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Enhancing Pelargonium peltatum propagation in the Azores: Role of cutting type and indole-3-butyric acid

Mejora de la propagación de Pelargonium peltatum en azores: Tipo de estaca y ácido indolbutírico

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ABSTRACT

Plants of the *Pelargonium* genus are widely distributed throughout the world, not only because of the beauty and durability of their inflorescences but also because of their adaptability to different environmental conditions. However, it is necessary to understand the most suitable types of cuttings for propagating this species and to evaluate the influence of indole-3-butyric acid on this process in order to support more efficient practices in the production of vigorous, high-quality seedlings. In this regard, the objective of this study was to evaluate the influence of the hormone IBA applied to different sections of the plant stem on the formation of viable *pelargonium* cuttings. To this end, cuttings were collected from three sections of the stem of *pelargonium* plants apical-, median- e basal-cutting portions, with and without the application of the hormone IBA. The application of IBA to the plants positively influenced the roots, stem, leaves, and inflorescence of *Pelargonium*. Cuttings derived from the apical portion showed the most favorable results, while those from the basal sections achieved satisfactory growth only when treated with IBA, highlighting its potential as an effective strategy to enhance propagation efficiency and improve plant performance.

Keywords: apical portion; clonal propagation; cutting position; ornamental horticulture; plant development; plant growth regulators.

RESUMEN

Las plantas del género *Pelargonium* están ampliamente distribuidas en todo el mundo, no solo por la belleza y durabilidad de sus inflorescencias, sino también por su adaptabilidad a diferentes condiciones ambientales. Sin embargo, es necesario comprender cuáles son los tipos de esquejes más adecuados para la propagación de esta especie, así como la influencia del ácido indol-3-butírico (IBA) en este proceso, con el fin de favorecer prácticas más eficientes en la producción de plántulas vigorosas y de alta calidad. En este sentido, este estudio tuvo como objetivo evaluar la influencia de la aplicación de IBA en diferentes secciones del tallo sobre la formación de esquejes viables de *Pelargonium*. Para ello, se recolectaron esquejes de tres secciones del tallo de plantas de *Pelargonium*, las porciones apical, media y basal, tanto en ausencia como en presencia de la hormona IBA. La aplicación de IBA influyó positivamente en el desarrollo de las raíces, el tallo, las hojas y las inflorescencias de *Pelargonium*. Los esquejes derivados de la porción apical mostraron los resultados más favorables, mientras que aquellos provenientes de las secciones basales alcanzaron un crecimiento satisfactorio únicamente cuando fueron tratados con IBA, lo que resalta su potencial como una estrategia eficaz para mejorar la eficiencia de la propagación y el rendimiento de las plantas.

Palabras clave: Desarrollo de la planta; horticultura ornamental; porción apical; posición del esqueje; propagación clonal; reguladores del crecimiento vegetal.

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INTRODUCTION

Pelargoniums are ornamental plants with high commercial value, prized for the beauty and durability of their inflorescences. In addition to their aesthetic appeal, species within the Geraniaceae family are easily and rapidly propagated and cultivated, contributing to their growing popularity among florists and gardening enthusiasts (Wingate, 2022). This genus is widely distributed worldwide, not only for its ornamental value but also for its remarkable resilience to adverse conditions, including arid environments. Its adaptability to both indoor and outdoor settings throughout the spring-to-autumn growing season further enhances its commercial appeal (Madouh & Quoreshi, 2023).

Although pelargoniums can be propagated by seeds, vegetative propagation through cuttings is the most widely adopted method (Rapacz *et al*., 2024). As such, cultivating vigorous mother plants to produce high-quality cuttings becomes crucial in commercial geranium production (Brentari *et al*., 2020). Vegetative propagation by cuttings is widely practiced in both herbaceous and woody species, as it offers a reliable, cost-effective means of producing genetically identical plants (Rutledge *et al*., 2017). However, the success of vegetative propagation is closely tied to the type of cutting used. Endogenous auxins, phytohormones responsible for cell elongation and root induction, are produced in active growth regions such as the shoot apex, buds, and leaves. The concentration of these hormones in cuttings can vary widely depending on their physiological and genetic status, and they can also be supplied exogenously to enhance rooting (Vielba *et al*., 2020).

