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RESEARCH ARTICLE

Effects of Different Auxin Concentrations on Growth of Autumn Olive (*Elaeagnus umbellata* Thunb.) Saplings

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ABSTRACT

Autumn olive (*Elaeagnus umbellata* Thunb.) is a versatile plant used for numerous purposes in nature, distinguished by its medicinal and ecological benefits. Its ability to adapt and grow in challenging environmental conditions, improve soil, and survive with minimal water makes it a critical species, particularly in combating climate change. While this highly important plant can be propagated from seed, studies on its vegetative propagation are limited. The success of vegetative propagation is not solely a dependent on obtaining rooted cuttings; it depends on the production of high-quality saplings from these cuttings. Therefore, data on the effects of saplings grown from rooted cuttings on long-term growth performance are important to demonstrate the success of the application. This study was conducted to determine the optimal Indole-3-Butyric Acid (IBA) concentration for the growth of surviving individuals obtained from rooted cuttings at different time intervals (June 19, 2023, and December 8, 2023) over a period of one and a half years. For this purpose, the effects of different concentrations of Indole-3-Butyric Acid [IBA (1000 ppm, 5000 ppm, and 8000 ppm)] on the root collar diameter and sapling height in *Elaeagnus umbellata* saplings propagated from cuttings were investigated. A control group was also created without hormone application. It was found that IBA application improved the growth of *E. umbellata* saplings, but the first year of measurements were not sufficient to assess growth performance. Among the hormone concentrations tested over the long term, a dose of 5000 ppm IBA was found to be more effective on growth ($p<0.05$). The success of vegetative propagation depends on obtaining high-quality saplings that meet the desired standards. Therefore, to achieve long-term results, the rooting and sapling production processes must be considered.

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1. Introduction

Autumn olive (*Elaeagnus umbellata* Thunb.) is a member of the Elaeagnaceae family and grows native in Pakistan, China, India, Korea, and Japan. *E. umbellata* is commonly known as autumn olive and Japanese silverberry (Gamba et al., 2020). *E. umbellata* is a deciduous spiny branched shrub or small tree of about 3.5-5.5 m height and a diameter of 10 cm with clusters of elliptic, oblong, ovate, and alternate leaves (Ahmad et al., 2005, 2006; Chauhan et al., 2023). It is generally distributed at elevations of 1200–2100 m and grows at temperatures ranging from 43 to 55 °C (Ahmad & Kamal, 2002; Ahmad et al., 2006; Bhat et al., 2023) and a pH range of 5.5-9.5 (Ahmad et al., 2005). *E. umbellata,* which is very well adapted to arid conditions, prefers full sunlight and is capable of growing in saline, clay, and sandy soils. It grows very quickly and quickly covers the area where it is planted (Çelik & Çil,

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2021). Its bright red or yellow edible fruits are extremely rich in antioxidants, carotenoids, lycopene and many other carotenoids (Fordham et al., 2001, 2002; Ghellam et al., 2021). These berries contain 17 times more lycopene than tomatoes. Lycopene has been linked to the prevention of some chronic diseases, including prostate cancer (Nazir et al., 2025; Üreyen Esertaş & Cora, 2024). Therefore*, E. umbellata* berries play a beneficial role in protecting human health and reducing the risk of many diseases (Bhat et al., 2023; Fordham et al., 2001; Ghellam et al., 2021). These miraculous berries have great industrial potential because they can be used and processed in the food industry (Khattak, 2012), as well as in the pharmaceutical and cosmetic industries. The autumn olive is found wild or cultivated as an ornamental plant due to its dense branching, fragrant blossoms, pointed, long-elliptical leaves, and short stems (Petrescu & Paraschiv, 2022). It is used as a hedge in urban areas due to its ornamental value, drought tolerance, adaptability to different environments, and compact structure (Patel, 2015). It is also a suitable plant for open areas in forests, garden edges, and grass areas. Autumn olive is valuable for shelter and nesting, and its protein-rich berries provide a continuous food source for wildlife (Kohri et al., 2011; Munger, 2003). Root nodules on autumn olives are infected by an endophyte that maintains a symbiotic relationship with the roots and helps provide nitrogen or nutrients to the plant (Graham, 1964; Kim et al., 1993). Thanks to its nitrogen-fixing ability, it can grow in eroded and degraded soils and is used for the stabilization of these areas (Ahmad et al., 2005; Torrey, 1978). Because its root nodules contain nitrogen-fixing actinomycetes, it grows well even in infertile soils. This symbiosis allows for the fixation and subsequent utilization of atmospheric nitrogen (Clark & Hemery, 2006; Malinich et al., 2017; Torrey, 1978). Thanks to its nitrogen-fixing ability and its ability to withstand drought, diseases, and infertile soils, the autumn olives are widely planted in degraded lands, arid regions and along highways to prevent soil erosion (Fordham et al., 2002). These characteristics, which can be considered important against global climate change, are one of the most important problems of our time, further increasing the importance of this species. The autumn olive is also used in the reclamation of mining sites. Therefore, its exceptional resistance to adverse conditions and its ability to grow even in adverse conditions are crucial for the improvement of these areas (Fowler & Adkisson, 1980). Autumn olive, which stands out with its multifaceted benefits, is a new and alternative species for Türkiye and has not been adequately studied. *E. umbellata* is generally propagated by seed, with limited vegetative propagation. Few studies have been conducted on the propagation of *E. umbellata* by cuttings, with most studies focusing on seed production (Ciccarese & Jinks, 1997; Eckardt & Sather, 1987; Fowler & Fowler, 1987; Olson & Barbour, 2004).

