Effects of Indole-3-Butyric Acid Application on Rooting and Vegetative Development in Hardwood Cuttings of *Pterocarya fraxinifolia* (Poiret) Spach

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Effects of different concentrations of indole-3-butyric acid (IBA) were studied relative to the rooting success, morphological development, and biomass characteristics of hardwood cuttings of *Pterocarya fraxinifolia* (Poiret) Spach collected from Düzce, Türkiye. Using a factorial design involving two cutting thickness classes and six IBA concentrations, the rooting percentage, number of roots per rooted cutting, shoot length, shoot diameter, number of shoots, fresh and dry shoot weight, and fresh and dry root weights were analyzed. The interaction between IBA concentration and cutting thickness played an important role in the vegetative propagation of *Pterocarya fraxinifolia* cuttings, especially in terms of rooting success, morphological characteristics, and biomass development. In particular, 1000 ppm and 2000 ppm IBA treatments yielded the most balanced and effective results in terms of rooting, shoot and root development, and biomass production. Although the 8000-ppm dose increased shoot biomass, it suppressed root development, indicating a potential phytotoxic effect at high concentrations. Principal component analysis also supported these findings and showed that 1000 ppm and 2000 ppm IBA doses provided homogeneous and healthy development. The results obtained emphasize that the optimal IBA dose should be carefully selected for the sustainable vegetative propagation; especially applications in the range of 1000 to 2000 ppm can provide important contributions to the propagation and conservation of the species.

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INTRODUCTION

Riparian zones stand out as critical transition zones that provide interaction between terrestrial and aquatic ecosystems and protect aquatic ecosystems (Gregory *et al*. 1991; Naiman and Decamps 1997; Ewel *et al*. 2001; Lake 2005; Hale *et al*. 2014; Baş 2023). Forests in these regions provide significant environmental, economic and aesthetic benefits due to their high biodiversity despite harsh environmental conditions (Saki and Tamura 2008). Furthermore, coastal vegetation contributes to maintaining ecosystem balance by improving water quality, conserving biodiversity, and reducing erosion (Batlle-Aguilar *et al*. 2012; Hale *et al*. 2018). However, these fragile ecosystems face threats such as agriculture, urban development, grazing, and the associated spread of invasive species

(Imbert and Lefevre 2003; Smulders *et al*. 2008; Yousefzadeh 2018). These threats jeopardize the existence of many species in coastal forests, and *Pterocarya fraxinifolia* (Poiret) Spach is among the species negatively affected by these pressures.

Relict trees are generally defined as trees that were abundant in ancient times and spread over large areas, but nowadays their distribution areas have narrowed and they are found in small amounts. *Pterocarya fraxinifolia* (Poiret) Spach, known as Caucasian walnut, is known as a relict species (Milne and Abbott 2002; Song *et al*. 2021). The species is predominantly found in riparian forests of the Hyrcanian, Caucasian, and Irano-Turanian floristic regions (Kutbay *et al*. 1999; Song *et al*., 2021; Torun *et al*. 2024). Although it typically grows along riverbanks in lowland areas, its distribution can reach elevations of 600 to 800 m and, in some cases, up to 1200 m (Yaltırık and Efe 1994; Kozlowski *et al*. 2018; Yousefzadeh *et al*. 2018).

The natural populations of *Pterocarya fraxinifolia* are under various threats, necessitating the development of alternative strategies for its conservation and sustainable propagation. Seed propagation offers limited potential due to low germination rates, prolonged dormancy, and a high proportion of empty seeds (Çiçek and Tilki 2008). Therefore, vegetative propagation methods such as cutting propagation provide a valuable alternative for the conservation and multiplication of the species. Vegetative propagation enables the reproduction of superior genotypes and is an effective method for achieving genetic gain (Urgenc 1992). Moreover, seedlings produced from cuttings often exhibit superior growth performance during the early stages compared to those propagated from seeds (Çiçek *et al*. 2006).

