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Incorporation of Nanotechnology in Propagation Treatments by Cuttings of Jojoba (*Simmondsia chinensis* (Link) Schneider) Shrubs in Egypt and South Africa

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TWO independent factorial experiments were conducted at the Conservation Glasshouse of the Egyptian National Gene Bank, ARC, Giza, Egypt during the 2020 and 2021 seasons to enhance the rooting of wounded terminal stem cuttings of jojoba plants as well as the growth and chemical composition of the resulting transplants. The first experiment examined the effect of nano-Fe naphthaleneacetic acid (nFe-NAA) at 0, 100, 200, and 400 ppm, indole-3-butyric acid (IBA) either in its traditional form (t-IBA) at 0, 1000, 2000, and 4000 ppm or in nanoparticles loaded on Fe (nFe-IBA) at 0, 100, 200, and 400 ppm, and their interactions. Meanwhile, in the second experiment, the effect of NAA in nano form (n-NAA) at 0, 100, 200, and 400 ppm, IBA either in traditional form (t-IBA) at 0, 1000, 2000, and 4000 ppm or in nano form (n-IBA) at 100, 200, and 400 ppm, and their interactions were studied. In the first experiment, the sole and combined treatments improved the mean values of rooting percentage, number of roots per cutting, and root length, as well as branch length, number of branches per transplant, number of leaves per transplant, and fresh and dry weights of branches and roots, chlorophyll a, b, carotenoids, total sugars, indoles, and phenols in the newly formed transplants, with few exceptions in the two seasons. However, the combined treatments, especially the quick dipping of wounded cuttings' bases in either 200 or 400 ppm nFe-NAA solution and then in either 200 or 400 ppm nFe-IBA one, resulted in the best results in both seasons. A similar trend was also obtained in the second experiment, where the combinations surpassed the individual treatments, especially the combinations of dipping in n-NAA at either 200 or 400 ppm + n-IBA at either 200 or 400 ppm afterwards, as such four combinations scored the best results over all the other combinations. Besides, interacting between 4000 ppm t-IBA and n-NAA at either 200 or 400 ppm concentrations gave better results in some characters. Therefore, it is recommended to use both IBA and NAA rooting hormones together in the form of nanoparticles at either 200 or 400 ppm concentrations for each, either loaded or non-loaded on iron oxide, to get the best rooting of jojoba wounded cuttings and the highest quality of the new transplants from a commercial point of view.

Keywords: Adventitious roots formation, Jojoba (*Simmondsia chinensis* (Link) Schneider), Rooting, Traditional and nano-auxins (IBA and NAA).

Introduction

Jojoba (*Simmondsia chinensis* (Link) Schneider) is a drought-resistant, evergreen shrub belonging to the Simmondsiaceae family. It is a dioecious shrub native to Southwestern North America and the only species in the family Simmondsiaceae. Jojoba is important due to its unusual oil that has many uses depending on the modification technique used. Jojoba oil can be modified via hydrogenation,

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sulfurization, halogenation, sulfurhalogenation, phosphosulfurization, ozonization, hydrolysis, amidation, and many other techniques to be suitable for the production of cosmetics, pharmaceuticals, lubricants, and petrochemicals (Arya & Khan, 2016). Jojoba oil is also like sperm whale oil thus it can be used as food and in medicine (for the remedy of cancer, kidney disorder, stomach aches, and for easing childbirth and tending wounds) and for making seed cakes. Because of the different utilization of agro-technology related to this shrub and profitable yields, it is named "the Desert Gold" (Kureel et al., 2008).

Propagation of jojoba can be achieved by different methods, such as direct seed sowing, air layering, grafting, cuttings, and tissue culture techniques (Hassanein et al., 2022). Sexual propagation by seeds is easy, and the seeds are viable even after 11 years with a 38% germination rate (Bashir, 2007). However, plants produced by seeds are weak, less productive, and disease-prone. Also, they don't transplant well when first grown as nursery stock.

On the other hand, vegetative propagation can provide a high and uniform yield, early fruiting, reduced post-harvesting costs, and desirable clonal varieties (Hogan & Palzkill, 1983). In this regard, Guasso et al. (2021) mentioned that seed-derived plants are usually in low uniformity, and the alternative to address this problem is the cutting technique, a simple and fast method that generates individuals identical to the parent plant, maintaining the agronomic traits. Likewise, Hilgert et al. (2021) decided that the mini-cutting technique of tree species is an easy, quick, and effective method for maintaining desirable plant matrices and uniformity features.

However, some types of cuttings are hard-to-root and need, from a commercial point of view, to be treated with specific auxin at a special concentration to enhance root emission. The response of jojoba cuttings to conventional auxin treatments was detected by Howard et al. (1984), Yuan (2002), Bing & HanDong (2003), Kumar et al. (2008), Osman & Hassan (2013), Khattab et al. (2014) and Bala et al. (2020).

Similar observations were also obtained for other ornamental plants by Badawy et al. (2020) on *Ligustrum ovalifolium*, Mouden et al. (2020) on chrysanthemums, Muraleedharan et al. (2020) on polyantha roses, ZengJie et al. (2020) on *Rosa odorata* var. Odorata, Karimzadeh et al. (2021) on Damask roses, Mengzhao et al. (2021) on *Pyracantha angustifolia*, QiangQiang et al. (2021) on *Toona ciliata* var. pubescens, Rivera Melo et al. (2021) on *Pinus hartwegii*, Vlachau et al. (2021) on *Ballota acetabulosa*, Ghimire et al. (2022) on *Chrysanthemum indicum*, Karabulut & Saracoglu (2022) on *Morus nigra*, Kohler et al. (2022) on dahlias, osteospermum, scaevola, and geraniums, Masalova & Firsov (2022) on *Thuja occidentalis*, Sahai & Sinha (2022) on *Taxus baccata* subsp. Wallichiana, and Solgi & Sahraei (2022) on red willow (*Salix purpurea*).

Until the recent era, traditional auxins have played a role in agricultural development until the innovation of nanotechnology, which revolutionized various fields of modern industries. Nowadays, nanomaterials have considerable applications in pharmaceuticals, electronics, food, and agriculture (Gaafar et al., 2020; Abdelmawgoud et al., 2022; Ismail et al., 2022; Elnagar et al., 2023). Nanotechnology involves manipulating matter, transforming it into nanoparticles (NPs) that are measurable in nanometers (1-100nm) in at least one direction (Grover et al., 2012). The surface area of such particles is very large relative to their small size, which can make them very reactive. Because of their very small size and high reactivity, these particles can easily penetrate the roots and be transferred to the aerial parts of the plants (Banijamali et al., 2019). However, the use of nano hormones for rooting in the literature is very limited, but the usage of other nanomaterials in the agricultural sector has been reported by Shahrekizad et al. (2015) on sunflowers, Banijamali et al. (2019) on *Chrysanthemum morifolium* "Salvador," Alhasan (2020) on basil (*Ocimum basilicum* cv. Dolly), Mahmoud & Swaefy (2020) on sage (*Salvia officinalis*), and Rohim et al. (2020) on date palm cv. Barhee.

On other economic crops, parallel results were also obtained by Abdel-Aziz et al. (2016) on wheat (*Triticum aestivum*), Thangavelu et al. (2018) on *Nicotiana tabacum*, Burhan & Al-Hassan (2019) on wheat, Miranda-Villagomez et al. (2019) on rice (*Oryza sativa* ssp. *indica*), Rop et al. (2019) on maize, kale, and capsicum, and Hegazi et al. (2021) on Picual olive cultivars.

However, this study is an attempt to reveal the effect of conventional and nano forms of IBA solution, nano NAA solution, both alone or loaded on iron oxide nanoparticles (nFe-IBA and nFe-NAA) at various concentrations and their interactions on rooting of jojoba terminal cuttings and the quality of the resulting transplants under glasshouse conditions.

Materials and Methods

Two separate experiments were carried out at the conservation glasshouse of the National Gene Bank, ARC, Giza, Egypt, during the 2020 and 2021 seasons to determine the response of jojoba softwood stem cuttings to dipping in solutions of either IBA (traditional and nano formula) or NAA (nano form), both alone or loaded on iron oxide nanoparticles (nFe_3O_4) at different concentrations, and their interactions for rooting and shoot formation.

Therefore, terminal (softwood) stem cuttings at a length of 10-15cm were taken from one-year-old shoots of healthy and mature jojoba (*Simmondsia chinensis* (Link) schneider) shrubs cultivated in the National Gene Bank farm on March 15th for each season. The cuttings were washed well with tap water and then sterilized with a mixture of Topsin (70%) and Rizolex (50%) from Sumitoms Chemical Co., Ltd., Osaka, Japan, at a rate of 0.5g/L for each. The basal end of each cutting was wounded with 2 or 3 incisions (1cm length of the cortex) using a sterilized stainless-steel blade sharp cutter. Immediately after wounding, two separate experiments were performed as follows:

In the first experiment, sterilized cuttings were treated with the following: (a) no treatment, which served as the control, (b) a quick 10-second dip in a deionized hydro solution of 1-naphthaleneacetic acid (NAA) product from Sigma Chemical Co., USA loaded on iron oxide (Fe_3O_4) nanoparticles at concentrations of 0, 100, 200, and 400 ppm (factor A), (c) a quick dip in a deionized hydro solution of indole-3-butyric acid (IBA) product from Aldrich Chemical Co., Ltd., England either as a standalone (t IBA) at concentrations of 0, 1000, 2000, and 4000 ppm or loaded on iron oxide nanoparticles (nFe-IBA) at concentrations of 100, 200, and 400 ppm (factor B), and (d) where treatments of factor (A) were combined factorially with those of factor (B) to create twenty-eight interaction treatments. Both nFe-NAA and nFe-IBA were prepared by Nanotech Co., 6-October City, Giza, Egypt.

In the second experiment, wounded cuttings were treated with: (a) zero hormone (as control), (b) a quick dip in a deionized hydro solution of NAA nanoparticles (n-NAA) at concentrations of 0, 100, 200, and 400 ppm (factor A), (c) a quick dip in a deionized hydro solution of IBA, either alone in traditional form (t-IBA) at concentrations of 0, 1000, 2000, and 4000 ppm or as nanoparticles (n-IBA) at concentrations of 100, 200, and 400 ppm (factor B), and (d) where every level of factor (A) was combined with each one of factor (B) to create 28 interaction treatments. Cuttings of control treatment in both experiments were quickly dipped in distilled water for only 10 seconds.

Immediately after dipping, 4-5 cm of the treated cuttings and those of control were inserted into 10-cm-diameter plastic pots (one cutting per pot) filled with a 1:1:1 volumetric mixture of peatmoss, sand, and perlite (from the Egyptian Co. for manufacturing perlite) weighing 140g. Tables 1 and 2 show some physical and chemical properties of the peatmoss and sand used in the two seasons, respectively.

TABLE 1. Some physical and chemical properties of the used peat moss in both seasons

Organic matter (%)	Ash (%)	Density (mg/L)	PH value	Water relation capacity (%)	Salinity (g/L)	N (%)	P (%)	K (%)	Fe (ppm)	Mn (ppm)	Zn (ppm)
90-95	5-10	80-90	3.4	60-75	0.3	1.09	0.23	1.77	421	72	41

TABLE 2. Some physical and chemical properties of the sand used during the two studied seasons

Season	Particle size distribution (%)				S.P.	E.C. (ds/m)	PH	Cations (meq/L)				Anions (meq/L)		
	Coarse sand	Fine sand	Silt	Clay				Ca^{++}	Mg^{++}	Na^{+}	K^{+}	HCO_3^-	Cl^-	So_4^{--}
2020	89.03	2.05	0.40	8.52	23.01	3.56	7.9	7.50	1.63	33.6	0.50	3.20	22.0	18.03
2021	87.76	3.30	1.49	7.45	22.87	3.78	7.8	19.42	8.33	7.2	0.75	1.60	7.8	26.30

In the interaction treatments, cuttings were first dipped in nFe-NAA solution for 10 seconds, left to air dry for 10 minutes, and then dipped in either formula of IBA (t-IBA or nFe-IBA). The glasshouse temperature was set at 28-30°C and 80-85% relative humidity during the experiment. The lower part of the pots was buried in the wet sand on a fogged propagation bench until rooting occurred. After rooting, irrigation was done using an intermittent mist system.

The layout of each experiment in the two seasons was a factorial design in a completely randomized design, replicated thrice, with each replicate containing 5 cuttings (Mead et al., 1993).

