment. Thus, the study had 54 treatments including the controls as summarized in Table 1 below.

Preparation of Materials and Media

Suckers with three (3) fully differentiated internodes were harvested early in the morning from 12-year-old vigorous mother plants of CWD-r Robusta coffee varieties, KR1, KR3 and KR4 at NaCORI. The harvested suckers were clipped into 7 cm long stem cuttings, with a pair of half-cut leaves. The clipped stem segments were grouped as follows: -the first stem segment from the upper shoot was referred to as the 'soft-wood' segment, the second stem segment from the upper shoot was called the 'semi-hardwood' segment and the basal stem segment was referred to as the 'hardwood' segment.

Indole-3-Butyric Acid (IBA) rooting hormone was used to promote rooting in various stem segments. On the other hand, the black forest loam soil and lake sand in the ration of 2:1 were the rooting substrates used. The mixture was added directly into potting bags for initiation of cuttings. After the cuttings were prepared, their wounded

Table 1. Experimental treatments used for determining the best stem segments at different IBA rooting hormone concentration levels for enhancing rooting of CWD-r Robusta coffee cuttings

KR1	KR3	KR4
T_{11}= Softwood-IBA, 0 g/L	T_{31}= Softwood-IBA, 0 g/L	T_{41}= Softwood-IBA, 0 g/L
T_{12}= Softwood-IBA, 1 g/L	T_{32}= Softwood-IBA, 1 g/L	T_{42}= Softwood-IBA, 1 g/L
T_{13}= Softwood-IBA, 2 g/L	T_{33}= Softwood-IBA, 2 g/L	T_{43}= Softwood-IBA, 2 g/L
T_{14}= Softwood-IBA, 4 g/L	T_{34}= Softwood-IBA, 4 g/L	T_{44}= Softwood-IBA, 4 g/L
T_{15}= Softwood-IBA, 7 g/L	T_{35}= Softwood-IBA, 7 g/L	T_{45}= Softwood-IBA, 7 g/L
T_{16}= Softwood-IBA, 10 g/L	T_{36}= Softwood-IBA, 10 g/L	T_{46}= Softwood-IBA, 10 g/L
T_{17}= Semi-hardwood-IBA, 0 g/L	T_{37}= Semi-hardwood-IBA, 0 g/L	T_{47}= Semi-hardwood-IBA, 0 g/L
T_{18}= Semi-hardwood-IBA, 1 g/L	T_{38}= Semi-hardwood-IBA, 1 g/L	T_{48}= Semi-hardwood-IBA, 1 g/L
T_{19}= Semi-hardwood-IBA, 2 g/L	T_{39}= Semi-hardwood-IBA, 2 g/L	T_{49}= Semi-hardwood-IBA, 2 g/L
T_{10}= Semi-hardwood-IBA, 4 g/L	T_{310}= Semi-hardwood-IBA, 4 g/L	T_{410}= Semi-hardwood-IBA, 4 g/L
T_{111}= Semi-hardwood-IBA, 7 g/L	T_{311}= Semi-hardwood-IBA, 7 g/L	T_{411}= Semi-hardwood-IBA, 7 g/L
T_{112}= Semi-hardwood-IBA, 10 g/L	T_{312}= Semi-hardwood-IBA, 10 g/L	T_{412}= Semi-hardwood-IBA, 10 g/L
T_{113}= Hardwood-IBA, 0 g/L	T_{313}= Hardwood-IBA, 0 g/L	T_{413}= Hardwood-IBA, 0 g/L
T_{114}= Hardwood-IBA, 1 g/L	T_{314}= Hardwood-IBA, 1 g/L	T_{414}= Hardwood-IBA, 1 g/L
T_{115}= Hardwood-IBA, 2 g/L	T_{315}= Hardwood-IBA, 2 g/L	T_{415}= Hardwood-IBA, 2 g/L
T_{116}= Hardwood-IBA, 4 g/L	T_{316}= Hardwood-IBA, 4 g/L	T_{416}= Hardwood-IBA, 4 g/L
T_{117}= Hardwood-IBA, 7 g/L	T_{317}= Hardwood-IBA, 7 g/L	T_{417}= Hardwood-IBA, 7 g/L
T_{118}= Hardwood-IBA, 10 g/L	T_{318}= Hardwood-IBA, 10 g/L	T_{418}= Hardwood-IBA, 10 g/L

bases were immersed in different concentrations of IBA rooting hormone for 30 minutes. The cuttings were then planted vertically in a sterile sieved growth medium in potting bags (polybags) which were then maintained in a shedding house with shed intensity of 70%.

Data Collection

Data were collected after 90 days by establishing the number of rooted cuttings, dead cuttings, and total roots. In addition, root length as well as fresh and dry root mass were also determined.

Data Analysis

Data were entered into Microsoft Excel program and exported to the R software (Version 4.4.2, 2024-10-31 ucrt) for analysis. Chi-square analysis was used to compare the percentage of rooted cuttings across the three selected CWD-r varieties, the morphological age of the stem cuttings, and the levels of IBA concentration. In addition, analysis of variance (ANOVA) with general linear model (GLM) procedure was used to compare the rooting parameters including: - the number, length of longest as well as the fresh and dry weights of the roots across the three selected CWD-r Robusta coffee varieties. ANOVA was also used to determine the interaction effects between the morphological stage of the cuttings and IBA concentration as well as the effect of their combinations on the above-mentioned parameters. Means were separated by Scheffe test at 5%.

RESULTS AND DISCUSSION

Effect of Coffee Wilt Disease Resistant (CWD-r) Robusta Coffee Varieties on Rooting of Stem Cuttings

The results of the varietal effect on rooting of stem cuttings are presented in Table 2 below. The percentage of stem cuttings that rooted was not significantly ($\chi^2 = 0.9250$; $p = 0.6297$) different across the varieties, contradicting studies by Vallejos-Torres *et al.* (2020) and Magesa *et al.* (2020), who reported significant variations across varieties in Tanzania and Peru, respectively. However, CWD-r variety KR4 registered the higher number of rooted cuttings (84.3%) compared to KR1

(77.7%) and KR3 (72.3%). Similarly, Magasa *et al.* (2020) reported that the percentage of rooted cuttings of variety KP423-2 was 58.1% and higher than varieties N39-4 (44.6%) and KP423-1 (38.5%). Also, Arabica coffee variety Caturra showed a higher rooting percentage (63.34%) compared to the Pache (40%) and Nacional (55%) varieties when propagated by sprouts (Vallejos-Torres *et al.,* 2020). The variations in the percentage of the cuttings which rooted observed in our study is probably in part due to the differences in the genetic, physiological and morphological characteristics of the varieties tested (Vallejos-Torres *et al*., 2020; Magesa *et al*., 2020).