In the process of cutting propagation, the use of plant growth regulators (auxins) is a common practice to enhance rooting success. Among these, indole-3-butyric acid (IBA) is recognized as one of the most effective auxins in promoting adventitious root formation in many woody plant species (Hartmann and Kester 1997). While IBA or similar auxin compounds may occur in small amounts in plants naturally, the IBA used in propagation practices is typically a synthetic compound (Bartel *et al.* 2001; Bajguz and Piotrowska 2009). Its exogenous application is designed to mimic and enhance natural auxin activity at the base of cuttings. Although IBA is widely applied to increase rooting rates in cuttings, no study to date has investigated its effect specifically on *P. fraxinifolia*.

Therefore, experimental studies were designed to evaluate the effects of different IBA concentrations on the rooting success, morphological development, and biomass characteristics of *P. fraxinifolia* cuttings. In this study, it is hypothesized that: (1) the application of appropriate IBA concentrations would significantly increase the rooting percentage of cuttings; (2) IBA treatments would positively affect morphological parameters such as root number, shoot length, shoot diameter, and number of shoots, as well as biomass traits including fresh and dry shoot weight and fresh and dry root weight, thereby creating optimal conditions for vegetative propagation; and (3) excessively high IBA doses would induce phytotoxic effects, leading to reductions in these parameters. This study aimed to determine the optimal IBA concentration for effective rooting and healthy growth of *P. fraxinifolia* cuttings, thereby providing a scientific basis for the sustainable vegetative propagation and long-term conservation of the species. This study is the first to comprehensively investigate the combined effects of cutting thickness and a wide range of IBA concentrations on the rooting, morphological, and biomass responses in *P. fraxinifolia* cuttings. Furthermore, the findings are expected to offer valuable contributions to sustainable forestry, nursery production, and the restoration of riparian ecosystems by supporting the development of scientifically grounded vegetative propagation strategies for this species.

EXPERIMENTAL

Material and Methods

The hardwood cuttings of *P. fraxinifolia* used in this study were collected from the riparian zones of the Melen River basin, located in Düzce province, Türkiye. The rootstock trees from which the cuttings were taken were determined by taking into account the criteria of vigor, disease-free status, and strong shoot structure. The cuttings were divided into two groups based on their diameters and the shoot thickness of the species, and those thinner than 10 mm were classified as "thin cuttings" and those larger than 10 mm were classified as "thick cuttings". The length of the cuttings was determined to be approximately 15 cm (Fig. 1). Immediately after collection, the cuttings were wrapped in moist paper towels, sealed in polyethylene bags, and stored at 4 °C to preserve their physiological integrity and prevent desiccation. They were then transferred to the greenhouse and planted within 24 h.