Four months later, on July 15th, the rooted cuttings were gently lifted, and the following data were recorded: rooting percentage, which was calculated using the equation suggested by Khattab et al. (2014): Rooting %= R/T×100, where R is the number of rooted cuttings in the treatment and T is the total number of cuttings in the treatment; number of roots/cutting; longest root length (cm); number of branches/cutting; mean branch length (cm); mean number of leaves/cutting; as well as fresh and dry weights of roots and branches (g).

In fresh leaf samples taken from the middle part of the rooted cuttings (newly formed transplants), photosynthetic pigments (chlorophyll a, b, and carotenoids, mg/g f.w.), total sugars as a percentage, and total indoles and phenols (mg/g f.w.) were determined according to the methods described by Sumanta et al. (2014), Dubois et al. (1966), A.O.A.C. (1990) and Singleton et al. (1999), respectively.

The data were tabulated and subjected to analysis of variance using the Assistant Software Program explained by Silva & Azevedo (2016), followed by Duncan's New Multiple Range t-Test (Steel & Torrie, 1980) for means comparison.

Results

The first experiment: Effect of NAA loaded on Fe_3O_4 (nFe-NAA), IBA (either as t-IBA or as nFe-IBA), and their interactions on:

Rooting traits

The data presented in Tables 3 and 4 indicate that mean values of rooting %, No. of roots/cutting, and root length (cm) were significantly increased by the different concentrations of either t-IBA or nFe-IBA, reaching a maximum at 200 ppm nFe-IBA treatment over control and all other IBA treatments in both seasons. The second rank was occupied by 400 ppm nFe-IBA treatment, which gave lower means than 200 ppm nFe-IBA in most cases in both seasons. Additionally, t-IBA at 4000 ppm treatment scored in both seasons very close root lengths to those of 400 ppm nFe-IBA one, with non-significant differences among them.

Similarly, nFe-NAA treatments caused significant improvement in the means of different rooting parameters relative to control means, with the superiority of 400 ppm nFe-NAA treatment, which attained the highest rooting % and No. of roots/cutting with the longest root length in both seasons. However, 200 ppm nFe-NAA treatment in the first season, as well as 100 and 200 ppm nFe-NAA treatments in the second season, raised rooting % to values closely near to those of 400 ppm nFe-NAA treatment without significant differences between them. Also, 100 ppm nFe-NAA treatment elongated the root to a length greatly near to that of 400 ppm nFe-NAA one in the first season only.

Moreover, the interaction treatments exhibited a marked variance in their effects on rooting characters mentioned above. The highest rooting percentages (80.00% in the 1st season and 86.67% in the 2nd one) were acquired by combining dipping the cuttings' bases in 2000 ppm t-IBA and 100 ppm nFe-NAA solutions. The greatest number of roots per cutting was achieved in both seasons (37.33 and 39.67 roots/cutting, respectively) by interacting between 200 ppm concentrations of both nFe-IBA and nFe-NAA formula. However, the longest root length, which was 21.33cm in the first season and 23.83cm in the second one, was obtained by dipping the cuttings first in 400 ppm nFe-NAA solution and then in 200 ppm nFe-IBA one.

Growth traits of the newly formed transplants

It can be seen from the data averaged in Tables 4 and 5 that the 400 ppm nFe-IBA treatment hastened the mean values of branch length (cm) to the maximal values over control and all other IBA treatments in the two seasons. Meanwhile, the means of both the number of branches and leaves per transplant were increased by treating the cuttings with t-IBA at either 1000 or 2000 ppm concentrations. Furthermore, the 4000 ppm t-IBA treatment gave means of branch length very close to those attained by the superior treatment (400 ppm nFe-IBA) in the first and second seasons.

As for the effect of nFe-NAA treatments, it was noticed that both concentrations of 100 and 400 ppm had a better impact on branch length and the number of branches per transplant characters, giving the highest records with various significance levels in the two seasons. The highest means of the number of leaves per transplant character were acquired in both seasons by only 400 ppm nFe-NAA treatment, followed directly by 200 ppm nFe-NAA, which aptly took the second position in the two seasons.

The interaction treatments also exerted a pronounced effect on the growth parameters of the newly-formed transplants, attaining better results than the sole treatments, with the prevalence of 4000 ppm t-IBA + 100 ppm nFe-NAA interaction that gave the longest branch length (6.83 and 7.40 cm in the two seasons, respectively). The 4000 ppm nFe-IBA + 0.0 ppm nFe-NAA combination raised the mean number of branches per transplant in the first season to 2.34 branches and in the second season to 4.00 branches. The combination of 200 ppm t-IBA + 400 ppm nFe-NAA elevated the number of leaves per transplant to 21.33 and 23.00 leaves in the two seasons, respectively.

TABLE 3. Effect of traditional, nano-Fe auxins and their interactions on rooting percentage and roots number of *Simmondsia chinensis* (Link) Schneider transplants during 2020 and 2021 seasons

NAA treatments / IBA treatments		Control	nFe-NAA (ppm) 100	200	400	Mean (B)	Control	nFe-NAA (ppm) 100	200	400	Mean (B)
		Rooting (%)									
		First season (2020)					**Second season (2021)**				
Control		0.00 j	40.00 f	46.67 e	46.67 e	**33.33 F**	0.00 k	40.00 f	53.33 d	53.33 d	**36.67 E**
t-IBA (ppm)	1000	20.00 h	46.67 e	66.67 b	53.33 d	**46.67 D**	13.33 j	46.67 e	66.67 b	53.33 d	**45.00 D**
	2000	13.33 i	80.00 a	46.67 e	53.33 d	**48.33 C**	20.00 i	86.67 a	40.00 f	53.33 d	**50.00 C**
	4000	13.33 i	53.33 d	53.33 d	53.33 d	**43.33 E**	20.00 i	60.00 c	60.00 c	60.00 c	**50.00 C**
nFe-IBA (ppm)	100	33.33 g	46.67 e	53.33 d	60.00 c	**48.33 C**	26.67 h	60.00 c	53.33 d	60.00 c	**50.00 C**
	200	40.00 f	60.00 c	66.67 b	66.67 b	**58.33 A**	33.33 g	66.67 b	60.00 c	60.00 c	**55.00 A**
	400	46.67 e	40.00 f	60.00 c	66.67 b	**53.33 B**	40.00 f	33.33 g	66.67 b	66.67 b	**51.67 B**
Mean (A)		**23.81 C**	**52.38 B**	**56.19 A**	**57.14 A**		**21.90 B**	**56.19 A**	**57.14 A**	**58.09 A**	
		Number of roots/ transplant									
Control		0.00 v	12.00 rs	20.33 i	13.00 q	**11.33 F**	0.00 s	13.67 p	22.00 h	13.33 p	**12.25G**
t-IBA (ppm)	1000	15.67 n	15.00 o	8.00 u	21.00 gh	**14.92 E**	17.00 l	16.67 l	9.67 r	22.67 g	**16.50 F**
	2000	18.67 k	16.67 m	20.67 hi	19.33 j	**18.83 C**	19.33 j	18.34 k	22.00 h	20.67 i	**20.08 D**
	4000	11.67 s	31.67 b	13.00 q	26.67 e	**20.75 B**	13.33 p	33.33 b	14.34 o	28.33 d	**22.33 C**
nFe-IBA (ppm)	100	14.00 p	23.00 f	15.00 o	12.33 r	**16.08 D**	15.00 n	26.67 e	16.67 l	14.67 no	**18.25 E**
	200	10.67 t	14.33 p	37.33 a	29.33 c	**22.92 A**	12.67 q	16.00 m	39.67 a	30.67 c	**24.75 A**
	400	17.67 l	21.33 g	17.67 l	28.34 d	**21.25 B**	19.33 j	23.33 f	19.67 j	30.67 c	**23.25 B**
Mean (A)		**12.62 C**	**19.14 B**	**18.86 B**	**21.43 A**		**13.81 C**	**21.14 B**	**20.57 B**	**23.00 A**	

* nFe-NAA: nano-iron naphthaleneacetic acid, nFe-IBA: nano-iron indole butyric acid, t-IBA: traditional indole butyric acid.

* Means followed by the same letter in a column or row don't significantly differ according to Duncan's New Multiple Range Test at 5 % level

TABLE 4. Effect of traditional, nano-Fe auxins and their interactions on root and branch lengths of *Simmondsia chinensis* (Link) Schneider transplants during 2020 and 2021 seasons

IBA treatments \ NAA treatments		Control	nFe-NAA (ppm) 100	nFe-NAA (ppm) 200	nFe-NAA (ppm) 400	Mean (B)	Control	nFe-NAA (ppm) 100	nFe-NAA (ppm) 200	nFe-NAA (ppm) 400	Mean (B)
		First season (2020)					Second season (2021)				
		Root length (cm)									
Control		0.00 p	10.67 j	12.00 i	9.00 l	**7.92 F**	0.00 q	11.50 j	13.00 i	9.67 lm	**8.54 F**
t-IBA (ppm)	1000	9.00 l	9.33 l	7.00 o	10.00 k	**8.83 E**	9.83 l	10.00 l	7.83 p	10.83 k	**9.63 E**
	2000	17.00 d	9.17 l	12.67 h	12.67 h	**12.88 C**	17.67 d	9.97 l	13.33 i	13.40 i	**13.59 C**
	4000	15.84 e	15.83 e	8.50 m	14.20 g	**13.59 B**	16.83 e	16.87 e	9.67 lm	15.07 f	**14.61 B**
nFe-IBA (ppm)	100	17.67 c	13.00 h	7.67 n	7.00 o	**11.33 D**	18.50 c	14.34 g	9.33 mn	8.67 o	**12.71 D**
	200	8.50 m	9.83 k	16.67 d	21.33 a	**14.08 A**	9.17 n	10.73 k	17.90 d	23.83 a	**15.41 A**
	400	9.33 l	18.67 b	12.67 h	15.00 f	**13.92 AB**	10.67 k	20.07 b	13.83 h	16.90 e	**15.37 A**
Mean (A)		**11.05 B**	**12.36 A**	**11.02 B**	**12.74 A**		**11.81 C**	**13.35 B**	**12.13 C**	**14.05 A**	
		Branch length (cm)									
Control		0.00 u	2.00 n	3.00 j	3.17 i	**2.04 E**	0.00 r	1.63 p	5.67 e	3.83 i	**2.78 F**
t-IBA (ppm)	1000	4.17 e	6.67 b	1.00 r	1.00 r	**3.21 B**	4.77 f	6.10 d	2.00 o	2.10 o	**3.74 C**
	2000	2.50 l	3.67 f	2.00 n	3.50 g	**2.92 C**	3.17 k	4.23 g	2.47 m	4.13 g	**3.50 D**
	4000	0.67 t	6.83 a	0.84 s	5.00 d	**3.34 A**	1.57 pq	7.40 a	1.47 q	5.67 e	**4.03 B**
nFe-IBA (ppm)	100	1.33 p	6.00 c	1.33 p	2.67 k	**2.83 C**	2.73 l	6.67 b	2.33 n	4.00 h	**3.93 B**
	200	2.00 n	1.17 q	3.17 i	3.33 h	**2.42 D**	2.33 n	2.00 o	3.67 j	4.67 f	**3.17 E**
	400	2.33 m	1.47 o	5.00 d	5.00 d	**3.45 A**	4.17 g	2.33 n	6.00 d	6.33 c	**4.71 A**
Mean (A)		**1.86 D**	**3.97 A**	**2.33 C**	**3.38 B**		**2.68 C**	**4.34 A**	**3.37 B**	**4.39 A**	

* nFe-NAA: nano-iron naphthaleneacetic acid, nFe-IBA: nano-iron indole butyric acid, t-IBA: traditional indole butyric acid.

* Means followed by the same letter in a column or row don't significantly differ according to Duncan's New Multiple Range Test at 5 % level.