Furthermore, the number of roots produced, length of longest roots as well as the fresh and dry weights of roots varied significantly ($p \leq 0.05$) across the varieties, with all the values being highest on CWD-r variety KR4 (35.3, 9.6, 1.5 and 0.5, respectively; Table 3). Our finding agrees with research studies conducted on coffee by Vallejos-Torres *et al.* (2020) and Magesa *et al.* (2020; 2018). This could in part be due to the differences in morphological and genetic characteristics of the three coffee varieties which were evaluated (Espindula *et al.,* 2022; Magesa *et al*., 2018). In fact, variety KR4 which was the best performer in our study, has longer internodes compared to the other two CWD-r Robusta coffee varieties (Epedu, 2025). The longer internodes are associated with better nutritional reserves in the stem (Bazoni *et al*., 2020). Similarly, studies by Vallejos-Torres *et al.* (2020) showed that the best performing variety, caturra has a vigorous and compact appearance, with abundant lateral branches and these characteristics could be explained by the amount of nutritional reserves and carbohydrates present in the stem and by the amount of assimilates produced in the leaves. A positive relationship between carbohydrate content and rooting capacity as well as the number of roots produced has been reported in different woody and herbaceous species (Souza *et al*., 2019).

Effect of the Morphological Age on Rooting of Stem Cuttings Derived from Coffee Wilt Disease Resistant (CWD-r) Robusta Coffee Varieties

Depending on the juvenility or maturity of stem cuttings, they are categorized as softwood, semi-hardwood or hardwood (Rasool & Kumar, 2018) and the rooting ability of the cuttings depends on this morphological status

Table 2. Effect of varieties on rooting ability of stem cuttings derived from selected CWD-r Robusta coffee varieties

CWD-r variety	Rooted cuttings (%)	DF	Chi-Square	Pr > ChiSq
KR1	77.7	2	0.9250	0.6297
KR3	72.3			
KR4	84.3			

Table 3. Effect of variety on growth parameters of stem cuttings derived from selected CWD-r Robusta coffee varieties

Variety	Number of roots	Length of longest root (cm)	Fresh root weight (g)	Dry root weight (g)
KRI	26.1 ^{a}	8.3 ^{b}	1.0 ^{b}	0.2 ^{ab}
KR3	14.9 ^{b}	7.5 ^{b}	0.4 ^{c}	0.0 ^{b}
KR4	35.3 ^{a}	9.6 ^{a}	1.5 ^{a}	0.5 ^{a}
CV	21.9	15.5	12.9	27.5
P value	<0.0001	0.0003	<0.0001	0.0055

Means with the same letter are not significantly ($p \geq 0.05$) different using the Scheffe test.

(Simanjuntak & Wardani, 2021). However, results of our study showed that the percentage of rooted cuttings did not vary significantly (p≥0.05) across the selected three Coffee Wilt Disease (CWD-r) Robusta coffee varieties. Nevertheless, the highest percentage of stem cuttings that successfully produced roots (82%) were recorded on semi-hardwood cuttings (Table 4). This finding is in line with studies by Simanjuntak & Wardani (2021) and Magesa *et al*. (2020), who reported higher percentages of rooting in semi-hardwood cuttings compared to other types in coffee.

Our results further showed that the number of roots, length of the longest roots as well as fresh and dry weights of the roots were not significantly (p≥0.05) different across the morphological age of the stem cuttings (Table 5). Magesa *et al*. (2020) also found no significant difference across cutting positions for root length, number of lateral roots and number of fibrous roots per cutting of hybrid coffee varieties. However, the highest number of roots (29.1) was recorded on soft-wood cuttings. Similarly, Abigaba *et al*. (2020) and Kouakou *et al*. (2016) observed a higher number of roots on softwood cuttings of *Carissa edulis* and *Garcinia kola* (Heckel), though, related studies on coffee have reported better performance on semi-hardwood (Simanjuntak & Wardani, 2021). On the other hand, the longest root (8.9 cm) as well as the highest fresh (0.3 cm) and dry weights of roots and (1.1 g) were recorded on semi-hardwood cuttings, agreeing with studies on coffee (Simanjuntak & Wardani, 2021; Magesa *et al.*, 2020) and other plant species (Somasiri *et al*., 2023). Semi-hardwood cuttings are generally considered easy to be propagated due to their low production of secondary metabolites such as lignin and phenolic substance and high levels of auxin hormone in comparison with other cuttings (Simanjuntak & Wardani, 2021).

Effect of the Indole-3- Butyric Acid (IBA) Rooting Hormone Concentration Levels on Rooting of Stem Cuttings of Selected Coffee Wilt Disease Resistant (CWD-r) Robusta Coffee

Chi-square analysis revealed that the percentage of rooted stem cuttings of the three selected Coffee Wilt Disease resistant (CWD-r) varieties was not significantly (p≥0.05) different but, all the Indole-3-Butyric Acid (IBA) concentrations performed better than the control (0 g/L) treatment (Table 6). However, all the tested IBA concentrations performed better than the control (0 g/L IBA) and this finding emphasizes the

Table 4. Effect of morphological status of the cutting segment on the rooting ability of the cuttings of selected CWD-r Robusta coffee varieties

Morphological status	Rooted cuttings (%)	DF	Chi-Square	Pr > ChiSq
Softwood	75.7	2	0.2934	0.8635
Semi-hardwood	82.0			
Hardwood	76.7			

Table 5. Effect of morphological age on the number, length of the longest root as well as the fresh and dry weight of cuttings derived from selected CWD-r Robusta coffee varieties

Morphological age	Number of roots	Length of longest root (cm)	Fresh root weight (g)	Dry root weight (g)
Softwood	29.1 a	8.1 a	0.2 a	1.0 a
Semi-hardwood	24.6 a	8.9 a	0.3 a	1.1 a
Hardwood	24.4 a	8.6 a	0.2 a	1.0 a
CV	27	31.7	12.8	25
P value	0.4727	0.3276	0.7907	0.5282

Means with the same letter are not significantly (p≥0.05) different using the Scheffe test.

important roles played by IBA rooting hormone dosages in the physiological development of cutting of coffee (Vallejos-Torres *et al*., 2020).