Cutting propagation, one of the vegetative propagation methods, is one of the most important propagation methods for evergreen broad-leaved and coniferous plant species, as well as deciduous fruit and shrub species (Kantar, 2017). The most important advantages of cutting propagation are that it enables the production of a large number of genetically superior plants in a short time and that it is a low cost, fast and simple method (Çorbacı et al., 2023; İzgi, 2020; Yang et al., 2021). Plant growth regulators are of great importance in cutting propagation. Auxins are plant hormones that have a positive effect on root formation and cutting quality, particularly in cutting propagation (Blythe et al., 2007; Taiz & Zeiger, 2013; Tien et al., 2020). Auxins are primarily used to increase plant production by improving rooting percentages and can also improve plant quality parameters such as adventitious root number root system symmetry, and root/shoot ratio (Bryant & Trueman, 2015; Hunt et al., 2011). These parameters have significant effects on tree stability, tree survival, and trunk volume in the nursery and plantation. For example, raising the number of adventitious roots from one to five increases nursery survival by 11% (Goldfarb et al., 1998), tree height after two years by 23% (Haines et al., 1992), and trunk diameter after five years by 12% (Foster et al., 2000) in various *Pinus* species. Therefore, the application of plant growth regulators can stimulate both root and shoot development, supporting faster and stronger sapling formation in the nursery and field at later stages (Hartmann et al., 2011; Neto et al., 2024). Therefore, their role in almost all growth and development processes and in obtaining healthier saplings in the following years is quite important (Batista-Silva et al., 2024; Pulatkan & Kaya Şahin, 2022; Yan et al., 2017). Indole-3-butyric acid is one of the auxins commonly used for root stimulation (Hartmann et al., 1997; Ludwig-Müller, 2000). Indole-3-butyric acid is preferred due to its ability to initiate root formation, its stability, and its non-toxic to plants over a wide concentration range. However, studies on its effects on the growth and development of saplings produced from cuttings are insufficient. This study was conducted to determine the appropriate IBA concentration for the growth of surviving plants from rooted cuttings obtained with different hormone concentrations.

2. Materials and Methods

Hardwood cuttings taken from the last annual shoots of an only individual located on the Kanuni Campus of Karadeniz Technical University were used as material in the study. Cutting preparation took place in February 2022 in a sterile environment reserved for production at The Research and Application Greenhouse at Faculty of Forestry, Karadeniz Technical University (Figure 1a). To reduce water loss from the leaves during the rooting process, the lower 4-5 cm leaves of the cuttings were cut. A total of 200 cuttings, 50 for each group, were prepared at 15 cm in length and planted 3-4 cm apart, with their leaves touching each other (Figure 1b). Cuttings were treated with three different hormone dose concentrations of powder IBA (1000 ppm, 5000 ppm, and 8000 ppm) for 5 seconds, was planted in 100% perlite, a medium with high water retention and aeration capacity. A control group without hormone application was also created and planted in the same environment (Figure 1c). During the rooting period, the cuttings were watered regularly and the conditions inside the greenhouse were made suitable. The greenhouse temperature was kept constant at 25±1°C and humidity at 60-70%. Callus and root formation on cuttings were observed daily starting from four weeks. Towards the end of May, the cuttings were carefully removed, and rooting, survival rates, and health status were recorded (Figure 1d). Rooted cuttings obtained by vegetative propagation were planted in polyethylene bags (12 cm x 23 cm) consisting of a mixture of River Sand + Forest Soil + Red Soil (1:2:2) (Figure 1e). The root collar diameter (mm) and height of the saplings (cm) grown in open fields were measured at different time intervals (June 19, 2023, and December 8, 2023) and their growth were recorded (Figure 1f, g).