TABLE 5. Effect of traditional, nano-Fe auxins and their interactions on number of branches and leaves of *Simmondsia chinensis* (Link) Schneider transplants during 2020 and 2021 seasons

IBA treatments \ NAA treatments		Control	nFe-NAA (ppm) 100	nFe-NAA (ppm) 200	nFe-NAA (ppm) 400	Mean (B)	Control	nFe-NAA (ppm) 100	nFe-NAA (ppm) 200	nFe-NAA (ppm) 400	Mean (B)
		First season (2020)					Second season (2021)				
		Number of branches/transplant									
Control		0.00 f	2.00 b	1.33 d	1.33 d	**1.17 G**	0.00 h	3.67 b	2.67 e	2.67 e	**2.25 E**
t-IBA (ppm)	1000	2.33 a	2.00 b	2.00 b	2.00 b	**2.08 A**	3.33 c	3.33 c	3.00 d	3.67 b	**3.33 A**
	2000	1.67 c	1.33 d	2.00 b	2.00 b	**1.75 B**	3.00 d	2.67 e	3.33 c	3.33 c	**3.08 B**
	4000	1.00 e	2.00 b	1.00 e	1.67 c	**1.42 E**	2.00 g	2.67 e	2.67 e	3.00 d	**2.58 D**
nFe-IBA (ppm)	100	1.33 d	1.67 c	1.33 d	2.00 b	**1.58 D**	2.67 e	2.67 e	2.67 e	3.33 c	**2.83 C**
	200	1.67 c	1.00 e	1.00 e	1.33 d	**1.25 F**	3.00 d	2.33 f	2.33 f	2.67 e	**2.58 D**
	400	2.34 a	1.67 c	1.67 c	1.00 e	**1.67 C**	4.00 a	3.00 d	3.00 d	2.33 f	**3.08 B**
Mean (A)		**1.48 B**	**1.67 A**	**1.48 B**	**1.62 A**		**2.57 C**	**2.91 AB**	**2.81 B**	**3.00 A**	
		Number of leaves /transplant									
Control		0.00 p	12.67 j	16.67 d	12.67 j	**10.50 E**	0.00 q	14.00 jk	18.33 d	14.00 jk	**11.58 D**
t-IBA (ppm)	1000	14.67 g	18.67 c	13.33 i	15.33 f	**15.50 B**	16.00 g	20.00 c	15.00 h	17.33 e	**17.08 B**
	2000	14.67 g	12.00 k	20.67 b	21.33 a	**17.17 A**	16.33 fg	13.67 k	22.00 b	23.00 a	**18.75 A**
	4000	10.00 m	15.00 fg	7.33 o	18.67 c	**12.75 C**	11.33 n	16.00 g	10.00 p	20.33 c	**14.42 C**
nFe-IBA (ppm)	100	15.00 fg	14.67 g	10.00 m	12.00 k	**12.92 C**	16.67 f	16.67 f	11.67 n	13.67 k	**14.67 C**
	200	14.00 h	9.00 n	13.67 hi	12.00 k	**12.17 D**	18.67 d	10.67 o	14.67 hi	13.00 l	**14.25 C**
	400	12.67 j	11.33 l	16.00 e	12.00 k	**13.00 C**	14.33 ij	12.33 m	17.67 e	13.67 k	**14.50 C**
Mean (A)		**11.57 D**	**13.33 C**	**13.95 B**	**14.86 A**		**13.33 D**	**14.76 C**	**15.62 B**	**16.43 A**	

* nFe-NAA: nano-iron naphthaleneacetic acid, nFe-IBA: nano-iron indole butyric acid, t-IBA: traditional indole butyric acid.

* Means followed by the same letter in a column or row don't significantly differ according to Duncan's New Multiple Range Test at 5 % level.

In addition, the means of branch length were significantly improved by both 1000 ppm t-IBA + 100 ppm nFe-NAA and 100 ppm nFe-IBA + 100 ppm nFe-NAA interactions in the first and second seasons to be 6.67cm (Table 4) against 6.83 and 7.40 cm scored by the superior interaction mentioned above in both seasons, consecutively. Likewise, the mean number of branches per transplant was significantly increased to 2.33 branches in the first season and to 3.33 branches in the second one by connecting between 1000 ppm t-IBA and 0.0 nFe-NAA versus 2.34 and 4.00 branches obtained by the superior combination in both seasons, respectively. Also, combining 2000 ppm t-IBA and 200 ppm nFe-NAA raised the mean number of leaves per transplant to 20.67 and 22.00 leaves in comparison with 21.33 and 23.00 leaves attained by the dominant treatment in the first and second seasons, respectively.

Fresh and dry weights of branches and roots

According to the data listed in Table 6, it can be concluded that various concentrations and formulas of both IBA and NAA auxins used in the study caused significant increments in the mean values of fresh weight (g) for branches and roots. The highest fresh weight of branches in both seasons was observed with 100 ppm nFe-IBA, while the heaviest fresh weight of roots in both seasons was observed with 200 ppm nFe-IBA. Moreover, 400 ppm nFe-NAA was the only treatment that resulted in the heaviest fresh weights of both branches and roots in both seasons. However, interactions between the treatments exhibited diverse effects. For instance, combining 2000 ppm t-IBA and 0.0 nFe-NAA achieved the highest fresh weight of branches in both seasons (1.49 and 1.67g, respectively), whereas the fresh weight of roots increased by interacting between 200 ppm concentrations of both nFe-IBA and nFe-NAA, resulting in a mean of 9.34g in the first season and 9.29g in the second one.

In contrast to the results of fresh weight, the data in Table 7 showed that 2000 ppm t-IBA treatment hastened the dry weight of branches to the maximum value in the first season, while the dry weight of roots reached a maximum in the same season with both 2000 and 4000 ppm t-IBA treatments. However, in the second season, the highest dry weight of branches was achieved with 100 ppm nFe-IBA treatment, and the highest dry weight of roots was achieved with 200 ppm nFe-IBA treatment. On the other hand, nFe-NAA solution at concentrations of 0.0, 100, and 400 recorded the highest mean values of branch dry weight in both seasons. The heaviest root dry weight in the first season was obtained with 400 ppm nFe-NAA, and in the second season with both 100 and 400 ppm nFe-NAA treatments.

A similar trend to that observed in the case of the interaction effect on branch fresh weight was also observed regarding branch dry weight. However, for root dry weight, the opposite was true. The highest means of root dry weight were achieved in the first season with both 200 ppm nFe-IBA + 200 ppm nFe-NAA and 0.0 ppm t-IBA + 400 ppm nFe-NAA combinations, which gave 1.46 and 1.44g, respectively. In the second season, the highest mean was achieved by connecting between 4000 ppm t-IBA and 100 ppm nFe-NAA treatments which gave 1.98g roots d.w.

Chemical composition of the leaves

As shown in Tables 8, 9, and 10, the mean values of different constituents measured in this trial fluctuated in response to the various treatments employed in the study, with significant differences in both seasons. However, the highest concentration of chlorophyll a was not observed consistently in any of the treatments.

In both seasons, the highest concentration of total indoles (mg/g f.w.) was obtained by dipping the wounded cuttings in either a 4000 ppm t-IBA solution or a 200 ppm nFe-NAA solution, and also by combining these two individual treatments. The highest concentration of chlorophyll (mg/g f.w.) was recorded by 1000 and 4000 ppm t-IBA treatments, 200 and 400 ppm nFe-IBA treatments, all rates of nFe-NAA, and by combining 200 ppm nFe-IBA and 400 ppm nFe-NAA treatments. As for carotenoids concentration (mg/g f.w.), it was maximum by dipping in a 4000 ppm t-IBA solution, 200 and 400 ppm nFe-IBA solutions, as well as by combining 4000 ppm t-IBA and 200 ppm nFe-NAA.

The highest percentage of total sugars in both seasons was observed when wounded bases of cuttings were dipped in the following solutions: 4000 ppm t-IBA, 100 and 200 ppm nFe-IBA, 100 and 400 ppm nFe-NAA, as well as 4000 ppm t-IBA + 400 ppm nFe-NAA combined solution.

TABLE 6. Effect of traditional, nano-Fe auxins and their interactions on branches and roots fresh weight of *Simmondsia chinensis* (Link) Schneider transplants during 2020 and 2021 seasons

NAA treatments / IBA treatments		Control	nFe-NAA (ppm) 100	200	400	Mean (B)	Control	nFe-NAA (ppm) 100	200	400	Mean (B)
Fresh weight of branches (g)											
		First season (2020)					**Second season (2021)**				
Control		0.00 t	0.38 q	0.31 s	0.39 q	**0.27 G**	0.00 q	0.51 o	0.42 p	0.52 o	**0.36 G**
	1000	0.46 p	0.73 i	0.46 p	0.64 k	**0.57 F**	0.60 mn	0.86 i	0.61 mn	0.78 j	**0.71 F**
t-IBA (ppm)	2000	1.49 a	0.34 r	0.96 e	0.49 n	**0.82 B**	1.67 a	0.62 l-n	1.10 f	0.59 n	**1.00 C**
	4000	0.61 l	1.00 d	0.52 m	0.76 h	**0.72 D**	0.76 j	1.17 e	0.64 kl	0.89 h	**0.87 D**
	100	1.03 c	1.04 c	0.53 m	1.26 b	**0.96 A**	1.20 d	1.20 d	0.63 klm	1.36 b	**1.10 A**
nFe-IBA (ppm)	200	0.47 op	0.54 m	0.81 g	0.67 j	**0.62 E**	0.62 lmn	0.64 kl	0.98 g	0.86 i	**0.78 E**
	400	0.49 no	0.83 g	0.87 f	0.97 e	**0.79 C**	0.65 k	0.98 g	1.32 c	1.30 c	**1.06 B**
Mean (A)		**0.65 C**	**0.69 B**	**0.64 C**	**0.74 A**		**0.79 C**	**0.86 B**	**0.81 BC**	**0.90 A**	
Fresh weight of roots (g)											
Control		0.00 q	3.86 n	6.78 d	7.30 c	**4.49 F**	0.00 r	4.13 n	6.94 d	7.50 c	**4.64 E**
	1000	4.85 i	4.66 j	2.42 p	6.01 f	**4.48 F**	4.97 i	4.88 i	2.57 q	6.24 f	**4.67 E**
t-IBA (ppm)	2000	5.63 g	4.13 lm	6.00 f	6.25 e	**5.50 C**	5.84 g	4.31 m	6.22 f	6.52 e	**5.72 C**
	4000	2.50 p	8.35 b	4.30 kl	8.45 b	**5.90 B**	2.64 q	8.63 b	4.56 jk	8.60 b	**6.11 B**
	100	4.10 m	7.14 c	5.45 h	4.22 lm	**5.23 D**	4.34 lm	7.37 c	5.70 g	4.48 kl	**5.47 D**
nFe-IBA (ppm)	200	3.26 o	5.57 gh	9.34 a	7.14 c	**6.33 A**	3.68 o	5.77 g	9.29 a	7.35 c	**6.52 A**
	400	4.44 k	3.73 n	5.00 i	5.95 f	**4.78 E**	4.69 j	2.88 p	5.16 h	6.12 f	**4.71 E**
Mean (A)		**3.54 D**	**5.35 C**	**5.61 B**	**6.48 A**		**3.74 D**	**5.42 C**	**5.78 B**	**6.69 A**	

* nFe-NAA: nano-iron naphthaleneacetic acid, nFe-IBA: nano-iron indole butyric acid, t-IBA: traditional indole butyric acid.

* Means followed by the same letter in a column or row don't significantly differ according to Duncan's New Multiple Range Test at 5 % level.

