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Graft success and seedling growth responses of cashew (*Anacardium occidentalis*) to three concentrations of Indole Butyric Acid (IBA) and scion types

Bright Osei Poku, Ben Kwaku Branoh Banful, Irene Akua Idun
Paul Kweku Tandoh* and Michael Osei

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ABSTRACT

Cashew is an important tree crop with huge export potential and economic benefits. Seed propagation is a major problem because it takes the crop a much longer time to reach edible maturity compared to vegetative propagation. In addition, true-to-type plants cannot be assured through seed propagation. This experiment was conducted to determine the effects of different concentrations of IBA and three scion types on the graft success of cashews. The experimental design for the study was 4 x 3 factorial arrangements in a Randomized Complete Block Design (RCBD) with three replications. The first factor was IBA at four different concentrations (0 ml, 750 ml, 1000 ml, and 1250 ml). The second factor was scion types at three levels (softwood, semi-hardwood, and hardwood, respectively). Semi-hardwood cuttings treated with 1250 ml concentration of IBA took shorter days (13 days) to achieve graft success and had the highest percentage graft-take. For all the vegetative parameters studied (plant height, stem girth, number of leaves, root biomass and root length), semi-hardwood cuttings which were treated with 1250 ml concentration of IBA gave the best recordings and also had the highest percentage of survived seedlings after transplanting. In conclusion, for a successful graft success coupled with the corresponding growth of the seedlings, it is best to use 1250 ml of IBA concentration with semi-hardwood scion.

Keywords: Mersitems, Hormones, Cell wall, Callus, Sprouting

Department of Horticulture, Kwame Nkrumah University of Science and Technology, Kumasi-Ghana

*Corresponding author's email: pktandoh.canr@knust.edu.gh (Paul Kweku Tandoh)

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Introduction

Originally from Brazil, the cashew (*Anacardium occidentale* L.) is now widely grown throughout tropical regions, with notable expansion in India and East Africa during the 16th century (Silva *et al.*, 2024; Babatunde *et al.*, 2023; Palei *et al.*, 2019). Mango and pistachio trees also fall into this family, according to Shahrajabian and Sun (2023), and the foliage of cashew trees resembles that of pistachio trees quite a little. Evergreen cashew trees develop quickly to become huge, heavily branching trees that reach a height of about 15 meters (Helgason and Storgaard, 2023).

At the end of the pseudofruit, or pedicle, also known as the cashew apple or cashew fruit, the cashew nut grows externally in its hard shell that resembles a kidney (Malhotra *et al.*, 2017). The edible swelling fruit stem, or pedicel, is known as the cashew "apple"; at its tip, the cashew fruit, which contains the seed or "nut," hangs (Essien *et al.*, 2021). According to Shahrajabian and Sun (2023), the fruit is kidney-shaped, roughly the size of a large bean, and has a two-layered shell. Before handling the nut, the caustic oil on its exterior layer needs to be burned off (Swamy, 2021).

According to Olubode *et al.* (2018), cashew trees are hardy, quickly growing evergreen trees that can withstand droughts. The cashew apple itself has value, but the nut that forms at the base of the apple is highly prized as a roasted snack nut, in confectionary, and in cookery (Olife *et al.*, 2013). Many tribes enjoy drinking cashew apple juice, which can be fermented to produce a wine that resembles Madeira. Ojediran *et al.* (2024) and Akyereko *et al.* (2023) reported that cashew fruit pulp can be used to make syrup, candied fruit, jelly, and preserves. Relevant health advantages of cashew nuts include antioxidant activity, protection against cancer, heart health, nerve health, and vitamin sources (Vyavahare *et al.*, 2020). Additionally beneficial to health are cashew apples' anti-inflammatory, anti-oxidant, healing, and anti-obesity properties (Shahrajabian and Sun, 2023; Oliveira *et al.*, 2020).

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Jeyavishnu *et al.* (2021) reported that the global cashew industry has grown rapidly over the last decade, driven by increasing consumption of cashew nuts around the world. Cashew has become a valuable global commodity and an important cash crop, with world production reaching 300 million tons in 2023 (Sahie *et al.*, 2023; Dimoso *et al.*, 2024). Over the past few decades, cashew nuts have become a significant product with increasing economic potential (Babatunde *et al.*, 2023). The market for raw cashews is estimated to continue growing at an annual rate of 4.27 % between 2020 and 2025. It is expected to reach almost 7 billion US dollars by 2025. Due to significant production growth in some regions, such as West Africa, the cashew industry is anticipated to continue to be robust (Sierra-Baquero *et al.*, 2024; Bojang and Emang, 2023). The cashew crop's potential is being recognised by the Ghanaian market more and more (Hashmiu *et al.*, 2022; Ackah *et al.*, 2020).

Despite all the benefits we get from cashews, there are many challenges associated with their production. It includes the need to get true to-type seedlings with desirable qualities, resistant varieties against pests and diseases, early scion-rootstock formation, early germination of the cashew seeds and high-yielding varieties. These problems associated with cashews make it unattractive for commercial purposes. Grafting, which is known to be a potential alternative, isn't successful when used due to about (30-40 %) losses which could be attributed to poor graft-take or budding success as reported by Bester (2020). According to Abdel-Mohsen and Rashedy (2024), a significant increase in success rate and callus formation as callusing rate and callusing degree at the grafting zone indicated that IBA may have the potential to improve graft union formation. It is therefore imperative to consider the use of plant hormones to increase graft success. A class of naturally occurring chemical compounds known as plant hormones affects physiological functions at low doses. These hormones affect several processes such as stomatal movement as well as growth, differentiation, and development (Vaishnav and Chowdhury, 2023). According to Serivichyaswat *et al.* (2024), hormonal signals, and auxin in particular, are believed to play an important role in wound healing and vascular regeneration within the graft union zone, as well as profoundly influencing root morphology, increasing lateral root production, and inducing adventitious root. Karimi and Nowrozy (2017) stated that graft success percentage and survival were positively affected by scion type. However, the influence of different concentrations of IBA and scion types in the area of cashews is little and therefore a need to investigate this study. The objective of this study was to determine the effects of different concentrations of IBA and scion types on graft success of cashews.