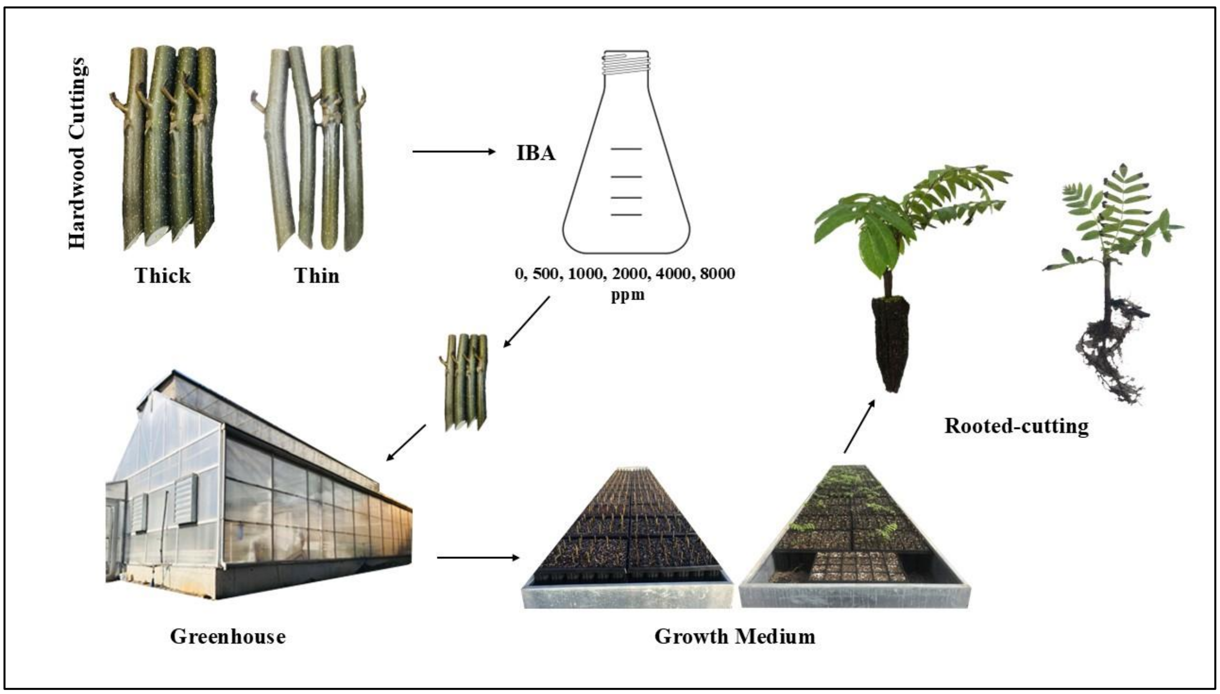

Fig. 1. Rooting process of *Pterocarya fraxinifolia* (Poiret) Spach hard stem cuttings

The rooting process was carried out in a fully automated greenhouse with a north-south orientation, using plastic containers measuring 6 × 6 × 20 cm. The rooting medium within the containers consisted of a 1:1 (v/v) mixture of peat and agricultural perlite. One day prior to planting the cuttings, the medium was irrigated to ensure adequate moisture and allow excess water to drain.

Six different IBA concentrations (0, 500, 1000, 2000, 4000 and 8000 ppm) were used in the study. During the preparation of IBA solutions, the hormone was first dissolved in alcohol and then diluted with distilled water. The prepared solutions were applied to the base of the cuttings for 5 s and then planted in 6 × 6 × 20 cm plastic containers (Fig. 1).

During the rooting period, the cuttings were maintained in a fully automated greenhouse with an average temperature range of 18 to 22 °C and humidity levels above 80%. The irrigation regime was regulated by misting and micro sprinkler system to maintain the humidity in the greenhouse above 80%. During the rooting process, cuttings were checked daily (Fig. 1).

The experiment was established according to the randomized plots experimental design with three replications. Steel types, treatment combinations, and replications were randomly assigned to the plots. The total number of cuttings used for the experiment was calculated as follows; 2 steel types (thin and thick) × 6 hormone doses (0, 500, 1000, 2000, 4000, 8000 ppm) × 3 replications x 30 cuttings = 1080 cuttings.

Approximately six months after planting, all rooted and unrooted cuttings were recorded, and rooting percentages (RP) were calculated. Morphological (number of roots (NR), shoot length (SL), shoot diameter (SD) and number of shoots (NS)) and biomass content (fresh and dry stem weight (FSW and DSW), fresh and dry root weight (FRW and DRW)) measurements were performed on rooted cuttings.

The normality of all obtained variables and homogeneity of variances were assessed using the Shapiro-Wilk test (shapiro.test function) and Bartlett's test (bartlett.test function) in R. Subsequently, a two-way analysis of variance (ANOVA) was performed to determine the effects of cutting type, hormone concentration, and their interaction on rooting success, morphological development, and biomass traits of *P. fraxinifolia* cuttings. When significant differences were detected, pairwise comparisons between groups were carried out using Tukey's Honest Significant Difference (HSD) test (TukeyHSD function). Additionally, principal component analysis (PCA) was applied to evaluate the effects of different IBA doses on rooting success, morphological characteristics, and biomass parameters. This multivariate technique identifies major sources of variation and visually represents group separation. All statistical analyses were carried out in R (R Core Team, 2018) and evaluated at the 5% significance level ($\alpha = 0.05$).