TABLE 7. Effect of traditional, nano-Fe auxins and their interactions on branches and roots dry weight of *Simmondsia chinensis* (Link) Schneider transplants during 2020 and 2021 seasons

NAA treatments / IBA treatments		Control	nFe-NAA (ppm) 100	200	400	Mean (B)	Control	nFe-NAA (ppm) 100	200	400	Mean (B)
Dry weight of branches (g)											
		First season (2020)					**Second season (2021)**				
Control		0.00 o	0.07 mn	0.08 m	0.10 l	**0.06 D**	0.00 n	0.14 m	0.14 m	0.17 l	**0.11 D**
	1000	0.29 b	0.13 jk	0.06 n	0.20 f	**0.17 C**	0.35 c	0.21 jk	0.12 m	0.27 f	**0.24 C**
t-IBA (ppm)	2000	0.45 a	0.14 jk	0.17 hi	0.12 k	**0.22 A**	0.51 a	0.20 k	0.21 jk	0.17 l	**0.27 B**
	4000	0.19 fg	0.25 de	0.14 j	0.19 fg	**0.19 B**	0.26 fg	0.31 e	0.23 ij	0.26 fg	**0.26 B**
	100	0.14 jk	0.25 cd	0.12 k	0.27 c	**0.20 B**	0.21 jk	0.42 b	0.22 ij	0.33 d	**0.30 A**
nFe-IBA (ppm)	200	0.25 cd	0.14 jk	0.19 fg	0.15 ij	**0.18 BC**	0.35 cd	0.21 jk	0.24 ghi	0.24 hi	**0.26 B**
	400	0.10 l	0.23 e	0.18 gh	0.27 bc	**0.20 B**	0.17 l	0.34 cd	0.25 gh	0.35 cd	**0.28 B**
Mean (A)		**0.20 A**	**0.17 B**	**0.13 C**	**0.19 AB**		**0.27 A**	**0.26 A**	**0.20 B**	**0.25 A**	
Dry weight of roots (g)											
Control		0.00 v	0.83 i	1.15 e	1.44 a	**0.86 C**	0.00 r	0.62 l	0.97 h	0.91 j	**0.62 G**
	1000	0.75 m	0.72 n	0.39 t	0.67 o	**0.63 F**	0.47 o	1.01 g	0.39 p	1.03 g	**0.73 F**
t-IBA (ppm)	2000	0.55 q	0.78 l	1.25 d	1.29 c	**0.97 A**	0.64 l	0.77 k	1.31 d	0.91 j	**0.91 D**
	4000	0.34 u	1.31 c	0.81 jk	1.36 b	**0.96 A**	0.28 q	1.98 a	0.56 n	1.09 f	**0.98 B**
	100	0.48 s	0.80 k	0.95 f	0.82 ij	**0.76 D**	0.63 l	1.10 f	1.29 d	0.76 k	**0.94 C**
nFe-IBA (ppm)	200	0.50 r	0.86 h	1.46 a	0.88 g	**0.92 B**	0.75 k	1.34 c	1.19 e	1.65 b	**1.23 A**
	400	0.89 g	0.49 rs	0.72 n	0.63 p	**0.68 E**	0.77 k	0.59 m	0.97 hi	0.95 i	**0.82 E**
Mean (A)		**0.50 D**	**0.83 C**	**0.96 B**	**1.01 A**		**0.51 C**	**1.06 A**	**0.95 B**	**1.04 A**	

* nFe-NAA: nano-iron naphthaleneacetic acid, nFe-IBA: nano-iron indole butyric acid, t-IBA: traditional indole butyric acid.

* Means followed by the same letter in a column or row don't significantly differ according to Duncan's New Multiple Range Test at 5 % level.

TABLE 8. Effect of traditional, nano-Fe auxins and their interactions on chlorophyll a and b concentration in the leaves of *Simmondsia chinensis* (Link) Schneider transplants during 2020 and 2021 seasons

NAA treatments / IBA treatments		Control	nFe-NAA (ppm) 100	200	400	Mean (B)	Control	nFe-NAA (ppm) 100	200	400	Mean (B)
		Chlorophyll a (mg/g F.W.)									
		First season (2020)					**Second season (2021)**				
Control		0.00 o	0.05 ij	0.04 ijk	0.04 ijk	**0.04 D**	0.00 n	0.06 hi	0.05 hij	0.05 hij	**0.04 D**
t-IBA (ppm)	1000	0.22 d	0.03 klm	0.11 g	0.04 jkl	**0.10 C**	0.23 d	0.03 jkl	0.12 f	0.04 ijk	**0.11 C**
	2000	0.08 h	0.04 jkl	0.05 ijk	0.05 ijk	**0.05 D**	0.08 g	0.04 jk	0.05 hij	0.05 hij	**0.06 D**
	4000	0.25 c	0.20 d	0.32 a	0.05 ijk	**0.20 A**	0.26 c	0.22 d	0.35 a	0.05 hij	**0.22 A**
nFe-IBA (ppm)	100	0.01 no	0.02 lmn	0.15 f	0.02 mno	**0.05 D**	0.01 mn	0.02klm	0.17 e	0.02lmn	**0.05 D**
	200	0.17 e	0.06 i	0.30 b	0.20 d	**0.18 B**	0.18 e	0.06 h	0.32 b	0.22 d	**0.20 B**
	400	0.09 h	0.21 d	0.25 c	0.17 e	**0.18 B**	0.09 g	0.23 d	0.27 c	0.18 e	**0.19 B**
Mean (A)		**0.12 B**	**0.09 C**	**0.17 A**	**0.08 C**		**0.12 B**	**0.10 C**	**0.19 A**	**0.09 C**	
		Chlorophyll b (mg/g F.W.)									
Control		0.00 h	0.01 fgh	0.01 fgh	0.02 fgh	**0.01 B**	0.00 g	0.01 fg	0.01 fg	0.02 fg	**0.01 B**
t-IBA (ppm)	1000	0.11 ab	0.02 fgh	0.02 fgh	0.01 h	**0.04 A**	0.12 ab	0.02 fg	0.02 fg	0.01 g	**0.04 A**
	2000	0.01 fgh	0.01 fgh	0.02 fgh	0.02 fgh	**0.01 B**	0.01 fg	0.01 fg	0.02 fg	0.02 fg	**0.01 B**
	4000	0.09 c	0.01 fgh	0.08 c	0.01 fgh	**0.05 A**	0.09 c	0.01 fg	0.09 c	0.01 g	**0.05 A**
nFe-IBA (ppm)	100	0.01 gh	0.01 fgh	0.04 e	0.01 h	**0.01 B**	0.01 g	0.02 fg	0.04 e	0.01 g	**0.02 B**
	200	0.04 de	0.01 h	0.05 de	0.13 a	**0.06 A**	0.05 de	0.01 g	0.06 de	0.14 a	**0.06 A**
	400	0.06 d	0.11 b	0.02 fg	0.02 f	**0.05 A**	0.07 d	0.12 b	0.02 f	0.02 f	**0.06 A**
Mean (A)		**0.04 A**	**0.02 A**	**0.03 A**	**0.03 A**		**0.05 A**	**0.03 A**	**0.04 A**	**0.03 A**	

* nFe-NAA: nano-iron naphthaleneacetic acid, nFe-IBA: nano-iron indole butyric acid, t-IBA: traditional indole butyric acid.

* Means followed by the same letter in a column or row don't significantly differ according to Duncan's New Multiple Range Test at 5 % level.

TABLE 9. Effect of traditional, nano-Fe auxins and their interactions on carotenoids and total sugars concentration in the leaves of *Simmondsia chinensis* (Link) Schneider transplants during 2020 and 2021 seasons

NAA treatments / IBA treatments		Control	nFe-NAA (ppm) 100	200	400	Mean (B)	Control	nFe-NAA (ppm) 100	200	400	Mean (B)
		Carotenoids (mg/g F.W.)									
		First season (2020)					**Second season (2021)**				
Control		0.00 l	0.03 ij	0.03 ij	0.02 ijk	**0.02 C**	0.00 l	0.03 ij	0.03 ij	0.02 ijk	**0.02 C**
t-IBA (ppm)	1000	0.15 b	0.02 ijk	0.06 fg	0.02 ijkl	**0.06 B**	0.16 b	0.02 ijk	0.07 g	0.02 ijkl	**0.07 B**
	2000	0.05 gh	0.02 ijk	0.03 hi	0.03 ij	**0.03 C**	0.05 h	0.02 ijk	0.04 hi	0.03 i	**0.03 C**
	4000	0.15 b	0.09 e	0.21 a	0.02 ijk	**0.12 A**	0.16 bc	0.10 f	0.23 a	0.03 ij	**0.13 A**
nFe-IBA (ppm)	100	0.01 kl	0.01 ijkl	0.08 e	0.01 jkl	**0.03 C**	0.01 kl	0.02 ijkl	0.09 f	0.01 jkl	**0.03 C**
	200	0.11 d	0.03 ij	0.14 bc	0.14 bc	**0.10 A**	0.12 e	0.03 i	0.14 cd	0.15 bcd	**0.11 A**
	400	0.07 f	0.15 b	0.13 cd	0.09 e	**0.11 A**	0.07 g	0.17 b	0.14 de	0.10 f	**0.12 A**
Mean (A)		**0.08 AB**	**0.05 BC**	**0.10 A**	**0.05 C**		**0.08 A**	**0.05 B**	**0.10 A**	**0.05 B**	
		Total sugars (%)									
Control		0.00 q	3.44 op	4.09 j	5.07 d	**3.15 F**	0.00 r	3.20 p	3.81 j	4.71 bc	**2.93 F**
t-IBA (ppm)	1000	5.13 d	4.33 h	4.24 i	3.39 p	**4.27 C**	4.77 b	3.94 h	3.90 hi	3.08 q	**3.92 C**
	2000	3.89 kl	4.30 hi	3.88 kl	3.83 lm	**3.98 D**	3.70 k	3.87 ij	3.61 l	3.41 o	**3.65 D**
	4000	3.78 mn	4.96 e	3.94 k	6.93 a	**4.90 A**	3.47 n	4.46 e	3.55 lm	6.17 a	**4.41 A**
nFe-IBA (ppm)	100	4.23 i	5.36 b	4.51 g	4.47 g	**4.64 B**	3.94 h	4.71 bc	4.29 f	4.11 g	**4.26 B**
	200	4.66 f	5.23 c	3.71 n	5.21 c	**4.70 B**	4.29 f	4.65 cd	3.49 mn	4.64 d	**4.27 B**
	400	3.93 k	3.47 o	4.31 hi	3.44 op	**3.79 E**	3.50 mn	3.23 p	3.92 hi	3.12 q	**3.44 E**
Mean (A)		**3.66 D**	**4.44 B**	**4.10 C**	**4.62 A**		**3.38 D**	**4.01 B**	**3.79 C**	**4.18 A**	

* nFe-NAA: nano-iron naphthaleneacetic acid, nFe-IBA: nano-iron indole butyric acid, t-IBA: traditional indole butyric acid.

* Means followed by the same letter in a column or row don't significantly differ according to Duncan's New Multiple Range Test at 5 % level.

TABLE 10. Effect of traditional, nano-Fe auxins and their interactions on total indoles and total phenols concentration in the leaves of *Simmondsia chinensis* (Link) Schneider transplants during 2020 and 2021 seasons

IBA treatments \ NAA treatments		Control	nFe-NAA (ppm) 100	nFe-NAA (ppm) 200	nFe-NAA (ppm) 400	Mean (B)	Control	nFe-NAA (ppm) 100	nFe-NAA (ppm) 200	nFe-NAA (ppm) 400	Mean (B)
		Total indoles (mg/g F.W.)									
		First season (2020)					**Second season (2021)**				
Control		0.00 t	3.61 e	5.01 d	1.41 n	**2.51 D**	0.00 t	3.32 e	4.55 d	1.31 n	**2.30 D**
t-IBA (ppm)	1000	2.29 j	0.09 st	5.87 b	2.43 hi	**2.67 C**	2.06 j	0.08 st	5.35 b	2.19 hi	**2.42 C**
t-IBA (ppm)	2000	5.31 c	2.05 k	2.46 hi	2.67 g	**3.12 A**	4.78 c	1.86 k	2.24 h	2.48 g	**2.84 A**
t-IBA (ppm)	4000	2.64 g	0.45 r	0.18 s	0.62 q	**0.97 G**	2.43 g	0.41 r	0.16 s	0.57 q	**0.89 G**
nFe-IBA (ppm)	100	1.62 m	0.72 q	0.63 q	1.89 l	**1.22 F**	1.49 m	0.65 q	0.59 q	1.72 l	**1.11 F**
nFe-IBA (ppm)	200	1.96 kl	1.16 o	2.49 h	2.34 ij	**1.99 E**	1.76 l	1.06 o	2.24 h	2.13 ij	**1.80 E**
nFe-IBA (ppm)	400	0.90 p	1.37 n	6.73 a	2.88 f	**2.97 B**	0.84 p	1.24 n	6.20 a	2.59 f	**2.72 B**
Mean (A)		**2.10 B**	**1.35 C**	**3.34 A**	**2.03 B**		**1.91 B**	**1.23 C**	**3.05 A**	**1.86 B**	
		Total phenols (mg/g F.W.)									
Control		0.00 n	1.54 d	1.61 c	1.61 c	**1.19 C**	0.00 n	1.40 d	1.50 c	1.50 c	**1.10 C**
t-IBA (ppm)	1000	1.55 d	0.79 j	1.40 e	1.64 c	**1.35 A**	1.42 d	0.74 j	1.30 e	1.48 c	**1.23 A**
t-IBA (ppm)	2000	1.55 d	0.87 i	1.73 b	1.14 g	**1.32 A**	1.41 d	0.78 i	1.55 b	1.06 g	**1.20 A**
t-IBA (ppm)	4000	1.70 b	0.69 k	0.30 m	0.34 m	**0.76 D**	1.58 b	0.63 k	0.27 m	0.31 m	**0.70 D**
nFe-IBA (ppm)	100	1.40 e	1.22 f	1.15 g	1.06 h	**1.21 C**	1.26 e	1.12 f	1.07 g	0.99 h	**1.11 C**
nFe-IBA (ppm)	200	0.86 i	1.05 h	2.43 a	0.68 k	**1.26 B**	0.79 i	0.98 h	2.26 a	0.62 k	**1.16 B**
nFe-IBA (ppm)	400	1.64 c	0.40 l	0.33 m	0.33 m	**0.67 E**	1.49 c	0.36 l	0.30 m	0.30 m	**0.61 E**
Mean (A)		**1.24 A**	**0.94 B**	**1.28 A**	**0.97 B**		**1.14 A**	**0.86 B**	**1.18 A**	**0.89 B**	

* nFe-NAA: nano-iron naphthaleneacetic acid, nFe-IBA: nano-iron indole butyric acid, t-IBA: traditional indole butyric acid.