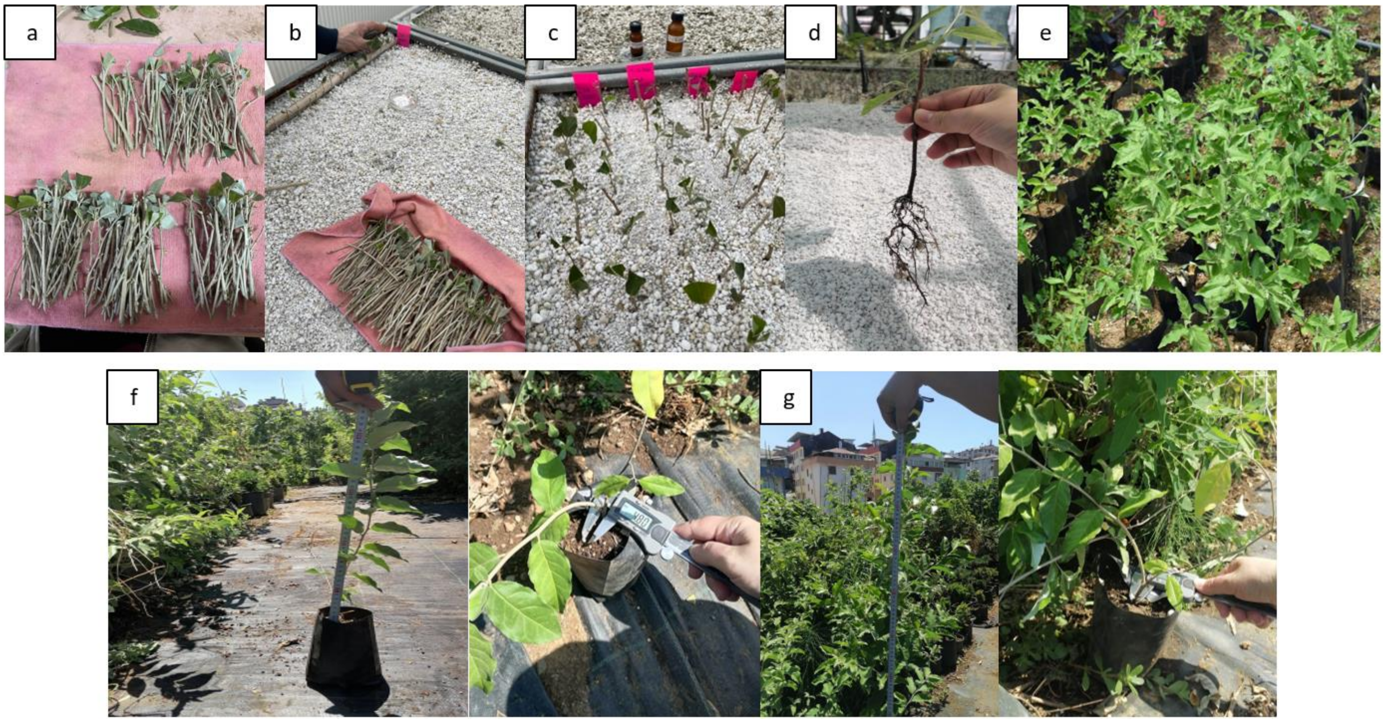

Figure 1. Hardwood cuttings of autumn olive (a), preparation (b), planting in perlite (c), observation of rooting data (d), planting of rooted cuttings in polyethylene bags in the open field (e), carrying out the first measurements on June 19, 2023 (f), carrying out the second measurements on December 8, 2023 (g).

2.1. Statistical Analysis

The IBM SPSS Statistics 23.0 statistical program was used to analyze the data. One-way analysis of variance was applied to determine the effects of hormone treatments on sapling growth, and homogeneous groups were identified using the Duncan test. Graphs were also generated for the results, and evaluations were made accordingly.

3. Results and Discussion

The effects of different IBA doses on the growth of *E. umbellata* saplings produced from cuttings were investigated. It was revealed that different hormone concentrations did not create a statistically significant difference in root length and root number measurements taken after the first rooting ($p>0.05$). However, measurements after transplanting revealed that different hormone concentrations produced statistically significant differences in root collar diameter and sapling height distributions.

The Kolmogorov-Smirnov test was used to test the normal distribution of root collar diameter and sapling height values from the measurements dated June 19, 2023. Accordingly, the data for both values were normally distributed ($p>0.05$) (Table 1). Whether the root collar diameter and sapling height showed a normal distribution as a result of hormone application was also evaluated with the box plot (Figure 2 and Figure 3).

Table 1. Normal distribution test of root collar diameter and sapling height measurements on June 19, 2023.

	Hormone	Kolmogorov-Smirnov[a]		
		Statistic	**df**	**Sig.**
Root collar diameter	Control	0.138	23	0.200*
	IBA 1000	0.129	23	0.200*
	IBA 5000	0.084	36	0.200*
	IBA 8000	0.112	27	0.200*
Sapling height	Control	0.115	23	0.200*
	IBA 1000	0.093	23	0.200*
	IBA 5000	0.131	36	0.125
	IBA 8000	0.090	27	0.200*

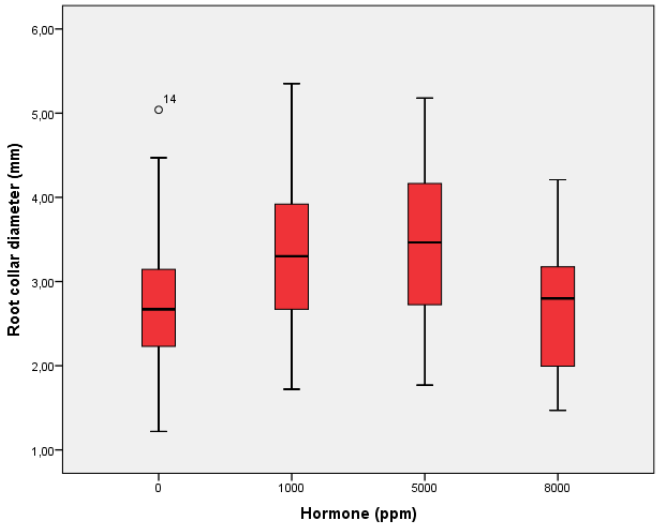

Figure 2. Box plot distribution of root collar diameter.