Nonetheless, achieving consistent rooting remains a challenge, often influenced by both intrinsic plant factors and environmental conditions. In this context, the use of growth regulators such as auxins has become increasingly important for improving rooting efficiency (D'Amelia *et al*., 2020; Mohammed *et al*., 2024; Świerczyński, 2024; Oğuztürk *et al*., 2025).

Among synthetic auxins, indole-3-butyric acid (IBA) has proven to be one of the most effective compounds in promoting root formation. Its superior chemical stability, low mobility within plant tissues, and resistance to photodegradation make it particularly well-suited for use in vegetative propagation protocols (Lakehal & Bellini, 2019). According to Bannloud and Bellini (2021), IBA consistently enhances rooting in a wide variety of plant species, especially those known for their rooting challenges.

Despite its widespread use, there is still a lack of comprehensive studies on the vegetative propagation of species within the Pelargonium genus, particularly *P. peltatum*. Therefore, this study aims to investigate the role of IBA in promoting root development in different types of cuttings of *P. peltatum*. By systematically evaluating the effects of exogenous IBA applications on various cutting types, this research seeks to optimize propagation techniques and improve the commercial production of this ornamental species. The results will not only contribute to a better understanding of hormonal influences on root induction in *P. peltatum,* but will also offer practical applications for the floriculture industry by enhancing the efficiency and quality of flower production in various regions worldwide, including the Azores.

MATERIAL AND METHODS

This study was conducted in the greenhouses of the Praia da Vitória flower nursery, located on Terceira Island in the Azores, during the peak of spring 2022. The experimental period benefited from the region's temperate maritime climate, characterized by an average temperature of 17.6°C, with daily maximums reaching 20 °C and minimums of 14°C. These ideal growing conditions provided a controlled environment to evaluate the effects of indole-3-butyric acid (IBA) on the vegetative propagation of *Pelargonium peltatum*, simulating commercial flower production.

To conduct the trial, cuttings were taken from three sections of the stem of pelargonium plants, the apical, middle, and basal portions, which were subjected to treatments in the absence and presence of the hormone IBA. The experimental design was entirely randomized, in a factorial scheme (2 × 3), with a total of six treatments. Each experimental unit consisted of three plants, with four replications per treatment.

On April 11, the cuttings were collected from mother plants installed in the nursery (Figure 1). The cuttings were pruned in the morning to ensure optimal hydration conditions and were kept in a container of water until staking. Following the traditional seedling production system, the cuttings were cut to lengths of between 10 and 15 cm, leaving only 2-3 terminal leaves and discarding the rest.

Figure 1: Example of a vegetative cutting, specifically a sub-apical (median) stem segment of *P. peltatum*

On the same day of harvest, depending on the treatment, the cuttings were immersed for 5 seconds in the IBA solution and immediately placed in a commercial universal substrate, without allowing them to dry. They were placed in 1-L plastic pots, following the standard propagation protocol used in the nursery (Copes & Mandel, 2000). After planting, the pots were randomly arranged on a greenhouse bench.

During the experimental period, the irrigation was carried out according to the usual watering schedule for reproductive plants, where the substrate was only wetted when necessary. No fertilization was carried out during this period, nor was it necessary to resort to any type of phytosanitary treatment. Weed control was performed manually, always following the nursery's usual protocol and care procedures.

Exactly 81 days elapsed between staking and harvesting the plants. While still in the greenhouse, the plants were carefully removed from their pots and their roots washed so that they were completely bare. The plants were then placed in plastic bags according to the treatments, separated by repetition, and transported to the laboratory for data measurement.

The data was collected in the Horticulture laboratory at the Angra do Heroísmo Campus of the University of the Azores. The following were assessed: size, fresh weight, and dry weight of roots per plant; number, fresh weight, and dry weight of leaves per plant; fresh weight and dry weight of stems per plant; number, fresh weight, and dry weight of inflorescences per plant. The survival percentage of *Pelargonium* plants was also evaluated. It was calculated as the proportion of cuttings that successfully developed roots and exhibited active growth relative to the total number of cuttings initially planted. The dry weight of the material was obtained after drying in a forced-air oven at 65°C for 48 hours, and the size of the roots was measured using a millimeter ruler (Rapacz *et al.*, 2024).