Furthermore, Table 7 below shows that the number of roots and the length of the longest roots varied significantly ($p \leq 0.05$) across the IBA concentration levels. The highest number of roots (31.5) was recorded under 2 g/L IBA concentration but was not significantly ($p \geq 0.05$) different from other IBA concentrations. Our finding is in line with earlier studies conducted on coffee variety *caturra* (Vallejos-Torres *et al*., 2020) and *Coffea arabica*. On the other hand, IBA concentration of 7 g/L produced the longest roots (9.6 cm) and this finding agrees with a study by Tomar *et al*. (2018) which reported that IBA concentration of 7,000 ppm (which is equivalent to 7 g/L of water) showed better rooting and plant percentage than other IBA concentrations assessed. Table 7 below further shows that application of IBA rooting hormone increased both fresh and dry weight of the roots, though not significantly ($p \geq 0.05$). The ability of IBA rooting hormone to enhance fresh and dry weight of roots of cuttings has been reported by other earlier studies (Prakash *et al*., 2023).

All in all, the exogenous application of the different concentrations of IBA increased the rate of rooting of the stem cuttings of the three selected CWD-r Robusta coffee varieties. This is through stimulation of callus, boosting inter-vascular cambium dedifferentiation and producing many cells which differentiated in root primordia and root cells (El-Banna *et al*., 2023; Khandaker *et al*., 2022; Mehta *et al*., 2018). The major function of IBA is to support the coupling between endogenous Indole-3-Acetic Acid (IAA) (which is a key regulator in the initiation and proliferation of adventitious roots) and amino acids, which results in the synthesis of the specific proteins essential for the formation of root initiation (Baý *et al*., 2020). IBA protein also breaks the hydrogen bonds between the cellulose microfibrils and thus promotes cell wall loosening and elongates the root cells (OuYang *et al*., 2015). Application of IBA also promotes

Table 6. Effect of IBA concentration on the rooting ability of stem cuttings of selected CWD-r Robusta coffee varieties

IBA concentration	Rooted cuttings (%)	DF	Chi-Square	Pr > ChiSq
0g/L	53.3	5	10.3093	0.0669
1g/L	88.7			
2g/L	84.3			
4g/L	77.7			
7g/L	88.9			
10g/L	86.7			

Table 7. Effect of concentration of IBA rooting hormone on the rooting ability of stem cuttings derived from selected CWD-r Robusta coffee varieties

IBA concentration	Number of roots	Length of longest root (cm)	Fresh root weight (g)	Dry root weight (g)
0g/L	9.8 ^{b}	5.8 ^{b}	0.5 ^{a}	0.1 ^{a}
1g/L	29.5 ^{a}	9.5 ^{a}	1.2 ^{a}	0.2 ^{a}
2g/L	31.5 ^{a}	9.1 ^{a}	1.2 ^{a}	0.5 ^{a}
4g/L	24.0 ^{ab}	8.3 ^{a}	1.1 ^{a}	0.2 ^{a}
7g/L	28.2 ^{a}	9.6 ^{a}	1.0 ^{a}	0.2 ^{a}
10g/L	27.3 ^{a}	8.0 ^{a}	1.0 ^{a}	0.2 ^{a}
CV	24.9	31	28	31
P value	0.0177	<0.0001	0.3779	0.1699

Means with the same letter are not significantly ($p \geq 0.05$) different using the Scheffe test starch hydrolysis and is involved in relocation of nutrients and sugars to the cutting base (Otiende & Maimba, 2020). Shekhawat & Manokari (2016) also stated that exogenous application of IBA may also increase the speed of translocation and movement of carbohydrates from the leaf to the cutting area of the stem and thus, promote root growth.

Combined Effects of Morphological Status of the Stem Cuttings and Concentration of Indole-3-Butyric Acid (IBA) Rooting Hormone on the Rooting of Selected CWD-r Robusta Coffee Varieties

Table 8 below shows that the interaction effects between morphological status of the stem cuttings and concentration of Indole-3-Butyric Acid (IBA) rooting hormone on the rooting were not signiciant ($p>0.05$) for all the three selected three CWD-r Robusta coffee varieties. However, results in Table 9 below show that the combined effect of the morphological status of the stem cuttings and concentration of IBA rooting hormone on the number of roots produced by stem cuttings was significant ($P<0.0001$) for all the three selected CWD-r Robusta coffee varieties. For KR1, the highest number of roots was produced by stem cuttings derived from softwood and applied with 10 g/L IBA. Similarly, using a Mississippi source of orange (*Rhododendron austrinum* (Small) Rehd. [Ericaceae]) and mountain (*Rhododendron canescens* (Michx.) Sweet) azalea, Knight *et al.* (2005) also found that treating softwood cuttings with 10,000 ppm K-IBA yielded the best rooting performance in terms of number of roots. On the other hand, the highest number of roots on stem cuttings of variety KR3 was recorded on hardwood cuttings applied with 2 g/L concentration of IBA, agreeing with studies on cuttings of hybrid Hazelnuts (Braun & Wyse, 2018) and grape (*Vitis vinifera* L.) (Maninderdeep, 2022). For variety KR4, the highest number of roots was recorded on stem cuttings derived from softwood and applied with a 2 g/L concentration of IBA. This trend has also been reported in earlier studies on *Jatropha curcas* L. (Bijalwan & Thakur, 2010) as well as sweet cherry, sour cherry, and mahaleb genotypes (Aydýn, 2023).

Similarly, the combined effect of the morphological status of the stem cuttings and concentration of IBA rooting hormone on the length of longest was significant ($P<0.0001$) for all the three selected CWD-r Robusta coffee varieties (Table 10). The maximum length of longest root was recorded on the hardwood cuttings treated with 2 g/L of IBA for varieties, KR1 and KR3 whereas, KR4 registered the highest length of the longest root on softwood cuttings treated with 7 g/L IBA. Our finding is in agreement with Markovski *et al.* (2015) who reported that the highest root length was observed on hardwood cuttings of GF 8/L stone fruit treated with 2% IBA. Similarly, Ahmed *et al.* (2003), recorded the longest roots on Peach variety G655 treated with 2,500 ppm IBA. The increase in root length is attributed to the action of auxin and its activity causes hydrolysis and translocation of carbohydrates and nitrogenous substances at the base of cuttings, resulting into accelerated cell elongation and cell division (Singh *et al*., 2015).