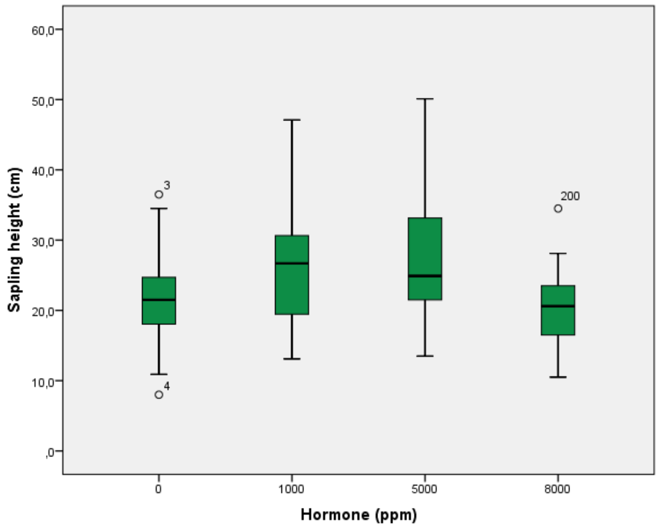

Figure 3. Box plot distribution of sapling height.

An examination of the box plot of the root collar diameter values reveals a normal distribution. However, one data appears to be extremely high in the control group's distribution. This data is considered negligible. On the other hand, the data show a statistically normal distribution, and the most ideal distribution in this distribution is shown by the data with the 5000 ppm IBA hormone.

An examination of the box plot of the sapling height values reveals a normal distribution. However, one data appears to be extremely high and one data appears to be extremely low in the control group's distribution. Similarly, one data appears to be extremely high in the distribution of the 8000 ppm IBA hormone group. This data point is considered negligible. On the other hand, the data show a statistically normal distribution, and the most ideal distribution in this distribution is shown by the data with the control group.

When variance analysis was applied to the root collar diameter and height measurements of *E. umbellata* saplings different hormone doses dated June 19, 2023, it was revealed that they showed statistically significant relationships ($p<0.05$) (Table 2).

Table 2. Analysis of variance (ANOVA) results for the effects of three different concentrations of IBA hormone (1000 ppm, 5000 ppm, and 8000 ppm) on root collar diameter and sapling height in *Elaeagnus umbellata* saplings on June 19, 2023.

		ANOVA				
		Sum of Squares	**df**	**Mean Square**	**F**	**Sig.**
Root collar diameter	Between Groups	13.18	3	4.39	5.39	0.002
	Within Groups	86.41	105	0.82		
	Total	99.59	108			
Sapling height	Between Groups	933.56	3	311.19	5.56	0.001
	Within Groups	5881.49	105	56.01		
	Total	6815.05	108			

Due to the statistical differences found between the hormone doses as a result of the analysis, the Duncan test was applied, resulting in homogeneous groups. Two distinct groups were formed based on the Duncan test results. The control and IBA 8000 ppm hormone doses were grouped in one group for root collar diameter and sapling height growth, while the IBA 1000 ppm and IBA 5000 ppm hormone doses were grouped in the other group (Table 3 and Table 4). Accordingly, there was no difference between the control and IBA 8000 ppm hormone doses in root collar diameter and sapling height growth. The IBA 1000 and IBA 5000 hormones showed better growth compared to these applications, but there was no statistical difference between the two.

Table 3. Duncan test results for IBA (1000 ppm, 5000 ppm, and 8000 ppm) hormone doses differing in root collar diameter.

Root Collar Diameter			
Duncan^{a,b}			
Hormone	N	Subset for alpha = 0.05	
		1	2
IBA 8000	27	2.67	
Control	23	2.79	
IBA 1000	23		3.37
IBA 5000	36		3.44
Sig.		0.640	0.775

Means for groups in homogeneous subsets are displayed.
a. Uses Harmonic Mean Sample Size = 26.355.
b. The group sizes are unequal. The harmonic mean of the group sizes is used. Type I error levels are not guaranteed.

Table 4. Duncan Test results for IBA (1000 ppm, 5000 ppm, and 8000 ppm) hormone doses differing in sapling height.

Sapling Height			
Duncan^{a,b}			
Hormone	N	Subset for alpha = 0.05	
		1	2
IBA 8000	27	20.49	
Control	23	21.72	
IBA 1000	23		26.14
IBA 5000	36		27.25
Sig.		0.554	0.592

Means for groups in homogeneous subsets are displayed.
a. Uses Harmonic Mean Sample Size = 26.355.
b. The group sizes are unequal. The harmonic mean of the group sizes is used. Type I error levels are not guaranteed.