Materials and Methods

Study location

The study was conducted in the Horticulture Department of KNUST, Kumasi with a geographical coordinate (6° 40′ 46.12″ N, 1° 33′ 51.7″ W). The site is in a semi-deciduous forest zone with an elevation of 186 m above sea level and a bimodal rainfall distribution. The major rainy season is from Late March to mid-July. There is a short dry spell from mid-September followed by the minor rainy season from mid-September to mid-November. The main annual relative humidity is 95% in the morning and about 60% at noon. The soil at the experimental site is Ferric Acrisol.

Source of planting materials

The seeds and scion for the project were obtained from Wenchi Farm Institute, Bono Region. The Wenchi Farm Institute is where the germplasm of cashews is assembled in Ghana. Seeds were a local variety, and the scion bank was obtained from a scion bank that was established in the year 2014.

Experimental design

The experimental design for the study was 4 x 3 Factorial arrangements in Randomized Complete Block Design (RCBD) with three replications. The first factor was IBA at four different concentrations (0 g/l, 750 g/l, 1000 g/l and 1250 g/l) and the second factor was scion types at three levels (Softwood, Semi-hardwood and Hardwood).

Experimental procedure

Cashew was planted in polythene bags at one cashew seed per bag. There were 10 polybags per treatment and 120 bags per replication. All cultural practices including watering and hand picking of weeds from the experimental site/area and in the bags were carried out. Eight weeks after germination, wedge grafting was carried out using various treatments. The arial part of the growing rootstock was cut to a height of about 10-15 cm leaving about two leaves. A vertical incision was made through the rootstock to about 3-4 cm. The scion that was used for the grafting was about 10 to 13 cm long and pencil size thick. The scion had 2 or more healthy vegetative buds, and the basal end was cut to a V-shaped wedge matching the opening in the rootstock.

Preparation of IBA concentrations

IBA was weighed according to their different concentration that is; 750 mg/l of 50% ethanol, 1000 mg/l of 50% ethanol, 1250 mg/l of 50% ethanol and no application of IBA at the Crops and Soil Science Department, Faculty of Agriculture, KNUST. With the aid of a digital electronic scale, the different rates of the IBA were weighed into a glass jar with one litre of alcohol containing 50% ethanol.

Procedure for treatment imposition

The scion was dipped in the various solutions according to their treatments before the scion was inserted into the opening of the rootstock. Grafting tape was used to tie the rootstock and the scion after the insertion. A plane polythene bag was used to cover the grafted seedling from the top of the scion to the base of the grafted area to prevent water from getting into the grafted part to cause rot. Grafted seedlings were left for two weeks for data collection to commence. Judicious watering and application of foliar fertilizer and fungicide were carried out at this stage till seedlings were ready for field planting.

Data collected

Percentage graft-take

This was expressed as the total number of graft successes over the total number of grafted seedlings multiplied by a hundred.

Percentage graft-take =

$$\frac{Number\ of\ successful\ graft}{Total\ number\ of\ grafted\ seedlings} \times 100$$

Vegetative growth of seedlings after grafting

The following vegetative parameters were collected;

Number of leaves

This was done by counting the leaves in two-week intervals from two weeks after planting till twelve weeks after planting.

Shoot height

This was measured using a meter rule or measuring tape in two-week intervals from two weeks after planting till twelve weeks after planting.

Root length

This was done by using a pair of dividers and a ruler to measure the root from the point of attachment of the root to the distal end of the rootstock.

Root biomass

The roots were cut from the point of attachment to the stock. The samples were washed through a submerged 250 µm sieve with running tap water to get rid of all the soil particles attached to them and the roots retained by and floating on the sieve were collected. Root samples were then oven-dried to constant weight at temperatures below 60°C and weighed using a precision scale.

Stem girth

This was measured using a vernier caliper. The close the vernier caliper was set to 00.00 reading. The caliper was open to measure the diameter of the stem of all the grafted seedlings of various treatments. The readings indicate the diameter of the stem for each treatment measured.

Percentage of survived seedlings after transplanting

This was done by counting the number of seedlings that survived after the successful graftage of plants in the various treatments within the time of study and was divided by the total number of plants transplanted and then multiplied by 100. The formula is given as:

Percentage of survived seedlings =

$$\frac{Number\ of\ survived\ seedlings\ after\ transplanting}{Total\ number\ of\ plants\ transplanted} \text{x}100$$

Data analysis

Data collected was subjected to analysis of variance (ANOVA) using Statistix software version 10.0 and treatment mean differences were separated using Tukey's Honestly Significant Difference (HSD) at 5% probability level.

Results

Effect of scion type and IBA concentrations on the number of days to 50% graftage of cashew

There were significant effect of scion type and IBA concentration interactions for the number of days to graftage (Table 1). The significantly highest number of days to graftage thus, 23 days was recorded by cashew seedlings grafted using softwood and was not treated with IBA while the least number of days to graftage of 13 days was recorded by seedlings grafted using semi-hardwood and was treated with 1250 ml concentration of IBA. Among the scion types, softwood recorded the highest number of days to graftage, which was similar to hardwood and the least was recorded by semi-hard. Among the concentrations, cashew seedlings which were not treated with the different concentrations of IBA recorded the highest number of days to graftage and the least was recorded by 1250 ml concentration of IBA (Table 1).

Table 1. Effect of scion type and IBA concentrations on number of days to 50% graftage of cashew.

Number of days to 50% graftage						
Concentrations of IBA (ml)						
Scion type		0	750	1000	1250	Means
Soft		23.00^{a}	20.00^{b}	17.00^{c}	16.00^{c}	19.00^{a}
Semi-hard		16.00^{c}	17.00^{c}	16.00^{c}	13.00^{d}	15.50^{b}
Hard		21.33^{ab}	17.00^{c}	20.00^{b}	17.00^{c}	18.83^{a}
Means		20.11^{a}	18.00^{b}	17.67^{b}	15.33^{c}	
CV=10.08						
HSD (0.05): Scion type=0.684, Concentration=0.873, Scion type* Concentration=1.979						

Means with similar alphabets are not different from each other at a probability value of 5%.
IBA: Indole Butyric Acid, HSD: Tukey's Honestly Significant Difference, CV: Coefficient of Variation, ml: milliliters.