On the other hand, the combined effect of the morphological status of the stem cuttings and concentration of IBA rooting hormone on the fresh roots produced by stem cuttings were signficant ($p\leq0.05$) for KR3 and KR4 but not KR1 ($p = 0.499$) (Table 11). For KR3, the highest fresh weight of the roots (10.8 g) was recorded on hardwood cuttings applied with 2 g/L of IBA while for KR4, the highest fresh weight of roots (13.0 g) was observed on softwood applied with 10 g/L of IBA and semi-hardwood treated with 2 g/L of IBA. Our finding is in agreement with studies by

Table 8. Interaction effects between morphological status of the stem cuttings and concentration of IBA rooting hormone on the rooting of the selected three CWD-r Robusta coffee varieties

Source of variation	DF	ANOVA SS	Mean square	F value	P value
CWD-r Robusta coffee variety KR1					
Number of roots					
Morphological status of stem cutting	2	852.65	426.32	0.74	0.4830
Indole-3-Butyric Acid (IBA) concentration	5	4989.66	997.93	1.73	0.1447
Morphological status*IBA concentration	10	2338.10	233.81	0.40	0.9384
Length of longest root					
Morphological status of stem cutting	2	27.3003810	13.6501905	1.88	0.1631
Indole-3-Butyric Acid (IBA) concentration	5	239.1316905	47.8263381	6.58	<.0001
Morphological status*IBA concentration	10	102.1836905	10.2183690	1.41	0.2040
Fresh weight					
Morphological status of stem cutting	2	1.29492989	0.64746495	0.78	0.4652
Indole-3-Butyric Acid (IBA) concentration	5	6.09461905	1.21892381	1.46	0.2181
Morphological status*IBA concentration	10	6.50449272	0.65044927	0.78	0.6471
Dry weight					
Morphological status of stem cutting	2	0.01883485	0.00941742	0.41	0.6681
Indole-3-Butyric Acid (IBA) concentration	5	0.09308750	0.01861750	0.80	0.5523
Morphological status*IBA concentration	10	0.13972527	0.01397253	0.60	0.8040
CWD-r Robusta coffee variety KR3					
Number of roots					
Morphological status of stem cutting	2	282.91	141.45	0.73	0.4884
Indole-3-Butyric Acid (IBA) concentration	5	1558.60	311.72	1.60	0.1777
Morphological status*IBA concentration	10	1500.47	150.05	0.77	0.6548
Length of longest root					
Morphological status of stem cutting	2	51.27626665	25.63813332	3.39	0.0421
Indole-3-Butyric Acid (IBA) concentration	5	52.12035781	10.42407156	1.38	0.2493
Morphological status*IBA concentration	10	61.20965760	6.12096576	0.81	0.6205
Fresh weight					
Morphological status of stem cutting	2	0.44629330	0.22314665	2.97	0.0611
Indole-3-Butyric Acid (IBA) concentration	5	0.41145536	0.08229107	1.09	0.3759
Morphological status*IBA concentration	10	0.86870852	0.08687085	1.16	0.3438
Dry weight					
Morphological status of stem cutting	2	0.00415825	0.00207913	3.41	0.0415
Indole-3-Butyric Acid (IBA) concentration	5	0.00945123	0.00189025	3.10	0.0169
Morphological status*IBA concentration	10	0.00692167	0.00069217	1.13	0.3579
CWD-r Robusta coffee variety KR4					
Number of roots					
Morphological status of stem cutting	2	5917.76	2958.88	3.99	0.0238
Indole-3-Butyric Acid (IBA) concentration	5	6148.07	1229.61	1.66	0.1596
Morphological status*IBA concentration	10	12916.50	1291.65	1.74	0.0932
Length of longest root					
Morphological status of stem cutting	2	3.6787036	1.8393518	0.25	0.7810
Indole-3-Butyric Acid (IBA) concentration	5	90.4948946	18.0989789	2.44	0.0446
Morphological status*IBA concentration	10	125.5189105	12.5518911	1.69	0.1040
Fresh weight					
Morphological status of stem cutting	2	2.13754872	1.06877436	0.68	0.5096
Indole-3-Butyric Acid (IBA) concentration	5	8.25002873	1.65000575	1.05	0.3958
Morphological status*IBA concentration	10	23.48178922	2.34817892	1.50	0.1638
Dry weight					
Morphological status of stem cutting	2	2.78512512	1.39256256	0.85	0.4327
Indole-3-Butyric Acid (IBA) concentration	5	9.01856628	1.80371326	1.10	0.3699
Morphological status*IBA concentration	10	18.37886334	1.83788633	1.12	0.3621

Table 9. Effects of variety, morphological age of the stem cuttings and Indole-3-Butyric Acid (IBA) concentration on number of roots produced by cutting of the three selected Coffee Wilt Disease resistant (CWD-r) Robusta coffee varieties

Treatment	KR1	KR3	KR4
Softwood-IBA_0 g/L	6.4 i	13.4 ab	3.6 ef
Softwood-IBA_1 g/L	17.0 g	2.2 b	51.8 abc
Softwood-IBA_2 g/L	7.2 i	6.6 ab	69.6 a
Softwood-IBA_4 g/L	12.4 g	6.4 ab	12.2 c
Softwood-IBA_7 g/L	22.8 f	15.8 ab	45.6 abc
Softwood-IBA_10 g/L	38.6 a	13.4 ab	64.2 ab
Semi-hardwood-IBA_0 g/L	1.4 j	5.0 b	2.2 f
Semi-hardwood-IBA_1 g/L	28.0 bc	9.2 ab	38.6 abc
Semi-hardwood-IBA_2 g/L	27.0 bcd	15.6 ab	38.2 abc
Semi-hardwood-IBA_4 g/L	27.0 bcd	19.8 ab	34.0 abc
Semi-hardwood-IBA_7 g/L	24.6 def	19.8 ab	16.2 c
Semi-hardwood-IBA_10 g/L	23.6 ef	19.2 ab	15.4 c
Hardwood-IBA_0 g/L	6.4 i	2.8 b	21.8 c
Hardwood-IBA_1 g/L	18.6 g	12.6 ab	22.8 bc
Hardwood-IBA_2 g/L	30.4 b	29.4 a	15.6 c
Hardwood-IBA_4 g/L	26.8 cde	3.6 b	26.0 bc
Hardwood-IBA_7 g/L	28.8 bc	4.0 b	48.0 abc
Hardwood-IBA_10 g/L	22.8 f	5.6 b	10.2 c
CV	14.3	12.6	12.9
P value	<0.00001	<0.00001	<0.00001

Means with the same letter are not significantly (p≥0.05) different using the Scheffe test.