RESULTS

Two-way ANOVA indicated a significant interaction between cutting type and hormone dose for fresh root weight ($P < 0.05$) and dry root weight ($p < 0.01$), whereas no significant interactions were observed for the other parameters. Furthermore, hormone dose alone had significant effects on rooting percentage ($p < 0.01$), number of roots ($p < 0.05$), shoot length ($p < 0.01$), number of shoots ($p < 0.05$), fresh shoot weight ($p < 0.01$), and dry shoot weight ($p < 0.05$) (Table 1). For *P. fraxinifolia* cuttings, the highest RP (26.66%) was found at 2000 ppm IBA dose in thin cuttings and the highest NR (22.33 roots per cutting) was found at 1000 ppm in thick cuttings. These results indicate that IBA application had significant positive effects on RP and NR, but this effect varied according to the dose level and thickness of the cuttings (Table 1). In terms of morphological traits, the highest SL (12.32 cm) and NS (1.83 shoots per cutting) were recorded in thick cuttings treated with 1000 ppm IBA. The comparatively low SL values in the control group (2.83 cm in thick cuttings and 4.46 cm in thin cuttings) underscore the positive effect of hormone application on shoot development. Although NS values increased in both thick and thin cuttings relative to the control (1.00 in thin and 0.67 in thick cuttings), these differences were of limited statistical significance. Overall, these results demonstrate that IBA enhances shoot formation, with the magnitude of its effect depending on both the applied dose and cutting thickness (Table 1). With respect to biomass traits, the highest FSW (14.86g) and DSW (4.00g) were observed in thick cuttings treated with 8000 ppm IBA, whereas the highest FRW (11.62g) and DRW (2.37g) occurred in thick cuttings treated with 1000 ppm IBA (Table 1).

Table 1. Rooting Success, Morphological Development, and Biomass Characteristics of *P. fraxinifolia* Stem Cuttings (Mean ± Standard Deviation