Effect of scion type and IBA concentrations on percentage graftage of cashew

There were significant effect of scion type and IBA concentration interactions for percentage graftage (Table 2). Significantly, the highest graftage percentage was recorded by cashew seedlings grafted using semi-hardwood and treated with 1250 ml IBA concentration while the least was recorded by seedlings grafted using hardwood and not treated with IBA. Among the scion types, semi-hardwood recorded the highest graftage percentage, and the least was recorded by the hardwood. Among the concentrations, 1250 ml concentration of IBA recorded the highest graftage percentage and the lowest was recorded by 750 ml concentration of IBA.

Table 2. Effect of scion type and IBA concentrations on percentage graftage of cashew.

Percentage graftage					
Concentrations of IBA (ml)					
Scion type	0	750	1000	1250	Means
Soft	36.67^{d}	16.67^{f}	26.67^{e}	56.67^{b}	34.17^{b}
Semi-hard	56.67^{b}	26.67^{e}	56.67^{b}	90.00^{a}	57.50^{a}
Hard	16.67^{f}	46.67^{c}	16.67^{f}	46.67^{c}	31.67^{b}
Means	36.67^{b}	30.00^{c}	33.33^{bc}	64.44^{a}	
CV=10.08					
HSD (0.05): Scion type=3.419, Concentration=4.364, Scion type*Concentration=9.896					

Means with similar alphabets are not different from each at a probability value of 5%.
IBA: Indole Butyric Acid, HSD: Tukey's Honestly Significant Difference, CV: Coefficient of Variation, ml: milliliters.

Effect of scion type and concentrations of IBA on plant height of cashew at week two

There were no significant effect of scion types and concentrations of IBA for shoot height at week two (Table 3).

Table 3. Effect of scion type and concentrations of IBA on shoot height of cashew at week two.

Concentrations of IBA (ml)					
Scion type	0	750	1000	1250	Means
Soft	28.53^{a}	28.03^{a}	28.43^{a}	28.80^{a}	28.45^{a}
Semi-hard	28.53^{a}	28.53^{a}	28.03^{a}	29.07^{a}	28.54^{a}
Hard	28.23^{a}	28.13^{a}	28.23^{a}	28.43^{a}	28.26^{a}
Means	28.43^{ab}	28.23^{b}	28.23^{b}	28.77^{a}	
CV=1.35					
HSD (0.05): Scion type=0.393, Concentration=0.502, Scion type*Concentration=0.137					

Means with similar alphabets are not different from each other at a probability value of 5%.
IBA: Indole Butyric Acid, HSD: Tukey's Honestly Significant Difference, CV: Coefficient of Variation, ml: milliliters.

Effect of scion type and concentrations of IBA on shoot height of cashew at week four

There were significant effect of scion type and IBA concentration interactions for shoot height at week four (Table 4). Significantly tallest plants were recorded by cashew seedlings grafted using softwood and were not treated with IBA while the least was recorded by seedlings grafted using hardwood and treated with 750 ml IBA concentration. Among the scion types, softwood recorded the tallest plants which were similar to the semi-hardwood while the shortest plants were recorded by the hardwood. Among the concentrations, 1250 ml IBA concentration recorded the tallest plants, and the least was recorded by 750 ml IBA (Table 4).

Table 4. Effect of scion type and concentrations of IBA on shoot height of cashew at week four.

Concentrations of IBA (ml)					
Scion type	0	750	1000	1250	Means
Soft	29.43^{a}	28.43^{fg}	29.03^{bc}	28.87^{cde}	28.94^{a}
Semi-hard	28.73^{cdef}	28.93^{bcd}	28.53^{ef}	29.27^{ab}	28.87^{a}
Hard	28.43^{fg}	28.13^{g}	28.63^{def}	28.63^{def}	28.46^{b}
Means	28.87^{ab}	28.50^{c}	28.73^{b}	28.92^{a}	
CV=0.40					
HSD (0.05): Scion type=0.199, Concentration=0.152, Scion type*Concentration=0.345					

Means with similar alphabets are not different from each other at a probability value of 5%.
IBA: Indole Butyric Acid, HSD: Tukey's Honestly Significant Difference, CV: Coefficient of Variation, ml: milliliters.

Effect of scion type and concentrations of IBA on shoot height of cashew at week six

There were significant effect of scion type and IBA concentration interactions for shoot height at week six (Table 5). Significantly tallest plants were recorded by cashew seedlings grafted using softwood and were not treated with IBA while the least was recorded by seedlings grafted using hardwood and treated with 750 ml IBA concentration. Among the scion types, softwood recorded the tallest plants which were similar to the semi-hardwood while the shortest was recorded by the hardwood. Among the IBA concentrations, 1250 ml recorded the tallest plants, and the least was recorded by 750 ml IBA (Table 5).

Table 5. Effect of scion type and concentrations of IBA on shoot height of cashew at week six.

	Concentrations of IBA (ml)				
Scion type	0	750	1000	1250	Means
Soft	29.63^{abc}	28.83^{cde}	29.43^{abcd}	30.13^{a}	29.51^{a}
Semi-hard	28.83^{cde}	29.13^{bcde}	28.93^{cde}	29.93^{ab}	29.21^{a}
Hard	28.53^{de}	28.23^{e}	28.73^{cde}	28.93^{cde}	28.61^{b}
Means	29.00^{b}	28.73^{b}	29.03^{b}	29.67^{a}	

CV=1.06
HSD (0.05): Scion type=0.315, Concentration=0.403, Scion type*Concentration=0.913

Means with similar alphabets are not different from each other at a probability value of 5%.
IBA: Indole Butyric Acid, HSD: Tukey's Honestly Significant Difference, CV: Coefficient of Variation, ml: milliliters.