Table 10. Effects of morphological age of the stem cuttings and Indole-3-Butyric Acid (IBA) concentration on length of longest roots (cm) produced by cutting of the three selected Coffee Wilt Disease resistant (CWD-r) Robusta coffee varieties

Treatment	KR1	KR3	KR4
Softwood-IBA_0 g/L	2.2 bcd	6.7 abcd	2.0 f
Softwood-IBA_1 g/L	3.6 de	3.9 cde	9.3 abc
Softwood-IBA_2 g/L	7.1 bcd	0.8 g	8.5 abc
Softwood-IBA_4 g/L	6.1 cd	5.3 bcd	6.4 bcd
Softwood-IBA_7 g/L	9.1 ab	5.9 bcd	13.0 a
Softwood-IBA_10 g/L	8.2 abc	6.7 abc	9.5 abc
Semi-hardwood-IBA_0 g/L	1.64 e	0.4 abcd	1.9 f
Semi-hardwood-IBA_1 g/L	5.3 cd	6.4 abc	11.9 ab
Semi-hardwood-IBA_2 g/L	8.1 abc	8.0 abc	8.4 abc
Semi-hardwood-IBA_4 g/L	7.6 abcd	7.7 abc	10.4 abc
Semi-hardwood-IBA_7 g/L	8.9 abc	9.44 ab	7.4 abc
Semi-hardwood-IBA_10 g/L	7.2 abcd	8.1 abc	9.4 abc
Hardwood-IBA_0 g/L	2.3 e	3.2 def	9.54 abc
Hardwood-IBA_1 g/L	7.3 abcd	7.1 abc	10.0 abc
Hardwood-IBA_2 g/L	9.9 a	10.8 a	7.5 abc
Hardwood-IBA_4 g/L	8.4 abc	1.4 fg	5.0 cd
Hardwood-IBA_7 g/L	8.2 abc	3.8 cde	10.8 abc
Hardwood-IBA_10 g/L	5.5 bcd	3.0 efg	4.5 d
CV	31	28	28
P value	<0.0001	<0.0001	<0.0001

Means with the same letter are not significantly (p≥0.05) different using the Scheffe test.

Malaviya *et al.* (2023) which showed that application of 2000 ppm on hardwood cuttings of *Dracaena marginata* resulted into the highest fresh weight of roots (7.19 g). This could partly be due to the fact that, treating hardwood cuttings with 2g/L of IBA produced higher number of roots (Table 9) as well as greater roots length (Tables 10), as also reported by Ingle & Venugopal (2009).

Furthermore, the combined effect of the morphological status of the stem cuttings and concentration of IBA rooting hormone on the dry weight of the roots produced by the stem cuttings were signficant ($p \leq 0.05$) for KR3 and KR4, but not for KR1 ($p = 0.459$) (Table 12). For KR3, the highest dry weight of the roots (0.06 g) was recorded on semi-hardwood cuttings applied with 1, 2, and 4 g/L of IBA as well as hardwood cuttings applied with 1 g/L of IBA while for KR4, the highest dry weight of roots (1.1 g) was

Table 11. Effects of morphological age of the stem cuttings and Indole-3-Butyric Acid (IBA) concentration on fresh weight of the roots (g) produced by cutting of the three selected Coffee Wilt Disease resistant (CWD-r) Robusta coffee varieties

Treatment	KR1	KR3	KR4
Softwood-IBA_0 g/L	0.1 a	0.20 bcde	0.3 bc
Softwood-IBA_1 g/L	0.5 a	0.09 de	1.6 abc
Softwood-IBA_2 g/L	0.4 a	0.02 e	1.8 abc
Softwood-IBA_4 g/L	0.7 a	0.34 bcd	0.7 abc
Softwood-IBA_7 g/L	0.7 a	0.40 abc	1.8 abc
Softwood-IBA_10 g/L	1.4 a	0.24 bcd	2.5 a
Semi-hardwood-IBA_0 g/L	0.2 a	0.40 abcd	0.2 c
Semi-hardwood-IBA_1 g/L	0.8 a	0.26 bcd	2.3 ab
Semi-hardwood-IBA_2 g/L	1.2 a	0.52 abc	2.5 a
Semi-hardwood-IBA_4 g/L	1.2 a	0.58 abc	1.5 abc
Semi-hardwood-IBA_7 g/L	0.9 a	0.44 abc	0.7 abc
Semi-hardwood-IBA_10 g/L	0.9 a	0.44 abc	0.7 abc
Hardwood-IBA_0 g/L	0.1 a	0.14 cde	0.9 abc
Hardwood-IBA_1 g/L	0.5 a	0.46 abc	1.5 abc
Hardwood-IBA_2 g/L	1.4 a	0.74 a	0.7 abc
Hardwood-IBA_4 g/L	1.4 a	0.12 de	1.0 abc
Hardwood-IBA_7 g/L	1.2 a	0.08 de	1.8 abc
Hardwood-IBA_10 g/L	0.4 a	0.19 cde	0.7 abc
CV	25	20	22
P value	0.499 ns	0.001	<0.0001

Means with the same letter are not significantly ($p \geq 0.05$) different using the Scheffe test.

Table 12. Effects of morphological age of the stem cuttings and Indole-3-Butyric Acid (IBA) concentration on the dry weight of the roots (g) produced by cutting of the three selected Coffee Wilt Disease resistant (CWD-r) Robusta coffee varieties

Treatment	KR1	KR3	KR4
Softwood-IBA_0 g/L	0.1 a	0.03 abcd	0.0 b
Softwood-IBA_1 g/L	0.1 a	0.00 d	0.4 ab
Softwood-IBA_2 g/L	0.1 a	0.01 cd	0.5 ab
Softwood-IBA_4 g/L	0.1 a	0.03 abc	0.1 ab
Softwood-IBA_7 g/L	0.1 a	0.03 abc	0.5 ab
Softwood-IBA_10 g/L	0.2 a	0.03 abc	0.6 ab
Semi-hardwood-IBA_0 g/L	0.0 a	0.04 abcd	0.0 b
Semi-hardwood-IBA_1 g/L	0.1 a	0.06 a	0.6 ab
Semi-hardwood-IBA_2 g/L	0.2 a	0.06 a	1.1 a
Semi-hardwood-IBA_4 g/L	0.2 a	0.06 a	0.3 ab
Semi-hardwood-IBA_7 g/L	0.1 a	0.03 abc	0.1 ab
Semi-hardwood-IBA_10 g/L	0.2 a	0.44 abc	0.1 ab
Hardwood-IBA_0 g/L	0.0 a	0.03 abc	0.1 ab
Hardwood-IBA_1 g/L	0.1 a	0.06 a	0.3 ab
Hardwood-IBA_2 g/L	0.2 a	0.05 ab	0.2 ab
Hardwood-IBA_4 g/L	0.2 a	0.01 cd	0.3 ab
Hardwood-IBA_7 g/L	0.2 a	0.00 d	0.3 ab
Hardwood-IBA_10 g/L	0.1 a	0.01 bcd	0.2 ab
CV	22	18	19
P value	0.459 ns	0.002	<0.0001