In measurements taken during the first year (June 19, 2023), the highest average root collar diameter (3.44 mm) and sapling height (27.25 cm) were achieved with the 5000 ppm IBA hormone dose. However, there was no statistical difference between the root collar diameter (3.37 mm) and height (26.14 cm) values obtained with the 1000 ppm hormone dose. The 8000 ppm IBA treatment and the no-hormone control group did not produce a significant difference in the growth of *E. umbellata* saplings, and the saplings exhibited lower root collar diameter and height (Table 3 and Table 4). The differences in root collar diameter and height caused by different hormone concentrations are clearly evident in Figure 4 and Figure 5. With the increase in hormone dose (IBA 8000 ppm), root collar diameter and height growth showed a low growth and there was no difference with the control application without hormone application, which also reveals that the increase in hormone dose has an inhibitory effect on growth.

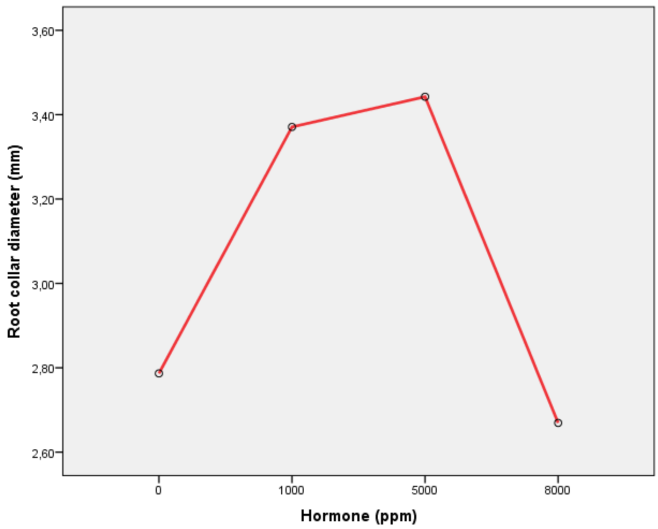

Figure 4. Effect of different hormone concentrations on root collar diameter in measurements conducted on June 19, 2023.

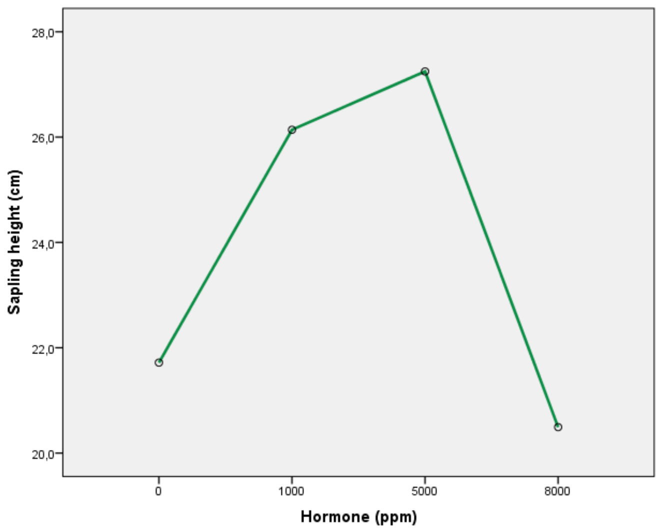

Figure 5. Effect of different hormone concentrations on sapling height in measurements conducted on June 19, 2023.

In measurements taken on December 8, 2023, root collar diameter was not normally distributed only for the control group ($p<0.05$), while height distribution was not normally distributed only for the IBA 8000 hormone dose ($p<0.05$) (Table 5). The box plot distribution of root collar diameter and sapling height as a result of hormone application is shown in Figure 6 and Figure 7.

Table 5. Normal distribution test of root collar diameter and sapling height measurements on December 8, 2023.

	Hormone	Kolmogorov-Smirnov[a]		
		Statistic	df	Sig.
Root collar diameter	**Control**	0.181	23	0.050
	IBA 1000	0.140	23	0.200*
	IBA 5000	0.105	35	0.200*
	IBA 8000	0.146	25	0.176
Sapling height	**Control**	0.171	23	0.079
	IBA 1000	0.140	23	0.200*
	IBA 5000	0.099	35	0.200*
	IBA 8000	0.213	25	0.005

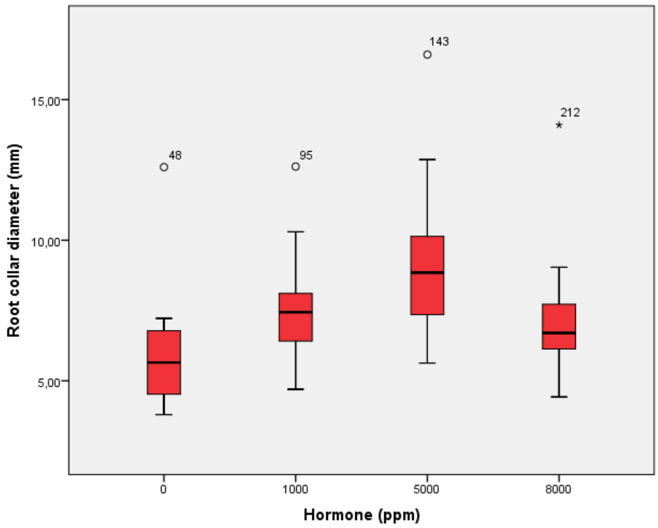

Figure 6. Box plot distribution of root collar diameter.