The data obtained was subjected to analysis of variance, and the means of the treatments, when significant, were compared using the Tukey test at 5% and 1% probability of error, using the AgroEstat statistical program.

RESULTS

Effects of IBA and Cutting Position on Survival Percentage of Pelargonium Cuttings

The data presented in Table 1 indicate that there was no difference in the survival rates of *P. peltatum* cuttings when comparing treatments with and without the application of indole-3-butyric acid (IBA). This suggests that, under the specific conditions of this experiment, the presence of exogenous auxin did not have a decisive effect on the overall viability of the cuttings. However, when the variable "stem section" is considered, a marked disparity in survival rates is evident. Cuttings derived from the apical portion of the stem had the highest survival rate, reaching 87.5%, while those obtained from the basal portion had a considerably lower survival rate, of 47.22%. This corresponds to a substantial 47% difference, highlighting the importance of the anatomical origin of the cutting in determining the success of propagation.

In contrast, the mid-stem section showed an intermediate survival rate that did not differ statistically from the apical section, indicating that cuttings from the upper and central portions of the stem have comparable physiological survival potential under the tested conditions.

Table 1. *Survival percentage of Pelargonium plants by treatment at the end of the experiment*

	Survival (%)
Hormone	
Absent	76.85 a
Presence	64.81 a
Stem section	
Apical	87.50 a
Median	77.78 a
Basal	47.22 b

F. (Hormone)	3.45 ^{NS}
F. (Stem section)	14.02**
F. (Horm. × Stem section)	0.63 ^{NS}
Coefficient of Variation (%)	22.4

Tukey test. *, ** significant at 5 and 1% probability, respectively. NS- non-significant.

Roots

The data presented in Table 2 demonstrate the significant and consistent effect of indole-3-butyric acid (IBA) on the rooting performance of *P. peltatum* cuttings. When analyzing the three main variables related to root development, namely root length, fresh mass, and dry mass, the data suggest that the application of exogenous auxin resulted in substantially improved rooting responses across all parameters.

Among the variables evaluated, the most significant improvement was recorded in the fresh mass of the root system, where the cuttings treated with IBA produced roots that were, on average, 57% heavier than those observed in the untreated cuttings. This considerable increase in biomass reflects a greater allocation of resources for root organogenesis and a more efficient establishment of functional root tissues in response to hormonal stimulation.

In terms of root length (Tables 2 and 3), cuttings subjected to IBA treatment developed root systems that were 29% longer, on average, than those in the untreated group. This finding highlights the role of auxins not only in promoting cell division but also in stimulating cell elongation that influences spatial expansion and the potential for soil exploration by plants.

Table 2. *Root length, fresh weight, and dry weight per Pelargonium plant under different treatments at the end of the experiment.*

Roots	Size (cm)	Fresh weight (g)	Dry weight (g)
Hormone			
Absence	15.92 b	0.42 b	0.186 b
Presence	22.40 a	0.97 a	0.318 a
Stem section			
Apical	21.20 a	0.71 a	0.273 a
Medial	17.85 a	0.72 a	0.261 a
Basal	18.44 a	0.64 a	0.222 a
F. (Hormone)	29.39**	228.16**	41.50**
F. (Stem section)	3.01^{NS}	2.02^{NS}	2.29^{NS}
F. (Horm. × Stem section)	5.93*	11.67**	6.46**
Coefficient of Variation (%)	15.27	12.92	19.91

Tukey test. *, ** significant at 5 and 1% probability, respectively. NS- non-significant.

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Taken together, these results confirm that the exogenous application of IBA significantly increases the efficiency of vegetative propagation of *Pelargonium peltatum* by stimulating root system development (Tables 3 and 4). The simultaneous increase in root size, fresh biomass and dry matter accumulation suggests an integrated hormonal response that improves the water and nutrient uptake capacity of the developing seedlings.