Means with the same letter are not significantly ($p \geq 0.05$) different using the Scheffe test

Table 13. Relationship between Indole-3-Butyric Acid (IBA) rooting hormone concentration and the number, length of the longest as well as fresh and dry weight of the roots produced by the three selected Coffee Wilt Disease resistant (CWD-r) Robusta coffee varieties

Parameter	DF	Parameter estimate	Standard error	t value	Pr
CWD-r Robusta coffee variety KR1					
Number of roots	1	0.03644	0.03116	1.17	0.2465
Length of longest of root	1	0.04981	0.15804	0.32	0.7536
Fresh root weight	1	0.21224	1.06051	0.20	0.8420
Dry root weight	1	-5.54876	6.27835	-0.88	0.3801
CWD-r Robusta coffee variety KR3					
Number of roots	1	0.08286	0.03863	2.14	0.0360
Length of longest of root	1	0.15396	0.18190	0.85	0.4007
Fresh root weight	1	-1.53586	2.16458	-0.71	0.4807
Dry root weight	1	-62.31883	18.42968	-3.38	0.0013
CWD-r Robusta coffee variety KR4					
Number of roots	1	0.00727	0.02047	0.36	0.7236
Length of longest of root	1	0.09166	0.17481	0.52	0.6017
Fresh root weight	1	-0.01242	0.85383	-0.01	0.9884
Dry root weight	1	-0.22116	0.63836	-0.35	0.7300

recorded on semi-hardwood cuttings applied with 2 g/L of IBA. Similarly, Muttaleb *et al.* (2017), reported that the highest dry root weight (0.328 g) was recorded on semi-hardwood cuttings of piper betle applied with 2,000 ml/ L of IBA. Increase in dry weight of roots might be due to the fact that the increase in the root number and length of roots resulted in higher accumulation of dry matter (Singh *et al*., 2019).

CONCLUSION AND RECOMMENDATION

In conclusion, our study revealed that the number of roots produced by stem cuttings was significantly influenced by the variety and concentration of the Indole-3- Butyric Acid (IBA) rooting hormone but not the morphological age of the stem cuttings. The highest number of roots was recorded on softwood treated with 10 g/L of IBA rooting hormone for KR1, hardwood cuttings treated with 2 g/L of IBA for KR3 and softwood cuttings treated with 2 g/L of IBA for KR4.

Coffee nursery operators are therefore advised to employ these variety-specific approaches for enhancing the rooting ability of the stem cuttings of these CWD-r Robusta coffee varieties. We also recommend that similar studies be conducted on one of the newly-released CWD-r Robusta coffee variety, KR8 which has also been reported for challenges of rooting in its stem cuttings.

REFERENCES

Abigaba, G; D.M. Byabashaija; E. Kamusiime; D. Kazigaba & R. Oluk (2020). Propagation of *Carissa edulis* using stem cuttings for domestication and conservation in Uganda. *GSC Biological and Pharmaceutical Sciences,* 12, 24–30.

Ahmed, M.S.; N.A. Abbasi & M. Amer (2003). Effects of IBA on hardwood cuttings of Peach rootstocks under greenhouse conditions. *Asian Journal of Plant Sciences,* 2(3), 265–269.

Aydýn, E. & E. Er (2023). The effect of different IBA doses on rooting in soft wood cuttings of rootstock candidate sweet cherry, sour cherry and mahaleb genotypes. *Turkish Journal of Food and Agriculture Sciences,* 5(1), 48–54.

Bai, T.; Z. Dong; X. Zheng; S. Song; J. Jiao; M. Wang & C. Song (2020). Auxin and its interaction with ethylene control adventitious root formation and development in apple rootstock. *Frontiers in Plant Science,* 11, 574881.10.3389/fpls.2020.574881.

Bazoni, P.A.; M.C. Espindula; L.E.B. Araújo; J.M. Vasconcelos & M. Campanharo (2020). Production of cuttings and nutrient export by *Coffea canephora* in different periods in the Southwestern Amazon. *Revista Brasileira de Engenharia Agrícola e Ambiental,* 24, 162–169.

Bijalwan, A. & Thakur (2010). Effect of IBA and age of cuttings on rooting behaviour of *Jatropha curcas* L. in different seasons in western. *African Journal of Plant Science,* 4, 387–390.

Braun, L. & D. Wyse (2019). Optimizing IBA concentration and stem and segment size for rooting of hybrid hazelnuts from hardwood. *Journal of Environmental Horticulture,* 37, 1–8.

CABI (2003). Surveys to assess the extent and impact of Coffee Wilt Disease in East and Central Africa. Final technical report. CAB International.

Caplan, D.; J. Stemeroff; M. Dixon; Y. Zheng (2009). Vegetative propagation of cannabis by stem cuttings: Effects of leaf number, cutting position, rooting hormone and leaf tip removal Deron. *Canadian Journal of Plant Science,* 98, 1–23.

El-Banna, M.F.; N.B.B. Farag; Y.L. Massoud; M.M. Kasem (2023). Exogenous IBA stimulated adventitious root formation of *Zanthoxylum beecheyanum* K. Koch stem cutting. *Histo-Physiological and Phytohormonal Investigation,* 197, 107639.

Epedu, E. (2025). *Evaluation of techniques for improving clonal propagation of wilt disease-resistant Robusta coffee planting materials in Uganda.* MSc thesis. Makerere University Kampala, Uganda.

Espýndula, M.C.; L.F.B. de. Araújo; J.M. Dýoclecýano; R.B. Rocha; J.R.M. Dýas & A.C. Verdin Filho (2022). New model of clonal garden for the production of Robusta coffee plantlets. *Pesquisa Agropecuaria Brasileira,* 57, e0294257.