Effect of scion type and concentrations of IBA on shoot height of cashew at week eight

There were significant effect of scion type and IBA concentration interactions for shoot height at week eight (Table 6). Significantly tallest plants were recorded by cashew seedlings grafted using softwood and treated with 1250 ml concentration of IBA which was similar to those grafted with semi-hardwood and treated with 1250 ml concentration of IBA while the least was recorded by seedlings grafted using hardwood and treated using 750 ml concentration of IBA. Among the scion types, softwood recorded the tallest plants which were similar to the semi-hardwood while the shortest was recorded by the hardwood. Among the concentrations, 1250 ml IBA concentration was recorded in the tallest plants, and the least was recorded by 750 ml concentration of IBA (Table 6).

Table 6. Effect of scion type and concentrations of IBA on shoot height of cashew at week eight.

	Concentrations of IBA (ml)				
Scion type	0	750	1000	1250	Means
Soft	29.63^{b}	29.13^{cd}	29.53^{b}	29.93^{a}	29.56^{a}
Semi-hard	28.93^{d}	29.13^{cd}	29.23^{c}	29.93^{a}	29.31^{b}
Hard	28.63^{e}	28.43^{e}	28.93^{d}	29.23^{c}	28.81^{c}
Means	29.07^{c}	28.90^{d}	29.23^{b}	29.70^{a}	

CV=0.34
HSD (0.05): Scion type=0.103, Concentration=0.131, Scion type*Concentration=0.297

Means with similar alphabets are not different from each other at a probability value of 5%.
IBA: Indole Butyric Acid, HSD: Tukey's Honestly Significant Difference, CV: Coefficient of Variation, ml: milliliters.

Effect of scion type and concentrations of IBA on shoot height of cashew at week ten

There were significant effect of scion type and IBA concentration interactions for shoot height at week ten (Table 7). Significantly tallest plants were recorded by cashew seedlings grafted using softwood and treated with 1250 ml IBA concentration which was like those grafted with hardwood and treated with 1250 ml IBA concentration while the least were recorded by seedlings grafted using hardwood and treated using 750 ml IBA concentration which was also similar to those not treated with IBA. Among the scion types, softwood recorded the tallest plants while the shortest was recorded by the hardwood. Among the concentrations of IBA, 1250 ml recorded the tallest plants, and 750 ml recorded the shortest plants (Table 7).

Table 7. Effect of scion type and concentrations of IBA on shoot height of cashew at week ten.

	Concentrations of IBA (ml)				
Scion type	0	750	1000	1250	Means
Soft	29.83^{abc}	29.23^{cde}	29.63^{bc}	30.40^{a}	29.78^{a}
Semi-hard	28.93^{de}	29.43^{cd}	29.53^{cd}	30.23^{ab}	29.53^{b}
Hard	28.73^{e}	28.63^{e}	29.23^{cde}	30.43^{a}	29.26^{c}
Means	29.17^{bc}	29.10^{c}	29.47^{b}	30.36^{a}	

CV=0.79
HSD (0.05): Scion type=0.239, Concentration=0.306, Scion type*Concentration=0.693

Means with similar alphabets are not different from each other at a probability value of 5%.
IBA: Indole Butyric Acid, HSD: Tukey's Honestly Significant Difference, CV: Coefficient of Variation, ml: milliliters.

Effect of scion type and concentrations of IBA on shoot height of cashew at week twelve

There were significant effect of scion type and IBA concentration interactions for plant height at week 12 (Table 8). Significantly tallest plants were recorded by cashew seedlings grafted using semi-hardwood and treated with 1250 ml IBA concentration while the shortest plants were recorded by seedlings grafted using semi-hardwood with no IBA treatment and were similar to seedlings grafted with hardwood with no IBA treatment. Among the scion types, softwood recorded the tallest plants which were like semi-hard while hardwood recorded the shortest plants. Among the IBA concentrations, 1250 ml recorded the tallest plants, while seedlings treated with 750 ml recorded the shortest plants and were similar in height to the seedlings that were not treated with IBA (Table 8).

Table 8. Effect of scion type and concentrations of IBA on shoot height of cashew at week twelve.

Concentrations of IBA (ml)					
Scion type	0	750	1000	1250	Means
Soft	29.93^{cd}	29.53^{e}	29.83^{de}	30.30^{bc}	29.90^{a}
Semi-hard	29.13^{f}	29.53^{e}	29.83^{de}	30.83^{a}	29.83^{a}
Hard	28.83^{f}	28.83^{f}	30.43^{b}	30.43^{b}	29.63^{b}
Means	29.30^{c}	29.30^{c}	30.03^{b}	30.52^{a}	
CV=0.45 HSD (0.05): Scion type=0.137, Concentration=0.175, Scion type*Concentration=0.396					

Means with similar alphabets are not different from each other at a probability value of 5%.
IBA: Indole Butyric Acid, HSD: Tukey's Honestly Significant Difference, CV: Coefficient of Variation, ml: milliliters.

Effect of scion type and concentrations of IBA on the number of leaves of cashew at week eight

There were significant effect of scion type and IBA concentration interactions for the number of leaves at week eight (Table 9). The significantly highest number of leaves at week eight was recorded by cashew seedlings grafted using semi-hardwood and treated with 1250 ml concentration of IBA while the least was recorded by seedlings grafted using hardwood and treated with 1000 ml concentration of IBA. Among the scion types, semi-hardwood recorded the highest number of leaves, and the least number of leaves was recorded by the hardwood. Among the IBA concentrations used, 1250 ml recorded the highest number of leaves, and the lowest number of leaves was recorded by the 1000 ml (Table 9).

Table 9. Effect of scion type and concentrations of IBA on number of leaves of cashew at week eight.

Concentrations of IBA (ml)					
Scion type	0	750	1000	1250	Means
Soft	1.73^{b}	0.43^{f}	0.78^{e}	1.23^{d}	1.05^{b}
Semi-hard	1.53^{c}	0.83^{e}	1.23^{d}	4.30^{a}	1.98^{a}
Hard	0.13^{h}	1.23^{d}	0.33^{g}	1.53^{c}	0.81^{c}
Means	1.13^{b}	0.83^{c}	0.78^{d}	2.36^{a}	
CV=2.61 HSD (0.05): Scion type=0.034, Concentration=0.044, Scion type*Concentration=0.099					

Means with similar alphabets are not different from each other at a probability value of 5%.
IBA: Indole Butyric Acid, HSD: Tukey's Honestly Significant Difference, CV: Coefficient of Variation, ml: milliliters.