Table 3. *Root sizes per pelargonium plant as a function of the presence and absence of hormone and the stem sections tested*

	Size Roots (cm)	
	Absent	**Presence**
Apical	19.82 A a	22.56 A a
Median	15.58 B ab	20.08 A a
Basal	12.33 B b	24.52 A a

Tukey's test with lower-case letters comparing the effect of the stem sections (vertical) and upper-case letters comparing the hormone effect (horizontal).

It is also worth noting that the magnitude of the hormone effect was more pronounced in variables directly related to biomass (fresh and dry weight) than in mere dimensional expansion (length), indicating that IBA contributes not only to the initiation of rooting but also to the thickening and functional development of root tissues, which are critical parameters for the establishment and long-term resilience of ornamental plants propagated by cuttings.

Table 4. *Fresh and dry weight of roots per pelargonium plant as a function of the presence and absence of hormone and the stem sections tested.*

	Fresh weight Roots (g)	
Apical	0.50 B a	0.92 A a
Median	0.51 B a	0.94 A a
Basal	0.24 B b	1.04 A a
	Dry weight Roots (g)	
Apical	0.254 A a	0.292 A a
Median	0.190 A ab	0.332 A a
Basal	0.113 B b	0.330 A a

Tukey's test ($p \leq 0.05$), with lower-case letters comparing the effect of the stem sections (vertical) and upper-case letters comparing the hormone effect (horizontal).

Stems

The results obtained for the variable "stem biomass" in *P. peltatum* cuttings are summarized in Tables 5 and 6. The application of indole-3-butyric acid (IBA) had a significant effect on both the fresh and dry weights of the stem portions, regardless of the cutting origin. Cuttings treated with IBA produced stems with significantly greater mass accumulation compared to untreated cuttings.

Quantitatively, stems derived from hormone-treated cuttings showed an average increase of 32% in fresh weight and 26% in dry weight, compared to their untreated counterparts. This effect was consistent among replicates and statistically significant ($p \leq 0.05$), indicating a clear increase in vegetative biomass in response to hormone treatment.

Table 5. *Fresh weight and dry weight of the stem per pelargonium plant, according to the treatments tested, at the end of the experimental period.*

Stem	Fresh weight (g)	Dry weight (g)
Hormone		
Absent	3.31 b	0.612 b
Presence	4.85 a	0.822 a
Stem sections		
Apical	4.81 a	0.743 a
Median	3.71 b	0.732 a
Basal	3.73 b	0.675 a
F. (Hormone)	36.53**	38.27**
F. (Stem section)	8.02**	1.52^{NS}
F. (Horm. × Stem section)	0.09^{NS}	5.25*
Coefficient of Variation (%)	15.36	11.5

Tukey test. *, ** significant at 5 and 1% probability, respectively. NS- non-significant.

When evaluating the effect of the cutting along the stem (apical, median, and basal), only the fresh weight of the stems was significantly influenced by this factor. The highest fresh mass values were recorded in cuttings originating from the apical section, followed by the median and basal sections, respectively. However, for dry mass, no statistically significant differences were observed between the portions of the stem, suggesting that, although water content and turgidity may vary, the accumulation of structural dry matter was not significantly affected by the position of the stem.

Table 6. *Stems dry weight per pelargonium plant as a function of the presence and absence of hormone and the stem sections tested.*

	Dry weight Stems (g)	
	Absent	**Presence**
Apical	0.713 A a	0.774 A a
Median	0.570 B ab	0.893 A a
Basal	0.552 B b	0.799 A a

Averages followed by the same letter do not differ by Tukey's test ($p \leq 0.05$), with lower-case letters comparing the effect of the stem sections (vertical) and upper-case letters comparing the hormone effect (horizontal).

The interaction between hormone treatment and cutting origin is shown in Table 6. Untreated basal cuttings presented the lowest values of fresh and dry mass of the stem. Their fresh weight was approximately 30% lower than basal cuttings treated with the hormone and 38% lower than median cuttings treated with the hormone. These results indicate that IBA hormone stimulates the basal part of the plant, making it more active.