Filho, P.F.M.C.; D.C. Baitelle; S.deJ. Freitas; W.S. da Silva; P.C. dos Santos; W.P. Rodrigues; S.deP. Freitas; I.L.deJ. Freitas; T. Locatelli; A.C.V. Filho & G.B. Miranda (2018). Effect of growth regulators in production and rooting of *Coffea arabica* L. minicuttings. *American Journal of Plant Sciences,* 9, 628–636.

Giuriatto, J.J.T.; M.C. Espindula; L.F.B. de Araújo; J.M. Vasconcelos & M. Campanharo (2020). Growth and physiological quality in clonal seedlings of Robusta coffee. *Revista Ciencia Agronomica,* 51.

Hunt, R.W.; S. Chinnasamy; A. Bhatnagar & K.C. Das (2010). Effect of biochemical stimulants on biomass productivity and metabolite content of the microalga, *Chlorella sorokiniana*. *Applied Biochemistry and Biotechnology,* 162, 2400–2414.

ICO (2019). Country Coffee Profile: Vietnam. International Coffee Organization (ICO). International Coffee Council (ICC).

Ingle, M.R. & C.K. Venugopal (2009). Effect of different growth regulators on rooting of stevia (Stevia rebaudiana Bertoni) cuttings. *Karnataka Journal of Agricultural Sciences,* 22, 460–461.

Khandaker, M.M.; A. Saidi; N.A. Badaluddin; N. Yusoff; A. Majrashi; M.M. Alenazi; M. Saifuddin; Md.A. Alam & K.S. Mohd (2022). Effects of Indole-3-Butyric Acid (IBA) and rooting media on rooting and survival of air layered wax apple (*Syzygium samarangense*) CV Jambu Madu. *Brazilian Journal of Biology,* 82.

Knight, P.R.; C.H. Coker; J.M. Anderson; D.S. Murchison & C.W. Watson (2005). Mist Interval and K-IBA concentration influence rooting of orange and mountain azalea. *Native Plants Journal,* 6, 111–117.

Kouakou, K.L.; J.P. Dao; K.I. Kouassi; M.M. Beugré; M. Koné, J.-P. Baudoin & I.A. Zoro Bi (2016). Propagation of *Garcinia kola* (Heckel) by stem and root cuttings. *Silva Fennica,* 50, 1588.

Kyalo, G.; G.H. Kagezi; N.O. Olango; M. Anyijuka; V. Twesigye; J.K. Musasizi; D. Nuwagaba; C. Aijuka; P.C. Apunyo; G. Arinaitwe & E.L. Niyibigira (2025). Incidence, damage and management of the major pests and diseases of Robusta coffee, [*Coffea canephora* (Pierre Ex A. Froehner)] in Uganda. *Journal of Agricultural Science,* 17, 70–83.

MAAIF (2025). Ministry of Agriculture, Animal Industry and Fisheries (MAAIF) Monthly Coffee Report May 2025. Coffee Year 2024/25 Issue 8.

Magesa, J.; T. Msogoya & C. Rweyemamu (2020). Effects of cutting position along mother plants on rooting of hybrid coffee varieties. *Journal of Agricultural and Crop Research,* 8, 113–119.

Magesa, J.M.; T.J. Msogoya & C.L. Rweyemamu (2018). Effects of growth media on rooting of stem cuttings of hybrid coffee varieties. *African Journal of Agricultural Research,* 13, 41–46.

Malaviya, S.B.; B.V. Thumar; K.N. Dobariya; J.S. Parsana & A. Varma (2023). Efficacy of IBA on rooting of cuttings, growth and survival of dracaena (*Dracaena marginata*). *Research Matrix,* 1(10), 39–43.

Maninderdeep, S.G. (2022). Study of IBA containing rooting powder on root induction behavior of hardwood cutting of grape (*Vitis vinifera* L.). *Indian Journal of Agricultural Research.* 56, 389–395.

Markovski, A.; M. Popovska & V. Gjamovski (2015). Investigation of the possibility for production of some stone fruit rootstocks by rooting cuttings. *Acta Agriculturae Serbica,* 20, 75–83.

Mehta, S.; H.A. Singh & K. Singh (2018). Effect of IBA concentration and time of planting on rooting in pomegranate (*Punica granatum*) cuttings. *Journal of Medicinal Plants Studies,* 6, 250–253.

Musoli, C.P.; A. Kangire; T. Leroy; A. Nabaggala; S. Nakendo; S. Olal; J. Ochugo; C. Kabole; J. Pande; C. Cilas; A. Charrier; D. Bieysse; J. Ogwang & D.T. Kyetere (2008). Towards a variety resistant to coffee wilt disease (CWD): A case for Robusta coffee (*Coffea canephora*) in Uganda. *22nd International Conference on Coffee Science (ASIC),* pp. 1472–1479, Montpellier, France.

Musoli, P.; P. Cubry; P. Aluka; C. Billot; M. Dufour; F. De Bellis; D. Pot; D. Bieysse; A. Charrier & T. Leroy (2009). Genetic differentiation of wild and cultivated populations: Diversity of *Coffea canephora* Pierre in Uganda. *Genome,* 52, 634–646.

Musoli, P.; S. Olal; A. Nabaggala; C. Kabole (2003). Response of Robusta coffee populations to *Fusarium xylarioides* infection under screenhouse condition in Uganda. *Uganda Journal of Agricultural Sciences,* 8, 31–36.

Musoli, P.C.; A. Nalukenge; E. Kananura; H.G. Kagezi; B. Magambo; S. Olal; P. Aluka; N. Olango & W.W. Wagoire (2017). Technical report on candidate wilt resistant varieties of Robusta coffee, due for commercialization. Presentation to the Ministry of Agriculture, Animal Industries and Fisheries (MAAIF) variety release committee.

Musoli, P.C.; C. Cilas; D. Pot; A. Nabaggala, S. Nakendo; J. Pande, A. Charrier; T. Leroy & D. Bieysse (2013). Inheritance of resistance to coffee wilt disease (*Fusarium xylarioides* Steyaert) in Robusta coffee (*Coffea canephora* Pierre) and breeding perspectives. *Tree Genetics and Genomes,* 9, 351–360.

Muttaleb, Q.A.; T.L. Abdullah; A.A. Rashid & S.A. Hassan (2017) Rooting of stem cuttings with different Indole 3 Butyric Acid (IBA) treatments and development of micropropagation protocol for *Piper betle* L. node culture. *American Journal of Plant Sciences,* 8, 3084–3100.