* Means followed by the same letter in a column or row don't significantly differ according to Duncan's New Multiple Range Test at 5 % level.

The results also showed that quick dipping in 2000 ppm t-IBA, 200 ppm nFe-NAA, and 400 ppm nFe-IBA + 200 ppm nFe-NAA solutions significantly increased the total indole concentration (mg/g f.w.) to maximal values in the first and second seasons. Meanwhile, this occurred for the total phenol concentration (mg/g f.w.) by quick dipping in 1000 and 2000 ppm t-IBA, 0.0 and 200 ppm nFe-NAA, and 200 ppm nFe-IBA + 200 ppm nFe-NAA solutions.

The second experiment: Effect of nano NAA (n-NAA), IBA (either as traditional (t-IBA) or as nanoparticles (n-IBA)) and their interactions on

Rooting traits

It is clear from the data averaged in Table 11 that the t-IBA at 1000 ppm treatment surpassed all the other IBA treatments by giving the highest rooting percentage in the two seasons. However, both 2000 ppm t-IBA and 400 ppm n-IBA treatments acquired the same percentage of rooting scored by the 1000 ppm t-IBA one (56.67%) in the second season only. Among n-NAA treatments, the 400 ppm n-NAA one significantly increased the rooting percentage to the highest values in both seasons (61.91 and 60.00%, respectively).

In general, interaction treatments were more effective on rooting percentage than the sole ones, as interacting between 2000 ppm t-IBA and 100 ppm n-NAA significantly raised the percentage of rooting in the first season to 93.33% and in the second one to 100.00%, exhibiting its dominance over all other interactions in the two seasons.

As the rooting percentage, the number of roots/cutting character (Table 11) was greatly affected by the different treatments of such work, where both 200 ppm n-IBA and 400 ppm n-NAA treatments and their interaction registered the utmost high number of roots/cutting in the first season (25.58, 23.76, and 44.00 roots/cutting, respectively), while in the second one, that was achieved by both 4000 ppm t-IBA and 100 ppm n-NAA treatments and their interaction, which gave 27.00, 25.52, and 41.00 roots/cutting, respectively.

TABLE 11. Effect of traditional, nano-auxins and their interactions on rooting percentage and roots number of *Simmondsia chinensis* (Link) Schneider transplants during 2020 and 2021 seasons

IBA treatments \ NAA treatments		Control	n-NAA (ppm) 100	n-NAA (ppm) 200	n-NAA (ppm) 400	Mean (B)	Control	n-NAA (ppm) 100	n-NAA (ppm) 200	n-NAA (ppm) 400	Mean (B)
Rooting (%)											
		First season (2020)					**Second season (2021)**				
Control		0.00 l	53.33 f	53.33 f	66.67 d	**43.33 F**	0.00 k	46.67 f	46.67 f	66.67 c	**40.00 D**
t-IBA (ppm)	1000	20.00 k	66.67 d	80.00 b	73.33 c	**60.00 A**	20.00 j	66.67 c	73.33 b	66.67 c	**56.67 A**
	2000	20.00 k	93.33 a	46.67 g	60.00 e	**55.00 C**	20.00 j	100.00 a	46.67 f	60.00 d	**56.67 A**
	4000	26.67 j	66.67 d	53.33 f	60.00 e	**51.67 D**	26.67 i	66.67 c	53.33 e	60.00 d	**51.67 B**
n-IBA (ppm)	100	26.67 j	66.67 d	60.00 e	46.67 g	**50.00 E**	33.33 h	60.00 d	60.00 d	46.67 f	**50.00 C**
	200	33.33 i	40.00 h	40.00 h	46.67 g	**40.00 G**	33.33 h	33.33 h	40.00 g	46.67 f	**38.33 E**
	400	46.67 g	33.33 i	66.67 d	80.00 b	**56.67 B**	46.67 f	33.33 h	73.33 b	73.33 b	**56.67 A**
Mean (A)		**24.76 D**	**60.00 B**	**57.14 C**	**61.91 A**		**25.71 D**	**58.10 B**	**56.19 C**	**60.00 A**	
Number of roots/transplant											
Control		0.00 q	13.67 j	14.67 i	20.00 g	**12.08 G**	0.00 s	16.00 k	16.00 k	22.00 h	**13.50 G**
t-IBA (ppm)	1000	12.67 kl	10.00 n	8.00 o	22.00 f	**13.17 F**	14.00 mn	12.00 pq	10.00 r	23.33 g	**14.83 F**
	2000	13.00 jk	25.00 e	13.00 jk	20.00 g	**17.75 E**	14.67 lm	27.00 f	15.33 kl	21.33 hi	**19.58 E**
	4000	6.67 p	39.00 b	12.00 l	38.34 b	**24.00 B**	14.34 m	41.00 a	12.67 op	40.00 b	**27.00 A**
n-IBA (ppm)	100	19.00 h	36.33 c	18.34 h	11.00 m	**21.17 C**	20.67 ij	38.33 c	20.33 j	12.33 pq	**22.92 C**
	200	10.33 mn	12.00 l	36.00 c	44.00 a	**25.58 A**	11.67 q	14.33 m	41.00 a	33.00 d	**25.00 B**
	400	12.00 l	28.67 d	25.00 e	11.00 m	**19.17 D**	13.33 no	30.00 e	26.33 f	12.33 pq	**20.50 D**
Mean (A)		**10.52 C**	**23.52 A**	**18.14 B**	**23.76 A**		**12.67 D**	**25.52 A**	**20.24 C**	**23.48 B**	

* n-NAA: nano- naphthaleneacetic acid, n-IBA: nano- indole butyric acid, t-IBA: traditional indole butyric acid.
* Means followed by the same letter in a column or row don't significantly differ according to Duncan's New Multiple Range Test at 5 % level.

Regarding the root length (cm) criterion, the results in Table 12 indicate that the longest root length attained in both seasons was a consequence of dipping the wounded bases of cuttings either in 400 ppm n-IBA solution or in 100 ppm n-NAA solution, or in both solutions (combined treatment), which elevated means of this trait to 42.6cm in the first season and to 45.67 in the second one. Likewise, 200 ppm n-NAA treatment elongated the root length in both seasons to values closely near to those registered by 100 ppm n-NAA treatment.

Growth traits of the new formed transplants

As shown in Tables 12 and 13, great variable effects of auxins were observed on growth characters of the resulted transplants, but the excellence for branch length (cm) character in the first season was ascribed to 200 ppm n-IBA treatment and both 200 and 400 ppm n-NAA treatments, and also to the interactions between the latter two treatments of n-NAA and 4000 ppm t-IBA treatment, as these tow interactions prolonged the branch length to 24.63 and 24.97 cm, respectively dominating over all. A similar trend was observed in the second season, where a combination of 200 ppm n-IBA + 100 ppm n-NAA increased branch length to 25.97cm, which occupied the same rank as the two best interactions observed in the second season.

The highest number of branches per transplant (Table 13) was recorded with 4000 ppm t-IBA and 400 ppm n-IBA treatments (3.50 and 3.58 branches per transplant, respectively), as well as with 100 and 200 ppm n-NAA treatments (3.43 and 3.38 branches, respectively), in the first season. In the second season, the highest number of branches was achieved with 200 ppm of either n-IBA (5.09) or n-NAA (4.95). The highest records of combined treatments were acquired in the first season with 400 ppm n-IBA + 100 ppm n-NAA combination (5.33), while in the second season, it was achieved with 200 ppm n-IBA + 200 ppm n-NAA.

TABLE 12. Effect of traditional, nano-auxins and their interactions on root and branch lengths of *Simmondsia chinensis* (Link) Schneider transplants during 2020 and 2021 seasons

NAA treatments / IBA treatments		Control	n-NAA (ppm) 100	n-NAA (ppm) 200	n-NAA (ppm) 400	Mean (B)	Control	n-NAA (ppm) 100	n-NAA (ppm) 200	n-NAA (ppm) 400	Mean (B)
		First season (2020)					Second season (202)1				
		Root length (cm)									
Control		0.00 n	7.30 k	15.20 f	6.00 l	**7.13 F**	0.00 q	8.13 n	16.30 g	6.50 o	**7.73 F**
	1000	8.37 j	7.13 k	6.30 l	12.00 h	**8.45 E**	9.53 k	8.03 n	6.80 o	13.07 i	**9.36 E**
t-IBA (ppm)	2000	11.03 i	12.07 h	7.10 k	12.50 h	**10.68 D**	11.83 j	13.10 i	7.93 n	13.47 hi	**11.58 D**
	4000	3.77 m	13.17 g	20.10 e	7.60 k	**11.16 D**	4.30 p	14.00 h	21.00 f	8.20 mn	**11.88 D**
	100	8.80 j	32.17 c	34.50 b	7.20 k	**20.67 B**	9.27 kl	33.67 d	36.00 b	8.77 lm	**21.92 B**
n-IBA (ppm)	200	10.63 i	12.17 h	8.40 j	21.07 d	**13.07 C**	11.37 j	13.20 i	13.54 hi	22.20 e	**15.08 C**
	400	6.50 l	42.60 a	32.20 c	7.20 k	**22.13 A**	7.07 o	45.67 a	34.34 c	8.53 mn	**23.90 A**
Mean (A)		**7.01 C**	**18.09 A**	**17.69 A**	**10.51 B**		**7.62 C**	**19.40 A**	**19.42 A**	**11.53 B**	
		Branch length (cm)									
Control		0.00 q	4.00 m	2.47 o	9.17 i	**3.91 E**	0.00 s	4.83 o	2.97 q	9.84 j	**4.41 F**
	1000	1.63 p	4.93 l	11.83 h	8.37 j	**6.69 C**	2.27 r	5.50 n	12.83 h	9.00 k	**7.40 D**
t-IBA (ppm)	2000	3.31 n	5.63 k	9.30 i	8.43 j	**6.67 C**	3.97 p	6.13 lm	10.50 i	9.17 k	**7.44 D**
	4000	2.38 o	4.83 l	24.63 ab	24.97 a	**14.20 B**	2.83 q	5.67 n	25.93 a	26.07 a	**15.13 C**
	100	8.32 j	22.80 c	12.50 g	14.50 f	**14.53 B**	8.80 k	24.17 b	13.70 g	16.33 e	**15.75 B**
n-IBA (ppm)	200	14.67 f	24.33 b	19.40 e	21.17 d	**19.89 A**	15.23 f	25.97 a	20.77 d	22.50 c	**21.12 A**
	400	9.30 i	4.90 l	5.57 k	3.63 mn	**5.85 D**	10.00 j	5.70 mn	6.40 l	4.34 p	**6.61 E**
Mean (A)		**5.66 C**	**10.20 B**	**12.24 A**	**12.89 A**		**6.16 C**	**11.14 B**	**13.30 A**	**13.89 A**	

* n-NAA: nano- naphthaleneacetic acid, n-IBA: nano- indole butyric acid, t-IBA: traditional indole butyric acid.

* Means followed by the same letter in a column or row don't significantly differ according to Duncan's New Multiple Range Test at 5 % level.