Properties	Type	Hormone (ppm)					
		Control	500	1000	2000	4000	8000
RP (%)	Thin	7.77 (±1.92)^{ab}	15.55 (±5.09)^{abc}	11.10 (±5.09)^{abc}	26.66 (±3.33)^{c}	11.10 (±1.93)^{abc}	11.10 (1.92)^{abc}
	Thick	2.22 (±1.92)^{b}	16.66 (±11.55)^{abc}	7.77 (±3.85)^{ab}	17.77 (±5.09)^{abc}	13.33 (±3.34)^{abc}	18.88 (±9.62)^{ac}
NR (piece)	Thin	8.00 (±1.73)^{ab}	7.33 (±2.89)^{ab}	9.47 (±3.23)^{ab}	18.03 (±10.78)^{ab}	13.61 (±1.64)^{ab}	16.33 (±5.35)^{ab}
	Thick	3.00 (±2.65)^{b}	9.89 (±3.47)^{ab}	22.33 (±8.50)^{a}	12.33 (±4.25)^{ab}	11.67 (±2.87)^{ab}	19.67 (±14.56)^{ab}
SD (mm)	Thin	4.94 (±0.91)^{a}	5.01 (±0.31)^{a}	5.08 (±0.19)^{a}	5.06 (±0.39)^{a}	5.32 (±0.12)^{a}	4.78 (±0.25)^{a}
	Thick	3.43 (±3.02)^{a}	6.65 (±1.55)^{a}	6.02 (0.74)^{a}	5.83 (±1.01)^{a}	5.74 (±0.19)^{a}	5.99 (±0.53)^{a}
SL (cm)	Thin	4.46 (±0.84)^{ab}	5.24 (±1.34)^{ab}	6.79 (±1.38)^{ab}	7.54 (±3.27)^{ab}	7.84 (±2.03)^{ab}	9.13 (±4.15)^{ab}
	Thick	2.83 (±2.56)^{b}	6.83 (±1.25)^{ab}	12.32 (±3.38)^{a}	7.58 (±3.68)^{ab}	10.11 (±3.68)^{ab}	12.04 (±4.34)^{a}
NS (piece)	Thin	1.00 (±0.00)^{ab}	1.39 (±0.54)^{ab}	1.37 (±0.32)^{ab}	1.22 (±0.39)^{ab}	1.25 (±0.23)^{ab}	1.58 (±0.38)^{ab}
	Thick	0.67 (±0.58)^{b}	1.07 (±0.13)^{ab}	1.83 (±0.29)^{a}	1.00 (±0.00)^{ab}	1.40 (±0.53)^{ab}	1.48 (±0.46)^{ab}
FSW (g)	Thin	5.10 (±2.78)^{ab}	3.17 (±2.10)^{b}	7.39 (±2.67)^{abc}	5.84 (+1.29)^{abc}	5.95 (±0.42)^{abc}	5.51 (±1.20)^{abc}
	Thick	3.09 (±2.74)^{b}	6.86 (±3.54)^{abc}	13.21 (±1.53)^{ac}	11.76 (±5.06)^{abc}	13.08 (±5.69)^{ac}	14.86 (±4.96)^{c}
DSW (g)	Thin	1.25 (±0.58)^{a}	1.19 (±0.56)^{a}	1.72 (±0.54)^{ab}	2.19 (±1.19)^{ab}	1.69 (±0.20)^{ab}	1.50 (±0.35)^{ab}
	Thick	0.83 (±0.73)^{a}	1.84 (0.75)^{ab}	3.28 (±0.34)^{ab}	2.79 (±1.76)^{ab}	3.18 (±0.93)^{ab}	4.00 (±1.55)^{b}
FRW (g)	Thin	3.18 (±2.06)^{ab}	1.84 (±0.85)^{a}	6.23 (±2.01)^{abde}	5.50 (±1.36)^{abe}	4.10 (±0.09)^{abe}	4.57 (±1.06)^{abe}
	Thick	1.75 (±1.51)^{a}	6.60 (±2.53)^{abcde}	11.62 (±2.00)^{c}	10.90 (±2.88)^{cd}	8.96 (±1.53)^{cde}	7.04 (±1.05)^{bcde}
DRW (g)	Thin	0.65 (±0.13)^{abc}	0.43 (±0.20)^{ac}	1.06 (±0.33)^{abce}	1.21 (±0.42)^{abce}	0.684 (±0.06)^{abc}	0.823 (±0.21)^{abce}
	Thick	0.32 (±0.28)^{c}	0.978 (±0.35)^{abce}	2.37 (±0.21)^{d}	1.74 (±0.68)^{de}	1.50 (±0.28)^{bde}	1.36 (0.25)^{abe}

The PCA results visually revealed the effects of different IBA doses on the morphological and biomass development of the cuttings. The first two components explained 65.2% of the variance. PCA showed that Dim2 accounted for 15.1%, while Dim1 accounted for 50.1% of the total variation and was directly related to biomass parameters such as FSW, FRW, DSW, and DRW (Fig. 2). In the analysis, the control group with no hormone treatment clustered in the negative direction of the Dim1 axis in PCA, while the other IBA doses were located more centrally. This indicates that there were significant changes in the development of the cuttings as the IBA dose increased. However, the group with IBA 8000 ppm was significantly separated from the other doses, suggesting a phytotoxic effect (Fig. 2). This supports the findings that high doses of IBA may adversely affect rooting success and lead to developmental retardation.