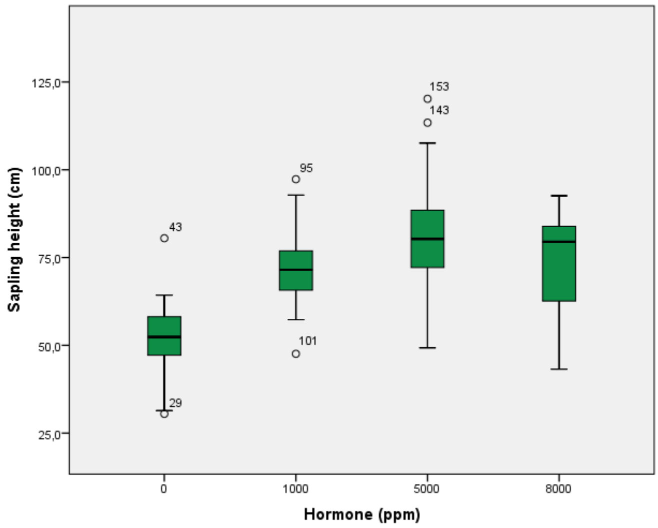

Figure 7. Box plot distribution of sapling height.

Examination of the box plot of the root collar diameter values reveals that the data are normally distributed. However, one data appears to be extremely high in the distribution of all groups. This data is considered negligible. On the other hand, the data are statistically normally distributed, and the most ideal distribution is shown in the data with 8000 ppm IBA hormone.

Examination of the box plot of the sapling height values reveals that the data are normally distributed. However, several data appear to be extremely high and two data appear to be extremely low. This data point is considered negligible. On the other hand, the data are statistically normally distributed, and the most ideal distribution is shown in the data with 1000 ppm IBA and 5000 ppm IBA groups.

When variance analysis was applied to the root collar diameter and sapling height measurements of *E. umbellata* saplings of different hormone doses dated December 8, 2023, it was revealed that they showed statistically significant relationships ($p<0.05$) (Table 6).

Table 6. Analysis of variance (ANOVA) results for the effects of three different concentrations of IBA hormone (1000 ppm, 5000 ppm, and 8000 ppm) on root collar diameter and sapling height in *Elaeagnus umbellata* saplings on December 8, 2023.

ANOVA						
		Sum of Squares	**df**	**Mean Square**	**F**	**Sig.**
Root collar diameter	Between Groups	147.96	3	49.32	11.72	0.000
	Within Groups	429.38	102	4.21		
	Total	577.34	105			
Sapling height	Between Groups	12328.08	3	4109.36	21.27	0.000
	Within Groups	19702.51	102	193.16		
	Total	32030.59	105			

Due to the statistical differences found between the hormone doses as a result of the analysis, the Duncan test was applied, resulting in homogeneous groups. Three different groups were formed based on the results of the Duncan test. The most effective hormone on both root collar diameter and height growth was the 5000 ppm IBA concentration, which constitutes a single group. The hormone doses of 1000 ppm and 8000 ppm IBA formed the same group for root collar diameter and sapling height growth. The lowest root collar diameter and height growth occurred in control cuttings without hormone treatment, which constituted a single group (Table 7 and Table 8).

Table 7. Duncan test results for IBA (1000 ppm, 5000 ppm, and 8000 ppm) hormone doses differing in root collar diameter.

Root Collar Diameter				
		Duncan[a,b]		
Hormone	N	Subset for alpha = 0.05		
		1	2	3
Control	23	5.82		
IBA 8000	25		6.97	
IBA 1000	23		7.51	
IBA 5000	35			8.97
Sig.		1.000	0.344	1.000

Means for groups in homogeneous subsets are displayed.
a. Uses Harmonic Mean Sample Size = 25.719.
b. The group sizes are unequal. The harmonic mean of the group sizes is used. Type I error levels are not guaranteed.

Table 8. Duncan Test results for IBA (1000 ppm, 5000 ppm, and 8000 ppm) hormone doses differing in sapling height.

Sapling Height				
		Duncan[a,b]		
Hormone	N	Subset for alpha = 0.05		
		1	2	3
Control	23	51.89		
IBA 1000	23		71.92	
IBA 8000	25		73.06	
IBA 5000	35			81.42
Sig.		1.000	0.768	1.000

Means for groups in homogeneous subsets are displayed.
a. Uses Harmonic Mean Sample Size = 25.719.
b. The group sizes are unequal. The harmonic mean of the group sizes is used. Type I error levels are not guaranteed.

In the second measurements made on December 8, 2023, the highest root collar diameter (8.97 mm) and sapling (81.42 cm) were obtained at the IBA 5000 ppm hormone dose. The lowest root collar diameter (5.82 mm) and height (51.89 cm) of *E. umbellata* saplings were observed in the control group, which received no growth hormone treatment. No significant difference was found in root collar diameter and height between the IBA 1000 (7.51 mm and 71.92 cm) and IBA 8000 ppm (6.97 mm and 73.06 cm) hormone doses (Table 7, Table 8). The differences in root collar diameter and height growth caused by different hormone concentrations are clearly evident in Figure 8 and Figure 9. All hormone doses significantly increased the growth characteristics of the saplings compared to the control group.