TABLE 13. Effect of traditional, nano-auxins and their interactions on number of branches and leaves of *Simmondsia chinensis* (Link) Schneider transplants during 2020 and 2021 seasons

NAA treatments / IBA treatments		Control	n-NAA (ppm) 100	n-NAA (ppm) 200	n-NAA (ppm) 400	Mean (B)	Control	n-NAA (ppm) 100	n-NAA (ppm) 200	n-NAA (ppm) 400	Mean (B)
		First season (2020)					Second season (2021)				
		Number of branches/transplant									
Control		0.00 l	3.00 f	2.67 g	1.33 k	**1.75 E**	0.00 l	4.33 f	4.00 g	2.67 k	**2.75 F**
	1000	2.00 i	3.00 f	3.33 e	2.33 h	**2.67 D**	3.33 i	4.33 f	4.67 e	4.00 g	**4.08 D**
t-IBA (ppm)	2000	1.67 j	4.00 c	2.33 h	2.67 g	**2.67 D**	3.00 j	5.00 d	3.67 h	3.67 h	**3.83 E**
	4000	3.00 f	3.33 e	4.00 c	3.67 d	**3.50 A**	4.67 e	4.67 e	5.67 c	4.33 f	**4.83 B**
	100	3.00 f	3.00 f	4.00 c	2.33 h	**3.08 C**	4.33 f	4.67 e	4.67 e	3.67 h	**4.33 C**
n-IBA (ppm)	200	2.34 h	2.33 h	4.67 b	4.00 c	**3.33 B**	3.67 h	3.33 i	8.34 a	5.00 d	**5.09 A**
	400	3.00 f	5.33 a	2.67 g	3.33 e	**3.58 A**	4.67 e	6.33 b	3.67 h	4.33 f	**4.75 B**
Mean (A)		**2.14 C**	**3.43 A**	**3.38 A**	**2.81 B**		**3.38 D**	**4.67 B**	**4.95 A**	**3.95 C**	
		Number of leaves/transplant									
Control		0.00 q	11.00 k	8.67 mn	9.00 lm	**7.17 E**	0.00 r	12.67 lm	10.33 o	12.33 m	**8.83 E**
	1000	6.00 p	11.00 k	13.33 h	15.33 f	**11.42 D**	8.34 p	12.67 lm	15.00 hi	17.00 f	**13.25 D**
t-IBA (ppm)	2000	7.00 o	12.00 j	14.67 g	12.00 j	**11.42 D**	8.33 p	13.67 k	17.67 e	15.33 h	**13.75 C**
	4000	6.33 p	12.33 ij	14.33 g	13.33 h	**11.58 D**	7.33 q	14.67 ij	16.67 f	15.33 h	**13.50 CD**
	100	7.33 o	16.33 e	23.00 c	19.00 d	**16.42 C**	8.33 p	17.67 e	25.67 b	21.33 d	**18.25 A**
n-IBA (ppm)	200	8.34 n	26.67 b	31.67 a	8.67 mn	**18.83 A**	10.00 o	13.00 l	33.33 a	10.00 o	**16.58 B**
	400	9.33 l	12.67 i	14.67 g	31.33 a	**17.00 B**	11.67 n	14.33 j	16.00 g	23.67 c	**16.42 B**
Mean (A)		**6.33 D**	**14.57 C**	**17.19 A**	**15.52 B**		**7.72 D**	**14.10 C**	**19.24 A**	**16.43 B**	

* n-NAA: nano- naphthaleneacetic acid, n-IBA: nano- indole butyric acid, t-IBA: traditional indole butyric acid.

* Means followed by the same letter in a column or row don't significantly differ according to Duncan's New Multiple Range Test at 5 % level.

Regarding the number of leaves per transplant, the results showed that 200 ppm of both n-IBA and n-NAA treatments and their interaction scored the greatest numbers in the first season (18.83, 17.19, and 31.67 leaves, respectively), as well as the interaction of 400 ppm n-IBA + 400 ppm n-NAA, which gave 31.33 leaves. In the second season, 100 ppm n-IBA, 200 ppm n-NAA, and the combination of n-IBA and n-NAA at a concentration of 200 ppm each attained the greatest leaf numbers (18.25, 19.24, and 33.33 leaves, respectively).

Fresh and dry weights of branches and roots

Remarkable variations also occurred with respect to the effect of auxin treatments on fresh and dry weights of transplant biomass (Tables 14 and 15), where 100 ppm n-IBA treatment, 0.0 and 100 ppm n-NAA treatments, and 100 ppm n-IBA + 200 ppm n-NAA interaction maximized the fresh weight of branches (g) in the two seasons. The 200 ppm n-NAA treatment also maximized the mean of this parameter in the second season. On the other hand, means of root fresh weight were maximized by 4000 ppm t-IBA and 400 ppm n-NAA treatments, as well as by 400 ppm n-IBA + 100 ppm n-NAA combination over all the other individual and combined treatments in both seasons.

In the case of branch dry weight mean (g), it was maximum in the first season with the quick dipping in the solution of either t-IBA (4000 ppm) or n-NAA (0.0, 100, and 400 ppm), but in the second season, it was achieved by dipping n-IBA or n-NAA at a concentration of 100 ppm each.

Moreover, the interaction between 4000 ppm t-IBA and 0.0 ppm n-NAA hastened the branch dry weight to maximal values in both seasons (0.70g). Likewise, root dry weight means were maximized in the first season by 4000 ppm t-IBA and 400 ppm n-NAA treatments and their interaction recording 1.33, 1.42, and 2.70g, respectively, while in the second season, it was achieved by 100 ppm n-IBA and 400 ppm n-NAA treatments, as well as by 100 ppm n-IBA + 100 ppm n-NAA combined treatment scoring 1.51, 1.57, and 3.01 g, respectively.

Chemical composition of the leaves

In most cases, auxin treatments applied in the current study improved concentrations of chlorophyll a, b, and carotenoids (mg/g f.w.) in the two seasons, as shown in Tables 16 and 17. However, the prevalence was for 4000 ppm t-IBA and 200 ppm n-NAA treatments and their interaction, which gave the highest concentration of chlorophyll a in the two seasons, while the highest concentration of chlorophyll b was obtained in both seasons by dipping the wounded cuttings in 1000 and 4000 ppm t-IBA solutions, 200 and 400 ppm n-IBA solutions, n-NAA solutions at all concentrations, and a solution of 200 ppm n-IBA + 400 ppm n-NAA combination. As for carotenoids concentration, it was maximized in the first and second seasons by 4000 ppm t-IBA and 200 ppm n-NAA treatments and their interaction. Also, 100 and 200 ppm n-IBA scored high concentrations, greatly near to those attained by 4000 ppm t-IBA treatment in the two seasons without significant differences between them.

Similarly, the results of total sugars percentages were unsteady in the two seasons (Table, 17), but the mastery was for 4000 ppm t-IBA and 400 ppm n NAA treatments and their interaction, which raised the percentages of such constituent in the first season to 5.48, 5.15 and 7.70%, and in the second one to 5.00, 4.73 and 7.01%, respectively.

As a result of dipping the wounded bases of cuttings in solutions of both 2000 ppm t-IBA and 200 ppm n-NAA, as well as solutions of 400 ppm n-IBA + 200 ppm n-NAA combined treatment, the concentration of total indoles (mg/g f.w.) was the highest in both seasons (Table 18). Similarly, the highest concentration of total phenols (mg/g f.w.) was observed by dipping the wounded bases of cuttings in solutions of 1000 and 2000 ppm t-IBA treatments, 0.0 and 200 ppm n-NAA treatments, and solutions of n-IBA + n-NAA combination (at 200 ppm for each). These treatments resulted in 1.51, 1.48, 1.39, 1.42, and 2.70 (mg/g f.w.) in the first season and 1.38, 1.34, 1.27, 1.31, and 2.51 (mg/g f.w.) in the second season, respectively. These results suggest that combined treatments are usually more effective than single treatments.

TABLE 14. Effect of traditional, nano-auxins and their interactions on branches and roots fresh weight of *Simmondsia chinensis* (Link) Schneider transplants during 2020 and 2021 seasons

IBA treatments	NAA treatments	Control	n-NAA (ppm) 100	200	400	Mean (B)	Control	n-NAA (ppm) 100	200	400	Mean (B)
		Fresh weight of branches (g)									
		First season (2020)					**Second season (2021)**				
Control		0.00 s	1.12 e	0.42 p	0.44 OP	**0.50 F**	0.00 s	1.28 g	0.62 pq	0.52 r	**0.61 G**
t-IBA (ppm)	1000	0.46 o	0.92 hi	0.73 l	0.42 P	**0.63 E**	0.59 q	1.17 jk	0.92 m	0.60 q	**0.82 F**
	2000	0.88 j	1.00 f	0.89 ij	1.20 D	**0.99 B**	1.04 l	1.23 hi	1.20 ij	1.43 e	**1.23 B**
	4000	1.97 b	0.34 q	0.82 k	0.65 M	**0.95 C**	2.27 b	0.60 q	1.04 l	0.80 n	**1.18 C**
n-IBA (ppm)	100	1.14 e	0.61 n	2.17 a	0.91 HI	**1.21 A**	1.48 d	0.80 n	2.47 a	1.02 l	**1.44 A**
	200	0.97 g	1.23 c	0.45 op	0.65 M	**0.82 D**	1.13 k	1.67 c	0.65 p	0.83 n	**1.07 E**
	400	0.92 h	0.98 fg	0.25 r	1.13 E	**0.82 D**	1.13 k	1.27 gh	0.75 o	1.37 f	**1.13 D**
Mean (A)		**0.91 A**	**0.89 A**	**0.82 B**	**0.77 C**		**1.09 A**	**1.14 A**	**1.09 A**	**0.94 B**	
		Fresh weight of roots (g)									
Control		0.00 o	2.50 l	4.97 g	9.37 e	**4.21 E**	0.00 r	3.93 n	5.73 jk	10.63 f	**5.08 E**
t-IBA (ppm)	1000	4.30 h	2.57 l	1.33 n	5.53 f	**3.43 F**	4.73 m	2.90 p	1.77 q	5.30 l	**3.68 F**
	2000	4.93 g	4.97 g	5.07 g	11.30 c	**6.57 C**	5.80 ij	5.80 ij	5.43 l	12.17 e	**7.30 C**
	4000	2.20 m	10.30 d	3.90 i	14.10 b	**7.63 A**	2.97 p	13.50 c	5.73 jk	15.20 b	**9.35 A**
n-IBA (ppm)	100	3.40 j	11.40 c	5.37 f	5.06 g	**6.31 C**	3.83 n	12.97 d	6.33 h	5.47 kl	**7.15 C**
	200	3.24 j	5.14 g	5.13 g	9.20 e	**5.68 D**	3.80 n	6.03 i	6.67 g	10.70 f	**6.80 D**
	400	2.83 k	14.70 a	5.03 g	5.53 f	**7.03 B**	3.27 o	15.93 a	5.80 ij	6.83 g	**7.96 B**
Mean (A)		**2.99 D**	**7.37 B**	**4.40 C**	**8.58 A**		**3.49 D**	**8.72 B**	**5.35 C**	**9.47 A**	

* n-NAA: nano- naphthaleneacetic acid, n-IBA: nano- indole butyric acid, t-IBA: traditional indole butyric acid.

* Means followed by the same letter in a column or row don't significantly differ according to Duncan's New Multiple Range Test at 5 % level.