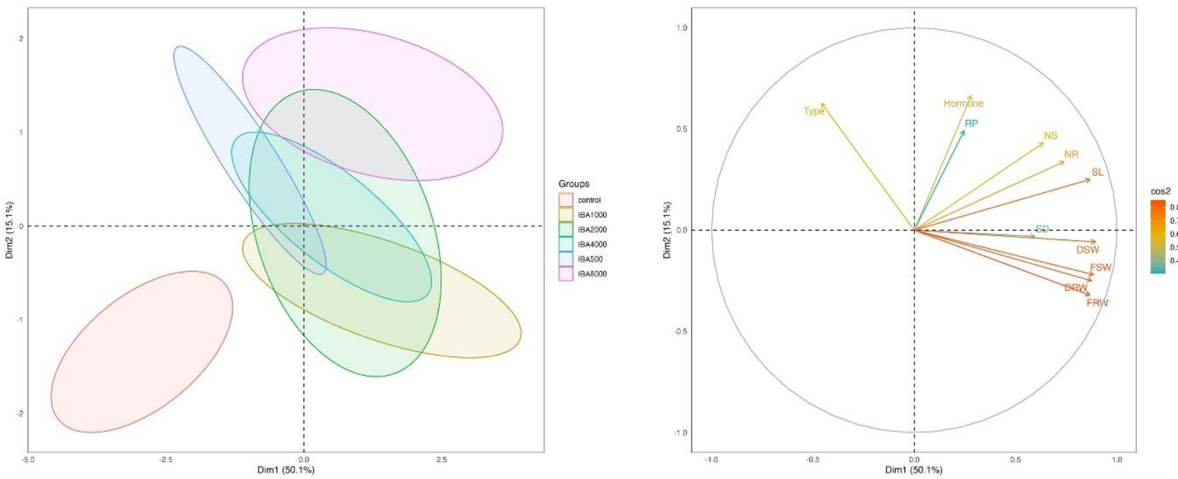

Fig. 2. Principal component analysis of different IBA concentrations on morphological and biomass development of *P. fraxinifolia* cuttings: Cos2 = positive or negative correlation relationships, Dim1 and Dim2 = represent the dimensions in which the relationships are most significant. The first two axes explained 65.2% of the data variance (Dim1= 50.1% and Dim2= 15.1%).

DISCUSSION

The present study demonstrated that the interaction between IBA concentration and cutting thickness plays a crucial role in the vegetative development of *P. fraxinifolia* hardwood cuttings, particularly in terms of rooting success, morphological traits, and biomass development. The findings revealed that both hormone concentrations and cutting types resulted in statistically significant differences in the rooting and growth processes. Specifically, the application of 2000 ppm IBA yielded the highest rooting percentage (26.66%) in thin cuttings, while the 1000 ppm dose positively influenced certain morphological parameters in thick cuttings. The findings indicate that the responsiveness of cuttings to hormone treatments is contingent on their thickness, suggesting that the optimal hormone dosage may vary according to the type of cutting.

The stimulatory effect of auxins on root formation in cuttings may vary due to physiological, biological, and anatomical differences among species (Hartmann *et al*. 2011). Furthermore, auxins can enhance root activation, thereby accelerating adventitious root formation randomly and leading to significant improvements in rooting success (Ercisli *et al*. 2003; Siddiqui and Hussain 2007; Kochhar *et al*. 2008; Peticilă *et al*. 2016; Sekhukhune and Maila 2024; da Silva Sousa *et al*. 2024). In this study, the highest rooting percentage (26.66%) was recorded in thin cuttings treated with 2000 ppm IBA. This result indicates that a moderate dose of IBA promotes adventitious root formation, with particularly fine diameter cuttings demonstrating a high degree of sensitivity to this dose. Furthermore, the observation that the RP value in the control group was considerably low indicates that the application of auxin is a decisive factor in determining the success of rooting. However, despite the use of IBA, the overall maximum rooting rate remained relatively low. One possible explanation for this outcome may relate to the greenhouse temperature conditions during the experiment, which were maintained at an average of 18-22 °C. Because environmental temperature plays a crucial role in cellular metabolism, hormone transport, and energy allocation during root initiation (Pacurar *et al.* 2014; Kunc *et al.* 2024). Therefore, the relatively cool conditions may have slowed physiological processes, leading to reduced rooting efficiency. The highest mean NR (22.33 roots per cutting) was observed in thick cuttings treated with 1000 ppm IBA. This suggests that thicker cuttings may have more root forming capacity at certain doses. However, in general, it is observed that both thick and thin cuttings in the IBA-treated groups reached higher root number compared to the control group.