Leaves

The results presented in Tables 7 and 8 confirm that exogenous hormone supplementation had a significant effect on leaf development in *P. peltatum* cuttings. Significant differences were observed in the three parameters evaluated: number of leaves per plant, fresh leaf mass, and dry leaf mass, depending on the presence or absence of the hormone. In the hormone-treated cuttings, the number of leaves increased by an average of 40%, fresh mass by 62% and dry mass by 59%, compared to untreated cuttings.

These values confirm the consistent stimulation of vegetative growth by IBA. Regarding the stem section, significant differences were identified only for the fresh and dry leaf mass. The number of leaves was not influenced by the position of the cutting (apical, median, or basal). For fresh mass, the apical cuttings presented the highest values, with an average increase of 39% in relation to the basal section and 25% in relation to the median section. A similar pattern was observed in dry weight, with the apical section showing an average increase of 29% compared to the basal section and 25% compared to the median section. No differences were found between the median and basal sections for any of the variables.

Table 7. *Number, fresh weight, and dry weight of leaves per pelargonium plant, according to the treatments tested, at the end of the experimental period.*

Leaves	**Leaves** (nº)	**Fresh weight** (g)	**Dry weight** (g)
Hormone			
Absence	8.15 b	4.57 b	0.410 b
Presence	13.54 a	11.86 a	0.995 a
Stem Sections			
Apical	11.50 a	10.41 a	0.855 a
Median	10.33 a	7.800 b	0.641 b
Basal	10.70 a	6.45 b	0.611 b
F. (Hormone)	80.87**	111.10**	117.17**
F. (Stem section)	1.33^{NS}	11.28**	8.10**
F. (Horm. × Stem section)	0.70NS	4.12*	13.72**
Coefficient of Variation (%)	13.50	20.60	18.10

Tukey test. *, ** significant at 5 and 1% probability, respectively. NS- non-significant.

The data in Table 8 indicate an interaction between cutting position and hormone treatment for leaf fresh weight. Under hormone application, basal and median cuttings showed the greatest relative gains in biomass: an increase of 84% in basal cuttings and 69% in median cuttings, compared to their untreated counterparts. Apical cuttings also responded positively to hormone application with a 27% increase in fresh weight. In the absence of hormone, leaves from apical cuttings exhibited a 54% higher weight than those from median cuttings and a 79% higher weight than those from basal cuttings.

Overall, fresh and dry leaf weights were the most sensitive variables to both hormone treatment and cutting position, particularly under untreated conditions, where apical cuttings consistently outperformed the others. Under hormone treatment, cuttings from the middle and basal sections showed the highest absolute gain, although apical cuttings maintained the highest overall biomass values.

Table 8. *Fresh and dry weight of leaves per pelargonium plant as a function of the presence and absence of hormone and the stem sections tested.*

Fresh weight Leaves (g)		
Apical	8.10 B a	12.71 A a
Median	3.80 B b	11.76 A a
Basal	1.78 B b	11.12 A a
Dry weight Leaves (g)		
Apical	0.763 B a	0.848 A a
Median	0.258 B b	1.024 A a
Basal	0.211 B b	1.012 A a

Tukey's test ($p \leq 0.05$), with lowercase letters comparing the effect of the stem sections (vertical) and upper-case letters comparing the hormone effect (horizontal).

Inflorescence

As shown in Table 9, hormonal treatment had a significant positive effect on all three inflorescence-related variables: number of inflorescences, fresh mass, and dry mass. Cuttings treated with IBA showed increases ranging from 52% to 57% compared to untreated cuttings.

Regarding cutting position, a greater number of inflorescences was observed in plants derived from the apical and basal sections, with the basal section showing a 30% increase compared to the untreated controls.

Table 9. *Number, fresh weight, and dry weight of leaves per pelargonium plant, according to the treatments tested, at the end of the experimental period.*

	Inflorescences (nº)	**Fresh weight** (g)	**Dry weight** (g)
Hormone			
Absent	2.22 b	1.98 b	0.343 b
Presence	5.05 a	4.07 a	0.727 a
Stem sections			
Apical	4.06 a	3.31 a	0.689 a
Median	4.03 a	3.32 a	0.559 b
Basal	2.83 b	2.45 a	0.356 c
F. (Hormone)	186.62**	48.52**	109.62**
F. (Stem section)	15.11**	3.70^{NS}	27.78**
F. (Horm. × Stem section)	3.32^{NS}	5.15^{NS}	1.02^{NS}
Coefficient of Variation (%)	13.96	24.32	16.8

Tukey test. *, ** significant at 5 and 1% probability, respectively. NS- non-significant.