Effect of scion type and concentrations of IBA on the number of leaves of cashew at week ten

There were significant effect of scion type and IBA concentration interactions for the number of leaves in week ten (Table 10). The significantly highest number of leaves at week ten was recorded by cashew seedlings grafted using semi-hardwood and treated with 1250 ml concentration of IBA while the least was recorded by seedlings grafted using hardwood and treated with 1000 ml concentration of IBA. Among the scion types, semi-hardwood recorded the highest number of leaves, and the least number of leaves was recorded by the hardwood. Among the IBA concentrations used, 1250 ml recorded the highest number of leaves, and the least number of leaves was recorded by 750 ml (Table 10).

Table 10. Effect of scion type and concentrations of IBA on number of leaves of cashew at week ten.

Concentrations of IBA (ml)					
Scion type	0	750	1000	1250	Means
Soft	2.23^{b}	0.43^{h}	0.83^{g}	1.73^{d}	1.31^{b}
Semi-hard	1.93^{c}	0.93^{f}	1.93^{c}	4.90^{a}	2.43^{a}
Hard	0.23^{i}	1.43^{e}	0.43^{h}	1.93^{c}	1.01^{c}
Means	1.47^{b}	0.93^{d}	1.07^{c}	2.86^{a}	
CV=2.11 HSD (0.05): Scion type=0.034, Concentration=0.044, Scion type* Concentration=0.099					

Means with similar alphabets are not different from each other at a probability value of 5%.
IBA: Indole Butyric Acid, HSD: Tukey's Honestly Significant Difference, CV: Coefficient of Variation, ml: milliliters.

Effect of scion type and concentrations of IBA on the number of leaves of cashew at week twelve

There were significant effect of scion type and IBA concentration interactions for the number of leaves at week 12 (Table 11). The significantly highest number of leaves at week 12 was recorded by cashew seedlings grafted using semi-hardwood and treated with 1250 ml concentration of IBA, while the least number of leaves was recorded by seedlings grafted using hardwood and treated using 1000 ml concentration of IBA. Among the scion types, semi-hardwood recorded the highest number of leaves, and the least number of leaves was recorded by hardwood. Among the IBA concentrations used, 1250 ml IBA concentration recorded the highest number of leaves, and the least number of leaves was recorded by 750 ml IBA (Table 11).

Table 11. Effect of scion type and concentrations of IBA on number of leaves of cashew at week twelve.

Concentrations of IBA (ml)						
Scion type		0	750	1000	1250	Means
Soft		2.43^{b}	0.43^{h}	0.83^{f}	1.83^{d}	1.38^{b}
Semi-hard		2.08^{c}	0.93^{f}	1.93^{d}	5.33^{a}	2.57^{a}
Hard		0.23^{i}	1.53^{e}	0.63^{g}	2.08^{c}	1.12^{c}
Means		1.58^{b}	0.97^{d}	1.13^{c}	3.08^{a}	
CV=2.96 HSD (0.05): Scion type=0.051, Concentration=0.066, Scion type*Concentration=0.149						

Means with similar alphabets are not different from each other at a probability value of 5%.
IBA: Indole Butyric Acid, HSD: Tukey's Honestly Significant Difference, CV: Coefficient of Variation, ml: milliliters.

Effect of scion type and concentrations of IBA on stem girth of cashew at week six

There were significant effect of scion type and IBA concentration interactions for stem girth at week six (Table 12). Significantly widest stem girth was recorded at week six by cashew seedlings grafted using semi-hardwood and treated with 1250 ml IBA concentration while the least was recorded by seedlings grafted using hardwood and treated using 1000 ml IBA concentration. Among the scion types, semi-hardwood was recorded as the highest and the least was recorded by hardwood. Among the concentrations of IBA used, 125 ml recorded as the widest and 750 ml recorded as the smallest was recorded by 750 ml IBA (Table 12).

Table 12. Effect of scion type and concentrations of IBA on stem girth of cashew at week six.

Stem Girth in Week Six Concentrations of IBA (ml)						
Scion type		0	750	1000	1250	Means
Soft		0.33^{d}	0.03^{f}	0.43^{c}	0.18^{e}	0.25^{b}
Semi-hard		0.53^{b}	0.33^{d}	0.18^{e}	1.50^{a}	0.64^{a}
Hard		0.03^{f}	0.18^{e}	0.03^{f}	0.18^{e}	0.11^{c}
Means		0.30^{b}	0.18^{c}	0.22^{c}	0.62^{a}	
CV=10.08 HSD (0.05): Scion type=0.034, Concentration=0.044, Scion type*Concentration=0.099						

Means with similar alphabets are not different from each other at a probability value of 5%.
IBA: Indole Butyric Acid, HSD: Tukey's Honestly Significant Difference, CV: Coefficient of Variation, ml: milliliters.

Effect of scion type and concentrations of IBA on stem girth of cashew at week eight

There were significant effect of scion type and IBA concentration interactions for stem girth at week eight (Table 13). Significantly widest stem girth at week eight was recorded by cashew seedlings grafted using semi-hardwood and treated with 1250 ml concentration of IBA, while the smallest was recorded by seedlings grafted using hardwood and treated with 1000 ml concentration of IBA. Among the scion types, semi-hardwood was recorded the widest and the least was recorded by hardwood. Among the IBA concentrations used, 1250 ml was recorded as the widest and the smallest was recorded as 750ml (Table 13).

Table 13. Effect of scion type and concentrations of IBA on stem girth of cashew at week eight.