Various studies have reported that the use of auxins in cuttings of different plant species has resulted in beneficial and successful developments in root formation (Negash 2002; Amri *et al*. 2010). However, in some plant species, auxin application may not promote rooting (Titon *et al*. 2003; Wendling and Xavier 2005; Ghimire *et al*. 2022). These species tend to root naturally without the need for exogenous auxins and exhibit high levels of endogenous free auxins (Menezes *et al*. 2018; Nunes Gomes and Krinski 2019; Nascimento *et al*. 2020). The results of this study indicate that auxin application had a significant positive effect on RP and NR, although this effect varied depending on the hormone concentration and cutting thickness. This finding is also consistent with the hypotheses previously proposed in this work. It supports the notion that optimal hormone concentrations can enhance rooting success, while excessively high doses may reduce or inhibit this effect (Alcantara *et al*. 2010; Sauer *et al*. 2013). Auxins are known to be important for the release of energy and the movement of proteins required for cell division in root primordia (Husen and Pal 2007). Moreover, exogenous auxins enhance the function of sugars as the primary carbon source for energy production during cell division, thereby stimulating root formation at the site of root initiation (Altman and Wareing 1975; Hassig *et al*. 1986; Agullo-Anton *et al*. 2011). Hartmann *et al*. (2011) reported that exogenous auxins activate vascular cambium cells, thereby supporting both root formation and shoot development. Moreover, it has been reported in a different study that more biomass is obtained when auxins provide sufficient amount of nutrients and water for plant growth (Sankhyan *et al*. 2003). Many researchers have succeeded in enhancing root formation using auxin application in vegetative propagation of plants. However, according to these studies, the mechanisms supporting root formation and development may differ (Altman and Wareing 1975; Hassig *et al*. 1986; Mesen *et al*. 1997; Agullo-Anton *et al*. 2011). The results of the present work show that exogenous IBA has a positive effect on the rooting and development of *P. fraxinifolia* cuttings.

Exogenous auxin applications have been reported to positively influence not only root development but also shoot growth (Kochhar *et al*. 2008; Ghimire *et al*. 2022). Similarly, in the present study, IBA treatments were observed to have significant effects on the shoot development of the cuttings. The highest values for SL (12.32 cm) and NS (1.83 shoots per cutting) were recorded in thick cuttings treated with 1000 ppm IBA. This finding reveals that, as in the rooting process, the effect of hormone application on shoot development also varies depending on both the application dose and the cutting thickness. These results also support the hypothesis mentioned at the beginning of the study that "IBA applications can provide optimum vegetative production conditions by positively affecting morphological parameters".

Similar to the study conducted by Kochhar *et al*. (2008), in the observations after planting the cuttings, it was determined that the shoots developed before the roots. In many samples, the cuttings did not root yet despite forming shoots. This situation shows that the balance between carbohydrate reserves and auxin levels plays an important role in determining the rooting ability of the cuttings (Nanda and Kochhar 1985).

The spare carbohydrates present in the cuttings initially support the shoot formation; with the development of the shoots, endogenous auxin synthesis increases and these hormones are transported to the lower parts of the cuttings and trigger the physiological signals that initiate the rooting process (Kochhar *et al*. 2008). However, the rapid and healthy development of the shoots may lead to a decrease in the rooting rate because the plant directs most of its limited energy reserves to shoot development. A similar situation was identified in this study: the highest RP (26.66%) was achieved at 2000 ppm IBA, whereas the highest values for shoot-related parameters, such as SL (12.32 cm) and NS (1.83 shoots per cutting), were recorded at 1000 ppm IBA. This difference is thought to result from a greater allocation of energy and resources to shoot development in the 1000 ppm IBA treatment group (Baş *et al*. 2024). Therefore, the direction and intensity of physiological responses of cuttings to hormone doses should be carefully evaluated in terms of both morphological development and rooting success.