TABLE 15. Effect of traditional, nano-auxins and their interactions on branches and roots dry weight of *Simmondsia chinensis* (Link) Schneider transplants during 2020 and 2021 seasons

IBA treatments	NAA treatments	Control	n-NAA (ppm) 100	200	400	Mean (B)	Control	n-NAA (ppm) 100	200	400	Mean (B)
		Dry weight of branches (g)									
		First season (2020)					**Second season (2021)**				
Control		0.00 r	0.32 f	0.16 o	0.19 n	**0.17 E**	0.00 s	0.29 k	0.23 mn	0.11 r	**0.16 D**
t-IBA (ppm)	1000	0.15 op	0.27 hi	0.20 mn	0.15 op	**0.19 D**	0.24 m	0.45 d	0.27 l	0.18 o	**0.28 C**
	2000	0.23 j	0.26 i	0.22 jkl	0.43 c	**0.28 B**	0.37 g	0.44 d	0.36 gh	0.30 jk	**0.37 B**
	4000	0.70 a	0.13 p	0.21 lm	0.19 n	**0.31 A**	0.70 a	0.13 q	0.35 hi	0.24 m	**0.35 B**
n-IBA (ppm)	100	0.26 hi	0.14 p	0.50 b	0.30 g	**0.30 AB**	0.31 j	0.31 j	0.61 b	0.39 f	**0.41 A**
	200	0.28 h	0.33 ef	0.19 n	0.23 jk	**0.26 C**	0.33 i	0.62 b	0.26 l	0.21 n	**0.36 B**
	400	0.21 klm	0.34 e	0.08 q	0.38 d	**0.25 C**	0.42 e	0.33 i	0.16 p	0.49 c	**0.35 B**
Mean (A)		**0.26 A**	**0.25 A**	**0.22 B**	**0.27 A**		**0.34 B**	**0.37 A**	**0.32 B**	**0.27 C**	
		Dry weight of roots (g)									
Control		0.00 u	0.39 s	0.95 j	1.10 g	**0.61 E**	0.00 v	0.38 s	0.62 p	1.27 f	**0.57 D**
t-IBA (ppm)	1000	0.87 k	0.47 r	0.17 t	1.00 i	**0.63 E**	0.78 m	0.53 q	0.26 u	0.73 n	**0.58 D**
	2000	0.52 p	0.48 qr	1.08 g	2.13 c	**1.05 C**	0.87 k	1.09 h	0.69 o	2.15 d	**1.20 C**
	4000	0.42 s	1.62 e	0.59 o	2.70 a	**1.33 A**	0.46 r	1.93 e	0.67 o	2.27 c	**1.33 B**
n-IBA (ppm)	100	0.74 l	2.00 d	0.70 mn	0.74 l	**1.05 C**	0.83 l	3.01 a	1.14 g	1.04 i	**1.51 A**
	200	0.68 n	0.51 pq	0.73 lm	1.04 h	**0.74 D**	0.88 k	0.59 p	0.99 j	2.23 c	**1.17 C**
	400	0.42 s	2.39 b	0.51 pq	1.21 f	**1.13 B**	0.33 t	2.49 b	1.29 f	1.29 f	**1.35 B**
Mean (A)		**0.52 D**	**1.12 B**	**0.68 C**	**1.42 A**		**0.59 D**	**1.43 B**	**0.81 C**	**1.57 A**	

* n-NAA: nano- naphthaleneacetic acid, n-IBA: nano- indole butyric acid, t-IBA: traditional indole butyric acid.

* Means followed by the same letter in a column or row don't significantly differ according to Duncan's New Multiple Range Test at 5 % level.

TABLE 16. Effect of traditional, nano-auxins and their interactions on chlorophyll a and b concentration in the leaves of *Simmondsia chinensis* (Link) Schneider transplants during 2020 and 2021 seasons

NAA treatments / IBA treatments		Control	n-NAA (ppm) 100	200	400	Mean (B)	Control	n-NAA (ppm) 100	200	400	Mean (B)
		First season (2020)					**Second season (2021)**				
		Chlorophyll a (mg/g F.W.)									
Control		0.00 n	0.05 hi	0.04 hij	0.04 hijk	**0.03 D**	0.00 n	0.05 hi	0.04 hij	0.04 hij	**0.03 D**
t-IBA (ppm)	1000	0.20 d	0.03 jkl	0.10 f	0.03 hijk	**0.09 C**	0.21 d	0.03 jkl	0.11 f	0.04 ijk	**0.10 C**
	2000	0.07 g	0.03 ijkl	0.04 hij	0.04 hij	**0.05 D**	0.08 g	0.04 ijk	0.05 hij	0.04 hij	**0.05 D**
	4000	0.22 c	0.18 d	0.29 a	0.04 hij	**0.18 A**	0.24 c	0.20 d	0.31 a	0.05 hij	**0.20 A**
n-IBA (ppm)	100	0.01 mn	0.02 klm	0.14 e	0.01 lmn	**0.05 D**	0.01 mn	0.02 klm	0.15 e	0.02 lmn	**0.05 D**
	200	0.15 e	0.05 h	0.26 b	0.18 d	**0.16 B**	0.17 e	0.06 h	0.29 b	0.20 d	**0.18 B**
	400	0.08 g	0.19 d	0.23 c	0.15 e	**0.16 B**	0.09 g	0.21 d	0.24 c	0.17 e	**0.18 B**
Mean (A)		**0.10 B**	**0.08 BC**	**0.16 A**	**0.07 C**		**0.11 B**	**0.09 C**	**0.17 A**	**0.08 C**	
		Chlorophyll b (mg/g F.W.)									
Control		0.00 f	0.01 f	0.01 f	0.02 f	**0.01 B**	0.00 h	0.01 fgh	0.01 fgh	0.02 fgh	**0.01 B**
t-IBA (ppm)	1000	0.10 ab	0.02 f	0.01 f	0.01 f	**0.03 A**	0.11 ab	0.02 fgh	0.02 fgh	0.01 gh	**0.04 A**
	2000	0.01 f	0.01 f	0.02 f	0.02 f	**0.01 B**	0.01 fgh	0.01 fgh	0.02 fgh	0.02 fgh	**0.01 B**
	4000	0.08 c	0.01 f	0.08 c	0.01 f	**0.04 A**	0.08 c	0.01 fgh	0.08 c	0.01 fgh	**0.05 A**
n-IBA (ppm)	100	0.01 f	0.01 f	0.04 de	0.01 f	**0.01 B**	0.01 gh	0.01 fgh	0.04 e	0.01 h	**0.01 B**
	200	0.04 d	0.01 f	0.05 d	0.12 a	**0.05 A**	0.04 de	0.01 gh	0.05 de	0.13 a	**0.06 A**
	400	0.05 d	0.09 b	0.02 ef	0.02 ef	**0.05 A**	0.06 d	0.10 b	0.02 fg	0.02 f	**0.05 A**
Mean (A)		**0.04 A**	**0.02 A**	**0.03 A**	**0.02 A**		**0.04 A**	**0.02 A**	**0.03 A**	**0.03 A**	

* n-NAA: nano- naphthaleneacetic acid, n-IBA: nano- indole butyric acid, t-IBA: traditional indole butyric acid.

* Means followed by the same letter in a column or row don't significantly differ according to Duncan's New Multiple Range Test at 5 % level.

TABLE 17. Effect of traditional, nano-auxins and their interactions on carotenoids and total sugars concentration in the leaves of *Simmondsia chinensis* (Link) Schneider transplants during 2020 and 2021 seasons

NAA treatments / IBA treatments		Control	n-NAA (ppm) 100	200	400	Mean (B)	Control	n-NAA (ppm) 100	200	400	Mean (B)
		First season (2020)					**Second season (2021)**				
		Carotenoids (mg/g F.W.)									
Control		0.00 l	0.02 ijk	0.02 ijk	0.02 ijk	**0.02 C**	0.00 l	0.02 ijk	0.03 ij	0.02 ijk	**0.02 C**
t-IBA (ppm)	1000	0.14 b	0.02 ijk	0.06 g	0.02 ijkl	**0.06 B**	0.15 b	0.02 ijk	0.06 g	0.02 ijkl	**0.06 B**
	2000	0.04 gh	0.02 ijkl	0.03 hi	0.02 ij	**0.03 C**	0.05 gh	0.02 ijk	0.03 hi	0.03 ij	**0.03 C**
	4000	0.13 b	0.08 e	0.19 a	0.02 ijk	**0.11 A**	0.15 b	0.09 e	0.20 a	0.02 ijk	**0.12 A**
n-IBA (ppm)	100	0.01 kl	0.01 ijkl	0.08 ef	0.01 jkl	**0.03 C**	0.01 kl	0.01 ijkl	0.08 ef	0.01 jkl	**0.03 C**
	200	0.10 d	0.02 ijk	0.12 bc	0.13 bc	**0.09 A**	0.11 d	0.03 ij	0.13 bc	0.14 bc	**0.10 A**
	400	0.06 fg	0.14 b	0.11 cd	0.08 e	**0.10 A**	0.07 fg	0.15 b	0.12 cd	0.09 e	**0.11 A**
Mean (A)		**0.07 AB**	**0.05 B**	**0.09 A**	**0.04 B**		**0.07 A**	**0.05 B**	**0.09 A**	**0.05 B**	
		Total sugars (%)									
Control		0.00 q	3.91 o	4.65 k	5.63 d	**3.55 F**	0.00 p	3.60 n	4.18 i	5.18 cd	**3.24 F**
t-IBA (ppm)	1000	5.70 cd	4.92 h	4.71 jk	3.76 p	**4.77 C**	5.13 d	4.53 g	4.24 i	3.42 o	**4.33 C**
	2000	4.37 m	4.72 jk	4.36 m	4.25 n	**4.43 D**	3.98 jk	4.25 i	3.97 jk	3.91 kl	**4.03 D**
	4000	4.24 n	5.51 e	4.48 l	7.70 a	**5.48 A**	3.82 m	5.13 d	4.03 j	7.01 a	**5.00 A**
n-IBA (ppm)	100	4.81 i	5.89 b	5.12 f	5.02 g	**5.21 B**	4.43 h	5.42 b	4.66 ef	4.62 f	**4.78 B**
	200	5.18 f	5.75 c	4.17 n	5.86 b	**5.24 B**	4.72 e	5.23 c	3.84 lm	5.45 b	**4.81 B**
	400	4.37 m	3.94 o	4.79 ij	3.82 p	**4.23 E**	4.02 j	3.63 n	4.40 h	3.55 n	**3.90 E**
Mean (A)		**4.10 D**	**4.95 B**	**4.61 C**	**5.15 A**		**3.73 D**	**4.54 B**	**4.19 C**	**4.73 A**	

* n-NAA: nano- naphthaleneacetic acid, n-IBA: nano- indole butyric acid, t-IBA: traditional indole butyric acid.

* Means followed by the same letter in a column or row don't significantly differ according to Duncan's New Multiple Range Test at 5 % level.

TABLE 18. Effect of traditional, nano-auxins and their interactions on total indoles and total phenols concentration in the leaves of *Simmondsia chinensis* (Link) Schneider transplants during 2020 and 2021 seasons

IBA treatments \ NAA treatments		Control	n-NAA (ppm) 100	n-NAA (ppm) 200	n-NAA (ppm) 400	Mean (B)	Control	n-NAA (ppm) 100	n-NAA (ppm) 200	n-NAA (ppm) 400	Mean (B)
Total indoles (mg/g F.W.)											
		First season (2020)					Second season (2021)				
Control		0.00 s	4.10 e	5.50 d	1.60 m	**2.80 D**	0.00 r	3.73 e	5.06 d	1.44 l	**2.56 C**
	1000	2.60 i	0.10 rs	6.60 b	2.70 hi	**3.00 C**	2.37 i	0.09 qr	6.01 b	2.48 hi	**2.74 B**
t-IBA (ppm)	2000	5.90 c	2.30 j	2.70 hi	3.00 g	**3.48 A**	5.37 c	2.07 j	2.43 hi	2.76 g	**3.16 A**
	4000	3.00 g	0.50 q	0.20 r	0.70 p	**1.10 G**	2.76 g	0.47 p	0.18 q	0.65 o	**1.02 F**
	100	1.80 l	0.80 p	0.70 p	2.10 k	**1.35 F**	1.66 k	0.74 o	0.64 o	1.95 j	**1.25 E**
n-IBA (ppm)	200	2.20 jk	1.30 n	2.80 h	2.60 i	**2.23 E**	2.00 j	1.21 m	2.52 h	2.42 hi	**2.04 D**
	400	1.00 o	1.50 m	7.40 a	3.20 f	**3.28 B**	0.93 n	1.38 l	6.88 a	2.91 f	**3.03 A**
Mean (A)		**2.36 B**	**1.51 C**	**3.70 A**	**2.27 B**		**2.15 B**	**1.38 C**	**3.39 A**	**2.09 B**	
Total phenols (mg/g F.W.)											
Control		0.00 o	1.69 e	1.77 d	1.79 cd	**1.31 C**	0.00 p	1.54 f	1.64 cd	1.61 de	**1.20 C**
	1000	1.77 d	0.88 k	1.55 f	1.82 c	**1.51 A**	1.59 e	0.80 l	1.44 g	1.68 bc	**1.38 A**
t-IBA (ppm)	2000	1.75 d	0.98 j	1.90 b	1.29 h	**1.48 A**	1.61 de	0.88 k	1.71 b	1.16 i	**1.34 A**
	4000	1.87 b	0.77 l	0.34 n	0.37 n	**0.84 D**	1.72 b	0.71 m	0.31 o	0.34 o	**0.77 D**
	100	1.54 f	1.34 g	1.31 gh	1.18 i	**1.34 C**	1.40 g	1.23 h	1.20 h	1.09 j	**1.23 C**
n-IBA (ppm)	200	0.97 j	1.20 i	2.70 a	0.75 l	**1.40 B**	0.88 k	1.08 j	2.51 a	0.69 m	**1.29 B**
	400	1.82 c	0.44 m	0.37 n	0.37 n	**0.75 E**	1.67 bc	0.41 n	0.35 o	0.33 o	**0.69 E**
Mean (A)		**1.39 A**	**1.04 B**	**1.42 A**	**1.08 B**		**1.27 A**	**0.95 B**	**1.31 A**	**0.98 B**	

* n-NAA: nano- naphthaleneacetic acid, n-IBA: nano- indole butyric acid, t-IBA: traditional indole butyric acid.