Regarding cutting position, a greater number of inflorescences was observed in plants derived from the apical and basal sections, with the basal section showing a 30% increase compared to the untreated controls. Compared to median and basal sections, apical cuttings consistently enhanced inflorescence production, underscoring their physiological advantage in floral differentiation.

DISCUSSION

The absence of significant differences in survival between apical and median cuttings corroborates the findings of Otiende *et al.* (2021), who described an acropetal gradient in rooting potential. This phenomenon, mainly attributed to higher endogenous auxin concentrations and hormonal homeostasis in the apical regions, contributes to the increased survival and rooting capacity observed in cuttings derived from the upper stem segments. Such physiological gradients reflect the intrinsic polarity of plant tissue development, where auxin plays a central role in promoting regenerative responses (Mohammed *et al.*, 2024).

The general stimulatory IBA on root development, particularly in cuttings derived from the basal and median regions, is consistent with the observations reported by Abass *et al.* (2024). These authors demonstrated that exogenous auxin application significantly increases root size, fresh weight, and dry weight in *Punica granatum* L. cuttings. The pronounced response in the basal and medial segments emphasizes the compensatory role of synthetic auxins in tissues with naturally reduced levels of endogenous hormones, which is very relevant for clonal propagation (Rutledge *et al.*, 2017).

Regarding shoot development, IBA application notably increased fresh and dry biomass, with more evident effects in apical cuttings. This observation is consistent with Mazzoni-Putman *et al.* (2021), who emphasized the role of auxins as key regulators of cell elongation, tissue differentiation, and biomass accumulation. These effects are further corroborated by the findings of Parađiković *et al.* (2012), who observed an increase in early vegetative growth in *Pelargonium* species under hormonal treatment. However, these authors also observed a decline in growth differentials at later stages of development, particularly during flowering, highlighting the temporal specificity of auxin responsiveness and the need to align hormone application with developmental windows.

In terms of leaf development, IBA application produced significant improvements in fresh and dry biomass, especially in cuttings from the basal and median segments. These results suggest that, while apical cuttings inherently exhibit superior vigor due to favorable endogenous hormonal profiles, the basal and median segments benefit more from exogenous hormonal inputs. These differential responses are in line with the work of Perrier *et al.* (2017), who emphasized the heterogeneity of physiological behavior among different stem regions, particularly in terms of biomass partitioning and resource allocation.

Regarding reproductive development, the positive impact of IBA extended to inflorescence parameters, confirming its role not only in vegetative but also reproductive improvement. The data revealed that, while apical cuttings maintained superior performance in terms of inflorescence quantity and biomass, basal and median cuttings showed the most pronounced relative gains when treated with IBA. These findings reinforce the conclusions of Quan *et al.* (2022), who demonstrated that auxins, especially when used in combination with gibberellins, can induce floral differentiation and promoting inflorescence development in several ornamental species.

Taken together, these results highlight the centrality of cutting origin and the application of exogenous hormones in optimizing *Pelargonium peltatum* propagation protocols. Although apical cuttings offer intrinsic advantages in terms of survival and vigor, the strategic use of IBA proves to be particularly valuable for improving the performance of physiologically less active stem regions. This integrated approach, which simultaneously considers the origin of the cutting and the application of growth regulators, has proven to be an effective strategy for standardizing the quality of propagated seedlings. By allowing the efficient use of different stem segments, it contributes significantly to the advancement of propagation practices, promoting greater sustainability, efficiency and uniformity in ornamental horticulture.

CONCLUSIONS

According to the results, the application of IBA had a positive effect on plant development in most of the evaluated parameters. Moreover, cuttings derived from the apical portion produced larger plants exclusively when treated with IBA, highlighting the importance of this hormone in promoting growth.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

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