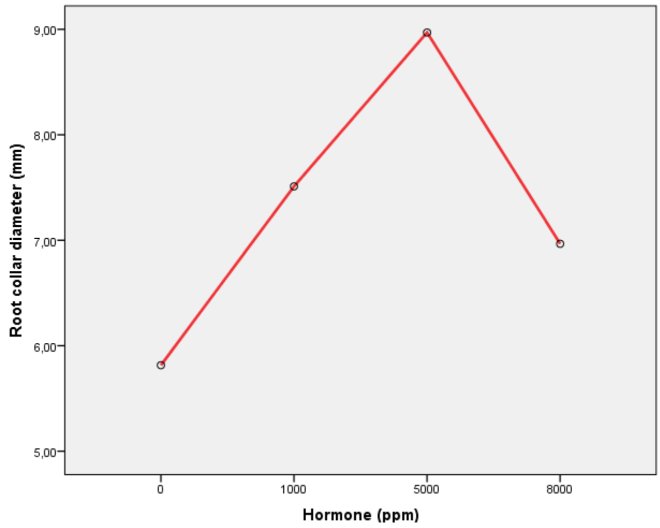

Figure 8. Effect of different hormone concentrations on root collar diameter in measurements conducted on December 8, 2023.

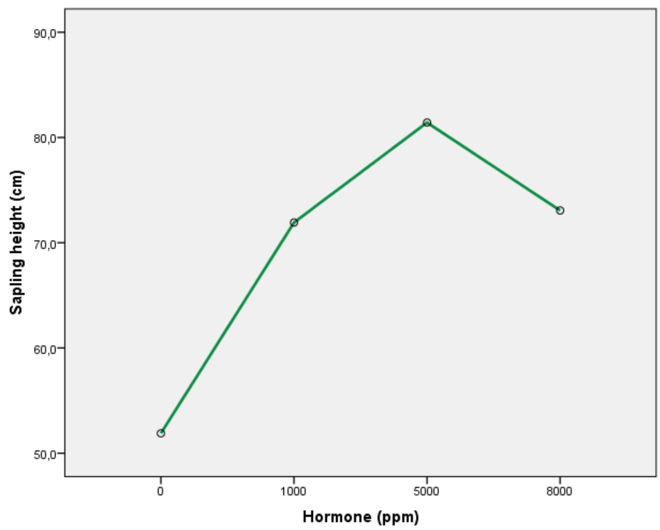

Figure 9. Effect of different hormone concentrations on sapling height in measurements conducted on December 8, 2023.

Based on these findings, when measurements taken at two different time intervals were evaluated together, it was revealed that IBA concentrations of 5000 ppm and 1000 ppm provided the highest sapling growth in the first measurement (June 19, 2023), and a concentration of 5000 ppm in the second measurement (December 8, 2023) resulted in the highest sapling growth. However, the best root collar diameter and height growth were achieved with a 5000 ppm IBA concentration in the second measurement after 1.5 years. Therefore, while expressing the effects of hormone concentrations on autumn olive cutting propagation, the importance of determining their long-term effects on sapling growth is better understood for obtaining accurate results.

While studies have extensively investigated the effects of different hormone concentrations on rooting and sapling quality of cuttings (Chen et al., 2023; Cüce, 2024; Çetin, 2024; Gerçekcioğlu & Aslan, 2021; İzgi, 2020; Khan et al. 2020), data on the long-term growth performance of saplings grown from these cuttings are limited. Furthermore, studies on the effects of different hormone concentrations on the rooting of cuttings of *E. umbellata*, a new and alternative plant in Türkiye, are also limited. The growth and development of saplings after planting in open fields is the most critical and long-term phase of a successful cuttings production process. Hormonal treatments directly support the production of high-quality saplings and indirectly improve the field performance of cuttings during this phase (Carlson, 1986; South et al., 1985; Wakeley, 1969). At the same time, during this phase, saplings leave the controlled environment and are exposed to natural environmental conditions. Therefore, long-term and regular monitoring of the growth of species will improve the process of producing healthy and high-quality saplings.