Stem Girth at Week Eight					
Concentrations of IBA (ml)					
Scion type	0	750	1000	1250	Means
Soft	1.03^{c}	0.33^{h}	0.78^{f}	0.88^{d}	0.76^{b}
Semi-hard	1.28^{b}	0.33^{h}	0.73^{g}	2.40^{a}	1.19^{a}
Hard	0.03^{i}	0.83^{e}	0.03^{i}	1.28^{b}	0.55^{c}
Means	0.78^{b}	0.50^{d}	0.52^{c}	1.52^{a}	
CV=1.00 HSD (0.05): Scion type=8.549, Concentration=0.011, Scion type*Concentration=0.025					

Means with similar alphabets are not different from each other at a probability value of 5%.
IBA: Indole Butyric Acid, HSD: Tukey's Honestly Significant Difference, CV: Coefficient of Variation, ml: milliliters.

Effect of scion type and concentrations of IBA on stem girth of cashew at week ten

There were significant effect of scion type and IBA concentration interactions for stem girth at week ten (Table 14). Significantly widest stem girth at week ten was recorded by cashew seedlings grafted using semi-hardwood and treated with 1250 ml concentration of IBA, while the smallest was recorded by seedlings grafted using hardwood and treated with 1000 ml concentration of IBA. Among the scion types, semi-hardwood was recorded as the widest and the smallest was recorded by hardwood. Among the concentrations of IBA, 1250 ml was recorded as the widest and the smallest recorded by 750 ml but was similar to 1000 ml (Table 14).

Table 14. Effect of scion type and concentrations of IBA on stem girth of cashew at week ten.

Stem girth at week ten Concentrations of IBA (ml)					
Scion type	0	750	1000	1250	Means
Soft	1.38^{c}	0.43^{h}	0.78^{f}	1.18^{e}	0.95^{b}
Semi-hard	1.48^{b}	0.53^{g}	1.23^{d}	3.40^{a}	1.68^{a}
Hard	0.13^{i}	1.23^{de}	0.18^{i}	1.48^{b}	0.79^{c}
Means	1.00^{b}	0.73^{c}	0.75^{c}	2.02^{a}	
CV=2.96 HSD (0.05): Scion type=0.034, Concentration=0.044, Scion type*Concentration=0.099					

Means with similar alphabets are not different from each other at a probability value of 5%.
IBA: Indole Butyric Acid, HSD: Tukey's Honestly Significant Difference, CV: Coefficient of Variation, ml: milliliters.

Effect of scion type and IBA concentrations on root biomass of cashew seedlings

There were significant effect of scion type and IBA concentration interactions for root biomass (Table 15). Significantly the largest root biomass was recorded by cashew seedlings grafted using semi-hardwood and was treated with 1250 ml concentration of IBA, while the least was recorded by seedlings grafted using softwood and not treated with IBA. Among the scion types, semi-hardwood recorded the largest root biomass while the least was recorded by the softwood and hardwood. Among the concentrations of IBA, 1250 ml recorded the largest root biomass, and the least was recorded by 0 ml but was similar with 750 ml and 1000 ml (Table 15).

Table 15. Effect of scion type and concentrations of IBA on root biomass.

Concentrations of IBA (ml)					
Scion type	0	750	1000	1250	Means
Soft	0.03^{c}	0.03^{c}	0.03^{c}	0.04^{b}	0.03^{b}
Semi-hard	0.03^{c}	0.04^{b}	0.04^{b}	0.08^{a}	0.05^{a}
Hard	0.03^{c}	0.03^{c}	0.03^{c}	0.04^{b}	0.03^{b}
Means	0.03^{b}	0.03^{b}	0.03^{b}	0.05^{a}	
CV=7.70 HSD (0.05): Scion type=2.961, Concentration=3.779, Scion type* Concentration=8.571					

Means with similar alphabets are not different from each other at a probability value of 5%.
IBA: Indole Butyric Acid, HSD: Tukey's Honestly Significant Difference, CV: Coefficient of Variation, ml: milliliters.

Effect of scion type and IBA concentrations on root length of cashew seedlings

There were significant effect of scion type and IBA concentration interactions for root length (Table 16). Significantly the longest root was recorded by cashew seedlings that were grafted using semi-hardwood scion treated with 1250 ml concentration of IBA, while the shortest root was recorded by seedlings grafted using softwood scion not treated with IBA. Among the scion types, semi-wood recorded the largest root biomass while the least was recorded by the softwood and hardwoods. Among the concentrations used, 1250 ml IBA concentration recorded the longest root, and the least was recorded by scions not treated with IBA (Table 16).

Table 16. Effect of scion type and concentrations of IBA on root length.

Concentrations of IBA (ml)					
Scion type	0	750	1000	1250	Means
Soft	21.37^{g}	24.57^{de}	26.97^{c}	28.87^{b}	25.44^{b}
Semi-hard	23.67^{ef}	24.67^{de}	28.77^{b}	36.17^{a}	28.32^{a}
Hard	22.87^{f}	24.77^{de}	25.47^{d}	27.37^{c}	25.12^{b}
Means	22.63^{d}	24.67^{c}	27.07^{b}	30.80^{a}	
CV=1.45 HSD (0.05): Scion type=0.392, Concentration=0.500, Scion type* Concentration=1.134					

Means with similar alphabets are not different from each other at a probability value of 5%.
IBA: Indole Butyric Acid, HSD: Tukey's Honestly Significant Difference, CV: Coefficient of Variation, ml: milliliters.

Effect of scion type and IBA concentrations on percentage survived seedlings after field transplanting

There were significant effect of scion type and IBA concentration interactions for the percentage of survived seedlings after field transplanting (Table 17). Significantly highest percentage of survived seedlings after transplanting was recorded by cashew seedlings grafted using semi-hardwood scion treated with 1250 ml concentration of IBA. The least was however, recorded by seedlings grafted using hardwood scion not treated with IBA, and were similar to seedlings grafted using softwood scion and treated with 750 ml concentration of IBA, as well as seedlings grafted using hardwood scion and treated with 1000 ml concentration of IBA. Among the scion types, semi-hardwood recorded the highest percentage of survived seedlings after transplanting and the least was recorded by the hardwood. Among the concentrations, 1250 ml IBA concentration recorded the highest percentage of survived seedlings after transplanting, while the least was recorded by 750 ml IBA.