* Means followed by the same letter in a column or row don't significantly differ according to Duncan's New Multiple Range Test at 5 % level.

Discussion

The results showed that most auxin treatments, either in traditional or nano forms, encouraged the rooting of the wounded jojoba stem cuttings with various significant differences. This may be attributed to their ability to activate cambium regeneration, cell division, and cell enlargement near the base of the cuttings to form adventitious roots (Kaur & Singh, 2022). In this regard, Zhang et al. (2021) observed that adventitious root primordium of *Hibiscus syriacus* cuttings originated from a group of parenchyma cells with a blunt conical shape located in the cross-region of pith rays and vascular cambium. These adventitious root primordia developed successfully.

The adventitious roots emerged from the wounded bases of jojoba cuttings and extended outward through lenticels. Jagiello-Kubiec et al. (2021) affirmed several anatomical changes at the bases of cuttings during root formation were accelerated by auxin treatment, owing to increasing endogenous indole acid and hydrogen peroxide (H_2O_2) levels, which were temporarily associated with intensive cell division in cuttings. The polyphenolic acid contents kept increasing during rooting above the initial levels of the cuttings. This was demonstrated by Ghimire et al. (2022), who revealed that IBA treatment promoted the synthesis and accumulation of phenolic compounds, mostly protochatechuic acid, chlorogenic acid, biochanin A, salicylic acid, caffeic acid, glycitein, and luteolin in *Chrysanthemum indicum* stem cuttings at the time of root formation. Thus, applying auxins is essential for early root formation, uniform rooting, and higher rooting success.

It was also suggested that the most reproducible and significant changes occurring after auxin application were a decrease in the level of zeatin-O-glucoside conjugates.

Hydrolysis of these conjugates might deliver free zeatin-type compounds that are consumed during the adventitious root growth and disappear afterwards (Kumar et al., 2008). Fu et al. (2020) found that the concentration and activity of indole acetic acid oxidase (IAAO), peroxidase (POD), and polyphenol oxidase (PPO) enzymes first increased at the beginning of auxin treatment and reached the maximum in the root group induction period, and then decreased. Likewise, Qiang Qinang et al. (2021) noticed that IBA during the rooting process promoted an increase in the contents of soluble sugar, starch, non-structural carbohydrates, and soluble proteins in the stem cuttings, besides increasing the activities of peroxidase (POD) and polyphenol oxidase (PPO) enzymes. Moreover, Das (2021) reported that the rate of flow of endogenous IBA from the apex to the base of the cuttings was governed by the relative effectiveness of gravity, which was in turn decided by the inclination of the cuttings.

The previous gains can be supported by those of Howard et al. (1984), who found that IBA at 4000 ppm increased the rooting percentage of non-wounded nodal jojoba cuttings to 58% and wounded ones to 65%. Yuan (2002) revealed that the rooting rates of cuttings taken from young female jojoba shoots treated with IBA, NAA, and IAA at 100 ppm concentration for each were 82%, 80%, and 76%, respectively. Bing & HanDong (2003) postulated that the rooting ratio of jojoba semi-hardwood cuttings was increased by soaking in a 1000 ppm IBA solution for 12h. Kumar et al. (2008) cited that IBA at 500 ppm treatment maximized the rooting percentage of jojoba juvenile cuttings to 36.25% compared to 10.83% in mature cuttings. Furthermore, Osman & Hassan (2013) clarified that the rooting ability of jojoba stem cuttings would be significantly improved (to higher than 80%) by dipping in a 3000 ppm IBA solution with 100% R.H. of the leaf surface of the cuttings through sprinkler irrigation, without saturating the rooting medium by using perlite and planting under partially shaded polyethylene sheet tunnels. On wounded and unwounded stem cuttings of jojoba, Khattab et al. (2014) elicited that IBA (3000 ppm) + NAA (500 ppm) treatment recorded the highest rooting percentage and did not significantly differ from IBA (3000 ppm) + NAA (500 ppm) + vitamin C (1000 ppm) treatment. The best results were attained by unwounded cuttings of IBA (3000 ppm) + NAA (500 ppm), wounded cuttings of IBA (3000 ppm) + NAA (500 ppm) + vit. C (1000 ppm), and IBA (5000 ppm) + NAA (500 ppm) + boric acid (0.5 ppm) treatment with insignificant differences. In addition, Bala *et al.* (2020) treated male and female mature stem cuttings of jojoba by dipping the basal part in a 500, 1000, 2000, and 3000 ppm of either IBA or NAA solution for 1 h and found that the highest rooting (68.9%) in male stem cuttings and 66.5% in female ones were obtained by 2000 ppm IBA solution. At this concentration, the maximum number of roots in male (12.5) and female (13.2) cuttings was recorded.

Results of such work also exhibited that nanoparticles of either IBA or NAA, whether loaded or non-loaded on iron oxide and applied alone or in combination, gave better results than applying the two auxins in only the traditional form. This may be attributed to the fact that such nanoparticles (NPs) are very small (1-100 nanometers) and have a very large surface area relative to their small size, which makes them very reactive and enables them to easily penetrate the roots and transfer to the aerial parts (Banijamali et al., 2019). In this regard, Thangavelu et al. (2018) found that using silver nanoparticles (AgNPs) with two auxin rooting hormones (IAA and IBA) exhibited dual actions as a root enhancer and pathogen destroyer through in vitro and ex vitro studies on stem explants taken from tobacco (*Nicotiana tabacum*) plants at a length of 1.5-2cm with one node. The dual action of hormone-stabilized AgNPs enhanced root growth 3-fold compared to the control and increased the rooting capability against root growth-inhibiting phytopathogens. Moreover, hormone-AgNPs left no toxicity to treated plants. Thus, this hormone-AgNPs conjugate can address the current challenges of horticulture plant root development and plant disease management for sustainable agricultural crop production.

On micro propagated picual olive cv., Hegazi et al. (2021) claimed that silver nanoparticles (AgNPs) at 5 ppm gave the highest sprouting percentage, shoot length, number of shoots/explant, and number of leaves/shoot. In addition, Kara et al. (2021) pointed out that 1 ppm AgNPs improved the root and shoot development of grape rootstock cuttings, while 1 ppm AgNPs + 50 ppm IBA resulted in the highest number of nodes in shoots developing from cuttings.

Similar results were found by Shahrekizad et al. (2015) on Helianthus annuus, Banijamali et al. (2019) on *Chrysanthemum morifolium* “Salvador,” Alhasan (2020) on *Ocimum basilicum* cv. Dolly, and Mahmoud and Swaefy (2020), who found that nano-NPK fertilizer and nano-zeolites had superior effects on various growth parameters of *Salvia officinalis* subjected to water stress conditions compared to commercial NPK fertilizer. They also improved photosynthetic rate, stomatal conductance, WUE, CO_2 concentration, and RWC. The concentrations of pigments, total sugars, total phenolics, tannin, total flavonoids, macro and micro elements, GA_3, and activity of peroxidase and superoxide dismutase were positively affected.

Abdel-Aziz et al. (2016) on wheat, Burhan & Al-Hassan (2019) on wheat, Miranda-Villagomez et al. (2019) on rice, and Rop et al. (2019) also demonstrated similar results on several economic crops, stating that nano-NPK slow-release fertilizer enhanced growth and yield of maize, kale, and capsicum crops, just like commercial fertilizer, with potentially greater benefits, such as improving soil health and resilience.

Conclusion

Based on the results of the first experiment, it is recommended to dip the wounded bases of jojoba cuttings quickly (for 10 seconds) in either a 200 or 400 ppm nFe-NAA solution and then in either a 200 or 400 ppm nFe-IBA solution for best rooting and commercial production. While, High-quality transplants can be obtained by dipping the wounded bases of jojoba cuttings quickly (for 10 seconds) in either a 200 or 400 ppm n-NAA solution and then in either a 200 or 400 ppm n-IBA solution or in a 4000 ppm t-IBA solution to achieve the highest rooting percentage and high-quality transplants from a commercial point of view, according to the results of the second experiment.

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Authors’ contributions: Identify the problem and create the hypotheses by Amira Sh. Soliman, applying treatments, collecting and analysing data by Sayed A.M. Goda and writing the manuscript by Sayed A.M. Goda. While all authors contributed the revising, editing and publishing the final manuscript.

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دمج تكنولوجيا النانو في معاملات الإكثار بالعقل لشجرة الجوجوبا (*Simmondsia chinensis*) في مصر و جنوب إفريقيا

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أجريت تجربتين منفصلتين بصوبة الحفظ الزجاجية للبنك القومي للجينات ، مركز البحوث الزراعية، الجيزة، مصر، خلال موسمي 2020، 2021 لتشجيع تجدير العقل الساقية المجروحة لنبات الجوجوبا (*Simmondsia chinensis*) و النمو و التركيب الكيميائي للنباتات الناتجة. تم في التجربة الأولى دراسة تأثير كل من هرموني التجدير: نفثالين حمض الخليك (NAA) المحمل على الحديد النانو(nFe-NAA) بتركيزات صفر، 100، 200، 400 جزء في المليون وإندول حمض بيوتيريك (IBA) إما في صورته العادية أو التقليدية (t-IBA) بتركيزات صفر، 1000، 2000، 4000 جزء في المليون أو في صورة جزيئات دقيقة محملة على الحديد النانو (nFe-IBA) بتركيزات صفر، 100، 200، 400 جزء في المليون والتفاعلات بينهما. بينما في التجربة الثانية تم دراسة تأثير نفثالين حمض الخليك (NAA) النانو (nFe-NAA) بتركيزات صفر، 100، 200، 400 جزء في المليون وإندول حمض بيوتيريك (IBA) إما في صورته العادية (t-IBA) بتركيزات صفر، 1000، 2000، 4000 جزء في المليون او في صورة نانو (nFe-IBA) بتركيزات صفر، 100، 200، 400 جزء في المليون والتفاعلات بينهما. في التجربة الأولى حسنت المعاملات الفردية و المشتركة القيم المتوسطة لنسبة التجذير، عدد الجذور/عقلة و طول الجذر، كما حسنت طول الأفرع، عدد الأفرع/شتلة، عدد الأوراق/ شتلة والأوزان الطازجة و الجافة للأفرع و الجذور، تركيزات كلوروفيل أ، ب، الكاروتينويدات، السكريات الكلية، الأندولات و الفينولات في الشتلات الجديدة مع بعض الأستثناءات القليلة في كلا الموسمين. إلا أن المعاملات المشتركة، خاصة الغمس السريع لقواعد العقل المجروحة في محلول نفثالين حمض الخليك المحمل على حديد النانو (nFe-NAA) بتركيز 200 أو 400 جزء في المليون ثم بعد ذلك في محلول إندول حمض البيوتيريك المحمل على جزيئات حديد النانو (nFe-IBA) بتركيز 200 أو 400 جزء في المليون أعطت أفضل النتائج في كلا الموسمين. و لقد تم الحصول على إتجاه مشابه في التجربة الثانية، حيث تخطت معاملات التفاعل المشترك تأثير المعاملات الفردية، خاصة توليفات الغمس السريع في نفثالين حمض الخليك النانو (n-NAA) بتركيز 200 أو 400 جزء في المليون + إندول حمض البيوتيريك النانو (n-IBA) بتركيز 200 أو 400 جزء في المليون ، حيث أحرزت هذه التوليفات الأربعة أفضل النتائج على الأطلاق. إضافة إلى ذلك، أعطى التفاعل المشترك بين الغمس في محلول أندول حمض البيوتيريك العادي (t-IBA) بتركيز 4000 جزء في المليون وفي محلول نفثالين حمض الخليك النانو (n-NAA) بتركيز 200 أو 400 جزء في المليون نتائج أفضل في بعض الصفات. لذلك، يمكن التوصية بإستخدام كل من هرموني التجدير نفثالين حمض الخليك و إندول حمض البيوتيريك (NAA, IBA) معاً في صورة جزيئات نانو بتركيز 200 أو 400 جزء في المليون لكل منهما إما محملين أو غير محملين على جزيئات الحديد النانو للحصول على أفضل صفات تجذير لعقل الجوجوبا الساقية الطرفية المجروحة و أعلى جودة للشتلات الناتجة من الناحية التجارية.