In this study, measurements made on *E. umbellata* saplings at different time intervals revealed that 1000 ppm and 5000 ppm IBA applications increased growth characteristics compared to the control. Auxin helps the plant establish a strong root system, which in turn affects sapling characteristics. Studies have shown that IBA, in particular, increases the rooting ability of cuttings. Correspondingly, it has been reported to increase survival, sapling development, and the formation of high-quality saplings. It accelerates both biomass growth and morphological development by increasing the sapling's water and nutrient uptake capacity. Good root development also may provide an increase in photosynthetic activity and other activities performed on leaves (Tien et al., 2020; Wahab et al., 2001). As a result, saplings obtained from rooted cuttings treated with hormones become more vigorous, more resilient, and more productive in terms of growth. This is also supported by the results obtained in Chandramouli (2001) study on *Bursera penicillata* cuttings, reported that increasing IBA concentration also increased sapling height and leaf number. Khan et al. (2020) demonstrated that the optimum concentration for better rooting and survival of saplings derived from kiwi (*Actinidia deliciosa*) cuttings was achieved with a dose of 3000 ppm IBA. Jan et al. (2015) reported that IBA significantly improved the survival rate of different olive cuttings, with the lowest survival rate was recorded in the control. Appropriate IBA concentrations have been reported to provide better rooting, sprouting, and survival rates in many different plant species (Henrique et al., 2006; Husen et al., 2017; Shahzad et al., 2019). Bayraktar et al. (2018a) investigated the rooting characteristics of hardwood cuttings of autumn olive (*Elaeagnus umbellata*). The highest rooting percentage (70%) was achieved with 5000 ppm IBA and 5000 ppm NAA, while the lowest rooting percentage (33.33%) was achieved in the control group. Cuttings treated with 5000 ppm IBA were reported to produce longer roots and a higher root number compared to other treatments. Bayraktar et al. (2018b) studied the effects of different hormones and their doses (IBA 1000 ppm, IBA 5000 ppm, NAA 1000 ppm, and NAA 5000 ppm) on softwood cuttings of autumn olive, along with the effects of different growing environments. The results showed that the highest rooting percentage occurred as 100% in IBA 1000 ppm treatment in perlite rooting media. In a study conducted by Çelik and Çil (2021) investigating the effects of different hormone concentrations and cutting collecting time on the rooting of *E. umbellata* cuttings, the best rooting rate (97.33%) was achieved with applications of 1000 or 2000 ppm IBA in May and 500 ppm in July. The best root length (11.90 cm) was obtained with May cuttings containing 500 ppm IBA; the highest salable saplings rate (89.30%) was achieved with the 1000 ppm IBA treatment in May. However, the rooting rate (48%) was lowest in control cuttings taken in March. In another study investigating the effects of cutting collecting time and different IBA concentrations on the propagation of *Elaeagnus umbellata* by cuttings, in IBA treatments alone, the following were observed: the highest rooting rate (84.89%) was obtained from autumn olive cuttings treated with 500 ppm IBA, and the lowest rooting rate (77.78%) was obtained from control cutting. When the autumn olive cuttings were evaluated in terms of other characteristics, the highest root length (9.05 cm) was found in 2000 ppm IBA application; the highest number of roots (8.40) was found in 1000 ppm IBA application; and the highest average sapling height (73.81 cm) was found in autumn olive cuttings treated with 2000 ppm IBA. IBA application has also been reported to increase sapling survival. The highest value (77.33%) was found in the 1000 ppm IBA application (Çelik, 2016). However, in contrast, Bounous et al. (1992) found that the cutting collecting time or IBA doses was ineffective upon rooting of the dormant cuttings of autumn olive.

The first measurements in the study, increasing the hormone concentration (IBA 8000) resulted in decreased growth performance on root collar diameter and height. In this case, this may be due to the initial inhibitory effect of increasing hormone concentration. Khan et al. (2020) reported a gradual decrease in sapling height when IBA concentrations exceeded 3000 ppm in kiwi (*Actinidia deliciosa*) cuttings. It has been reported that the decrease in plant height at higher concentrations may be due to the inhibitory effect of IBA above the optimum concentration (de-Klerk et al., 1999; Han et al., 2009). Various studies also mention the inhibitory properties of high hormone concentrations (Doungous et al., 2019; Tien et al., 2020). Furthermore, no significant difference was found between the highest hormone application (8000 ppm IBA) and the control group in the first measurements. In the second measurements, the 8000 ppm IBA application showed better growth in root collar diameter and height compared to the control. Therefore, monitoring the long-term effects of hormone applications on the growth and development of autumn olives will be important for making more accurate decisions regarding field performance.

4. Conclusion

Today, the threats posed by global climate change are increasing the need for highly adaptable species that provide functional and numerous ecological benefits. Furthermore, the importance of medicinal and aromatic plant species in combating diseases and food shortages indirectly brought about by climate change is becoming better understood. This study examined the long-term growth performance of vegetatively propagated *E. umbellata*. Among the IBA concentrations tested over long periods, a concentration of 5000 ppm was found to be more effective on growth. It was determined that IBA application improved the growth of *E. umbellata* saplings, but the first year of measurements was insufficient to assess growth performance. Since the final product of cutting propagation studies will be saplings, obtaining high-quality saplings is crucial. However, many studies are limited to the rooting stage and do not provide sufficient data on long-term outcomes. Furthermore, the inability to determine the survival rate and long-term growth performance of the resulting rooted cuttings prevents a clear assessment of their success in practice. The success of vegetative propagation depends on obtaining high-quality saplings that meet the desired standards. Therefore, to achieve long-term results, the rooting and sapling production processes must be considered as a whole. Furthermore, many environmental and biological factors can influence vegetative propagation, depending on the species. The study tested only one hormone, IBA. Therefore, the number of studies investigating the effects of different hormones and their concentrations, different growing environments, cutting type and length, environmental conditions, and cutting collecting time on the rooting, sapling growth and development of *E. umbellata* should be expanded.

Conflict of Interest

The authors declare that they have no conflict of interest.

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