The biomass data obtained in the present work revealed that, in general, the shoot biomass was higher than the root biomass. This indicates that endogenous hormones in *P. fraxinifolia* cuttings support shoot development more prominently than root development. Similarly, Azad *et al*. (2016) also reported in their studies on various species that the effects of endogenous growth hormones on shoot development were more dominant compared to root development. The enhancement of shoot and root dry weights by exogenous auxins has also been supported by previous studies (Anuradha *et al*. 1993; Zheng *et al*. 2020; Ghimire *et al*. 2022).

In alignment with these findings, the present work determined that the exogenous application of IBA positively influenced biomass accumulation, as evidenced by increased FSW, DSW, and FRW, DRW compared to the control. The highest FSW (14.86 g) and DSW (4.00 g) values were obtained at 8000 ppm IBA, whereas the FRW (11.62 g) and DRW (2.37 g) values were observed at 1000 ppm IBA. This increase in root biomass may be associated with the high NR recorded at the same dose (Alam *et al*. 2007). Although some studies have reported that high concentrations of auxins can enhance DRW (Alam *et al*. 2007; El-Banna *et al*. 2023; Sekhukhune and Maila, 2024), in the present work, this effect was more pronounced in FSW and DSW.

Despite the increases observed at 8000 ppm, the decline in root development parameters may indicate a potential phytotoxic effect of high IBA concentrations. This supports the third hypothesis proposed in the present work: that high concentrations of IBA may cause developmental imbalances in plants by suppressing certain morphological parameters (Baul *et al*. 2010; Azad *et al*. 2016; Zheng *et al*. 2020). These findings are also supported by multivariate statistical analyses. The PCA clearly demonstrated the effects of IBA doses on the overall development of the cuttings. In the PCA plot, the groups treated with 1000 ppm and 2000 ppm IBA were positioned centrally, indicating homogeneous and balanced growth. This suggests that these doses provided optimal effects in terms of both shoot and root developments. In contrast, the cuttings treated with 8000 ppm IBA were located in an extreme area of the PCA space, separating them from the other groups. This separation indicates that, although high-dose IBA led to increases in certain growth parameters (*e.g.*, FSW and DSW), it negatively affected root development and resulted in unbalanced growth in terms of overall plant integrity. Thus, the PCA results confirm the potential phytotoxic effect of high-dose IBA and its suppressive role in morphological development.

CONCLUSIONS

This study is the first to reveal the effects of different indole-3-butyric acid (IBA) concentrations on rooting success, morphological development, and biomass formation in hardwood cuttings of *Pterocarya fraxinifolia*, and to evaluate the species' vegetative propagation potential.

1. The findings demonstrated that exogenous auxin concentration is necessary for effective root formation and development in *P. fraxinifolia* cuttings. Especially 1000 ppm and 2000 ppm doses give the most widespread and effective results in terms of both rooting rate and morphological and biomass characters. In contrast, although high-dose treatments (especially 8000 ppm) positively influenced some shoot traits, they were found to suppress root development and lead to imbalances in overall plant integrity.
2. The results emphasize the need for careful selection of IBA doses in applications for sustainable seedling production and conservation of *P. fraxinifolia*; they also reveal that exogenous hormone applications can significantly increase vegetative propagation success when used at appropriate levels.
3. Moreover, the use of these doses in applications such as sustainable seedling cultivation and riparian ecosystem restoration may contribute both to the conservation of the species and to increased production efficiency. In general, considering that the rooting capacity of the species is low, it can be recommended that future widths, different hormone options be tried, and the effects of cutting time and ambient temperatures be evaluated in detail.

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Declaration of Competing Interest

The authors have no conflict of interest to declare for this article.

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Data Availability Statement

The data that has been used is confidential.

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