Nakyagaba, W.N.; H. Talwana; S. Kyamanywa; G.H. Kagezi; Y. Bamutaze; D. Mfitumukiza; R. Twinomuhangi; H. Bukomeko; D. Mukasa; B. Fungo; P. van Asten & L. Jassogne (2024). Biophysical constraints to Robusta coffee productivity in low, moderate, and high rainfall Areas. *International Journal of Agronomy 2024,* 10.1155/ioa/4683226.

Noori, I.M. & A.A. Muhammad (2020). Rooting of peach [*Prunus persica* (L.) Batsch] hardwood cuttings as affected by IBA concentration and substrate pH. *Journal of Applied Horticulture,* 22, 33–37.

NPA (2024). Fourth National Development Plan (NDPIV) 2025/26–2029/30. National Planning Authority (NPA). Republic of Uganda.

Olango, N.D.K.; G. Kagezi; S. Olal; P. Kucel; R. Ekwaru; J. Kobusinge & G. Arinaitwe (2024). Distribution and severity of coffee pests and diseases in central Uganda. *Uganda Journal of Agricultural Sciences,* 22, 1–9.

Oliveira, D.H,; D.P. Baliza; T.T. Rezende; S.P. de Carvalho & R.J. Guimarães (2011). Influence of cutting length and environment on the growth of coffee seedlings obtained by rooting. *Coffee Science,* 5, 183–189.

Otiende, M.A. & F.M. Maimba (2020). Endogenous carbohydrate content of the cutting positions at time of severance and IBA concentration influence rooting of rosa hybrida rootstocks. *Journal of Environment and Agricultural Science,* 22, 1–9.

OuYang, F.W.J. (2015). Effects of cutting size and exogenous hormone treatment on rooting of shoot cuttings in Norway spruce [*Picea abies* L. Karst.]. *New Forests,* 46, 91–105.

Oyarce, J.C.; A.A. Camacho; L.G. Bobadilla; C.N. Vigo; H. Vásquez & G.S. Valqui (2021). Clonal propagation of *Coffea arabica* with indole butyric acid and acclimatization conditions in Amazonas, Peru. *International Journal of Agronomy 2021,* 1–8.

Peck, L. & E. Boa (2024). Coffee wilt disease: The forgotten threat to coffee. *Plant Pathology,* 73, 506–521.

Prakash, O.; K.D. Ameta; A.S. Rathore; Y. Choudhary & A.K. Saif (2023). Effect of indole-3-butyric acid (IBA), cow urine and vermiwash during winter season on tomato stem cuttings. *Biological Forum – An International Journal,* 15, 1116–1120.

Rasool, Z.A. & D. Kumar (2018). Effect of maturity stage of donor plant on propagation of *Diploknema butyracea* through branch cuttings. *World Journal of Agricultural Research,* 6, 15–19.

Salinas-Ruiz, J.; E. Ortiz-Cervantes; Hernández Lara A. Aguas-Atlahua & J. Velasco-Velasco (2021). Effect of organic substrates on the physiological development of coffee (*Coffea canephora* P.) cuttings. *Ecosistemas y Recursos Agropecuarios,* 8, 10.19136/era.a8n1. 2329.

Shekhawat, M.S. & M. Manokari (2016). Impact of auxins on vegetative propagation through stem cuttings of *Couroupita guianensis* Aubl.: A conservation approach. *Scientifica (Cairo) 2016,* 1–7.

Simanjuntak, B.H. & D.K. Wardani (2021). The effect of stem segment cuttings of robusta coffee (*Coffea canephora*) on growth of root and leaf sprout. *Asian Journal of Agriculture and Rural Development,* 11, 28–34.

Singh, G.; S. Kaur & A. Kaur (2019). Effect of ýba on rooting of hardwood cuttings of various peach genotypes, *Indian Journal of Pure & Applied Biosciences,* 7(4), 104–109.

Singh, K.K. & Y.K. Tomar (2015). Effect of planting time and indole butyric acid levels on rooting of woody cuttings of Phalsa (*Grewia asiatica* L.). *HortFlora Research Spectrum,* 4(1), 39–43.

Somasiri, I.V.; H. Herath; R.M.C.S. Ratnayake & S.P. Senanayake (2023). Propagation of *Antidesma alexiteria* and *Syzygium caryophyllatum*, two underexploited fruit plants in Sri Lanka: Effect of cutting types, potting media and auxin application. *Dendrobiology,* 89, 65–76.

Souza, J.M.A.; S. Leonel; M.S. Silva; M.A.O. Junior; R.C. Martins; A.C.B. Bolfarini & E.M. Ataíde (2019). Carbohydrate content and season collection of cuttings from

'Roxo de Valinhos' fig tree. *Comunicata Scientiae,* 10, 125–131.

Tomar, A.; D. Kumar & A. Srivastav (2018). Influence of Indole-3-Butyric Acid (IBA) in plant renaissance of *Rauvolfia Serpentina* (L). Benth.Ex Kurz. *Journal of Research and Education in Indian Medicine.* 24, 33–38.

Travis, J.L.; G. Diiro; D. Kawooya & S. Wunsch-Vincent (2018). Enhancing innovation in the Ugandan agri-food sector: Robusta coffee planting material & tropical fruit processing. WIPO Economic Research Working Papers 42, World Intellectual Property Organization - Economics and Statistics Division.

UCDA (2017). Annual Report Volume 25. Uganda Coffee Development Authority (UCDA). Mýnýstry of Agriculture, Animal Industry and Fisheries (MAAIF).

UCDA (2019). Robusta Coffee Handbook. Uganda Coffee Development Authority (UCDA). Mýnýstry of Agriculture, Animal Industry and Fisheries (MAAIF).

Ullah, Z.; S.J. Abbas; N. Naeem; G. Lutfullah; T. Malik; M. Atiq; U. Khan & I. Khan (2013). Effect of indolebutyric acid (IBA) and naphthaleneacetic acid (NAA) plant growth regulaters on Marigold (*Tagetes erecta* L.). *African Journal of Agricultural Research,* 8, 4015–4019.

Vallejos-Torres, G.; L.A. Arévalo; O. Ríos; A. Cerna &C. Marín (2020). Propagation of rust-tolerant *Coffea arabica* L. plants by sprout rooting in micro-tunnels. *Journal of Soil Science and Plant Nutrition,* 20, 933-940.

Wang, N.; L. Jassogne; P.J.A. van Asten; D. Mukasa; I. Wanyama; G. Kagezi & K.E. Giller (2015). Evaluating coffee yield gaps and important biotic, abiotic, and management factors limiting coffee production in Uganda. *European Journal of Agronomy,* 63, 1–11.

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