Table 17. Effect of scion type and IBA concentrations on the percentage of survived seedlings after field transplanting.

Concentrations of IBA (ml)					
Scion type	0	750	1000	1250	Means
Soft	18.33^{d}	8.33^{f}	13.33^{e}	28.33^{b}	17.08^{b}
Semi-hard	28.33^{b}	13.33^{e}	28.33^{b}	78.33^{a}	37.08^{a}
Hard	8.33^{f}	23.33^{c}	8.33^{f}	23.33^{c}	15.83^{b}
Means	18.33^{b}	15.00^{c}	16.67^{bc}	43.33^{a}	
CV=1.45 HSD (0.05): Scion type=1.481, Concentration=1.889 Scion type* Concentration=4.285					

Means with similar alphabets are not different from each other at a probability value of 5%.
IBA: Indole Butyric Acid, HSD: Tukey's Honestly Significant Difference, CV: Coefficient of Variation, ml: milliliters.

Regression analysis between some of the parameters

Root biomass significantly affected survived seedlings, such that 83% of the variation in the survived seedlings was attributed to the root biomass (Equation 1)

$Y_{(\text{Survived seedlings})} = 6.67219+954.74_{(\text{Root biomass})}$ Equation 1

$R^2=0.83$, $p=0.00$

Percent graftage significantly affected survived seedlings, such that 92% of the variation in the survived seedlings was attributed to the percent graftage (Equation 2)

$Y_{(\text{Survived seedlings})} = 6.67219+954.74_{(\text{Percent graftage})}$ Equation 2

$R^2=0.92$, $p=0.00$.

Correlation analysis between some parameters observed in the study

There were significant, positive and strong relationships between survived seedlings and root biomass (r=0.91), percentage graftage (r=0.96), leaves (r=0.96), root length (r=0.82) as well as between plant height and root length (r=0.67).

Table 18. Correlation analysis between some parameters observed in the study.

Variables	Correlation coefficient (r)	Probability level (5%)
Leaves and plant height	0.56	0.0007
Plant height and root length	0.67	0.0012
Survived seedlings and root biomass	0.91	0.0000
Survived seedlings and root length	0.82	0.0000
Graftage and survived seedlings	0.96	0.0000
Root biomass and plant height	0.61	0.0360
Survived seedlings and leaves	0.96	0.0000

Discussion

Results obtained from this study showed that the significantly highest number of days to graftage was recorded by cashew seedlings grafted using softwood scion and were not treated with IBA concentration while the least was recorded by seedlings grafted using semi-hardwood scion and treated with 1250 ml IBA concentration. This could be due to the faster hormonal action exerted by the application of 1250 ml of IBA on the semi-hardwood cuttings to induce early graftage as compared to the other concentrations of IBA. This observation agrees with the findings of El Malahi *et al* (2024), who indicated that IBA exerts a hormonal action as an auxin. According to Yeboah *et al.* (2020), softwood grafting has been identified as an effective method for propagating cashew trees, with several factors influencing graft success. Retaining mature basal leaves on 60-day-old rootstocks significantly improved graft union success. Using young, flexible shoots as scions—typically from the current season's growth—is the process of softwood grafting (Joshi, 2024). Auxins, which are plant hormones that stimulate growth, are abundant in these tender shoots and have a high metabolic activity (Sarkari *et al.*, 2024). They form connections more easily when grafted onto a rootstock that is suitable with them. Grafting occurs in the cambium layer, which is the thin, green layer directly beneath the bark (Bradley and Garner, 2017). Similar cambium features between cashew rootstocks and softwood scions allow for easier growth signal, nutrient, and water transfer (Mir *et al.*, 2023). Because wood grafts heal more quickly, vascular compatibility improves graft success (Ratner, 2023; Adhikari *et al.*, 2022). It is possible for the cambium layers of the scion and rootstock to fuse quickly, forming a seamless joint (Niu, 2011). The effective flow of nutrients made possible by this fusion encourages the growth of scions as well as the general development of trees. Higher IBA application rates may indirectly affect rooting by accelerating the translocation and transfer of sugar to the base of cuttings, according to Habib and Attiya (2016). The results of the study confirm the reports that IBA is more successful than CBA for root induction in *T. baccata* (Chauhan, 2018; Pandey *et al.*, 2011) and *C. deodara* (Shekhawat and Manokari, 2016). Furthermore, the semi-hardwood scion responded and rooted earlier than the softwood and hardwood scion. This is most likely because the semi-hardwood scion has more nutrients and comparatively more carbohydrate plants available to it. Semi-hardwood cuttings are thought to make the greatest scions, according to Lesmes-Vesga *et al.* (2022), because they have a higher store of carbohydrates and water, which guarantees the cuttings' first metabolisms before they deteriorate. Softwood cuttings of leaves from early seedlings are usually the finest for vegetative renewal. This demonstrates how crucial it is for the stock plant's physiological condition to regenerate (Leakey, 2017). The physiology, morphology, and phenology of donor plants, as well as their age, are always considered to be significant factors in the failure of stem cuttings to regenerate (Vahdati *et al.*, 2022; Marini and Fazio, 2018). Other factors that may be involved include the amount of carbohydrates in the plant as well as the contents of growth regulators and nutrients (Druege *et al.*, 2019). Among the IBA concentrations that were employed, cashew seedlings that were not treated with IBA developed successful grafts considerably later than those that were treated with a 1250 ml concentration of IBA, which developed effective grafts sooner. One probable conclusion is that cell function and action efficiency improve with increasing IBA concentration. Henrique *et al.* (2006) also observed similar results with *Pinus caribea* cuttings treated with paclobutrazol (PBZ). IBA, an auxin, most likely facilitated the transport of carbohydrates and other naturally occurring plant materials and nutrients to the rooting zone, where they were needed for cell division, the start of roots, and the growth of air-layered shoots (Babu *et al.*, 2022; Yeboah *et al.*, 2014). The current study's findings showed a general tendency of significantly higher vegetative development (plant height, number of leaves, and stem girth) in semi-hardwood scions treated with 1250 ml of IBA. This may be explained by the plant substances moving to a different site, which improved cell processes and eventually resulted in the creation of a graft union and the growth of seedlings. High sugar content in rootstocks is a sign of sustained energy production during the healing process, according to Rasool *et al.* (2020). Additionally, it contributed to the basipetal transport of other plant materials to the zone where they join and underwent fast cell division, resulting in the effective creation of grafts and the subsequent growth of seedlings (Mauro *et al.*, 2020). The study compared the mineral nutrition of cherry tree scions grafted onto various rootstocks and suggested that vigorous rootstocks facilitate the movement of endogenous plant substances to the grafting zone, enhancing graft success, as evidenced by rejuvenated shoots. Anatomical observations support this, as the rejuvenated shoots showed complete cell differentiation, a trait absent in young plants, which only exhibited cell expansion. The availability of IBA is likely responsible for the observed cell differentiation in the rejuvenated shoots, promoting callus formation, wound healing, and ultimately, graft success. (Vielba *et al.*, 2020; Lai and Lai, 2019). Only until the adventitious buds have matured into well-formed shoots is the root initiation apparent. It has been established that auxin and carbohydrates interact to create roots (Mishra *et al.*, 2022). IBA breaks down polysaccharides, enhancing metabolic activities that provide the necessary energy for the formation and elongation of meristematic tissues, which are crucial for root development and sprouting. This process stimulates the formation of roots (Abo El-Enien and Omar, 2018; Gupta *et al.*, 2016). In this investigation, cashew seedlings grafted using semi-hardwood scion treated with a 1250 ml concentration of IBA recorded the considerably highest root biomass, while seedlings grafted using softwood scion that was not treated with IBA recorded the lowest. Good rains fell during the field-establishing period, which contributed to the transplanted propagules' high survival rate. Therefore, it was not unexpected that 68% of the difference in the transplanted propagules' survival was explained by the month of field installation. Because the rooted cuttings possessed adventitious roots, while the transplanted plantlets had a longer tap root system, the transplanted plantlets' percent survival was generally higher than that of the rooted cuttings. As a result, the plantlets were more effective at exploring and utilizing soil resources compared to rooted cuttings with shallow adventitious roots. The shea nut tree naturally develops a long taproot with relatively few secondary and tertiary roots. This root structure allows it to access soil resources from deeper layers rather than the surface, which partly explains its slow growth in its natural environment. Overall hole depths, the transplanted rooted cuttings outgrew the plantlets in terms of growth, as evidenced by their recording of 1.7 times more leaves and 5.6 times larger stem girth. This may be because, six months after establishment, the rooted cuttings had a superior root system with more secondary and tertiary roots. This improved the rooted cuttings' capacity to investigate the soil's deeper and more superficial layers, which promoted growth. Transplanting rooted cuttings into a 52 cm deep hole significantly enhanced stem girth and leaf production compared to a 26 cm deep hole. This improvement can be attributed to the deeper hole supporting the natural formation of a long taproot, unlike the shallower hole, which restricted root growth and expansion. Additionally, the 52 cm depth provided the lowest soil temperature and highest soil moisture. High soil moisture supports water uptake by roots for shoot growth and increased photosynthesis, while moderate soil temperatures enhance the root system's ability to absorb water and nutrients efficiently (Calleja-Cabrera *et al.*, 2020; Luo *et al.*, 2016). Furthermore, the higher soil moisture at this depth likely created a favorable environment for soil microorganisms, which play a critical role in biogeochemical processes. These processes include organic matter decomposition and the production of hormones and organic acids that release nutrients, improving plant nutrient uptake (Prasad *et al.*, 2021; Nardi *et al.*, 2017). It has been discovered that the IBA transforms into IAA in numerous species. IBA is the most often used hormone among all the auxins because of its strong rooting ability (Abdel-Rahman, 2020). In the current investigation, cashew seedlings grafted using semi-hardwood and treated with 1250ml IBA concentration showed the best percentage of survived seedlings after transplantation. It's probable that the IBA's biggest worry increased the seedlings' ability to root, giving them the right stability and anchoring to ensure their survival. El-Banna *et al.* (2023), IBA has the tendency to induce root formation. In apple rootstock, IBA treatment changes the hormone levels and protein expression profiles linked to the generation of energy, carbohydrate metabolism, and phytohormone signaling, as well as rooting rates and root length (Wang *et al.*, 2024; Tahir *et al.*, 2022). Peroxisomal conversion of IBA to indole-3-acetic acid (IAA) and then peroxisomal nitric oxide (NO) production are the two steps in the mechanism of IBA-induced lateral root development. The lateral development of roots is greatly stimulated by the coordinated, spatiotemporal release of IAA and NO from peroxisomes (Bharti and Bhatla, 2015). These findings emphasize the intricate interaction of hormones and signaling molecules in IBA-mediated root activation. Moreover, the functioning of IBA is explained by mechanisms including variations in metabolisms and transport, increased stability, and slow-release sources of IAA. An essential growth metric that is useful for forecasting seedling establishment and growth is the seedling survival rate (SSR%). The application of IBA may have resulted in a larger percentage of surviving seedlings as compared to the control group's treatment. This could be attributed to the roots' faster growth, which was facilitated by IBA. At all IBA application concentrations, Khan *et al.* (2020) observed a steady rise in the SSR% of seedlings derived from kiwi cuttings. The surviving seedlings were greatly influenced by their root biomass, to the extent that 82% of the variation in the surviving seedlings could be ascribed to the root biomass. This shows that the grated cashew seedlings' total survival is significantly influenced by their root biomass.

Conclusion

It was determined that applying a 1250 ml concentration of IBA to semi-hardwood scions reduced the number of days needed to accomplish graft success, resulting in the best and greatest percentage of cashew graft-take. Semi-hardwood scions treated with a 1250 ml concentration of IBA performed best for all the vegetative metrics investigated (plant height, stem girth, number of leaves, root biomass, and root length). The largest percentage of seedlings that survived transplanting was from semi-hardwood cuttings treated with a 1250 ml concentration of IBA.

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