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Impact of cutting types and commercial plant growth regulators on the propagation of red star begonia (*Begonia rex-cultorum*)

Dampak kombinasi tipe stek dan zat pengatur tumbuh komersial terhadap perbanyakan begonia bintang merah (*Begonia rex-cultorum*)

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ABSTRACT

Begonia is an ornamental plant known for its beautiful, variegated leaves. Propagation of this plant via vegetative means, particularly using leaves, often encounters challenges such as drying, rotting, and mortality of cuttings, necessitating the use of plant growth regulators (PGRs) to support their development. This study aims to determine the optimal combination of cutting type and commercial PGR concentration for the growth of red star begonia leaf cuttings. A factorial completely randomized design (CRD) was employed with two factors: cutting type (whole leaves and leaf slices) and PGR concentration (250 ppm, 300 ppm, 350 ppm, and 400 ppm), each replicated three times. The results indicated that the best combination for leaf number, root length, primary root number, and survival rate was whole leaves with a PGR concentration of 400 ppm. For the earliest sprout emergence, the best treatment was a PGR concentration of 350 ppm. These findings can enhance the efficiency of vegetative propagation of red star begonia, reduce propagation failure rates, and provide practical guidance for growers and ornamental plant enthusiasts in selecting optimal methods and PGR concentrations.

ABSTRAK

Begonia bintang merah merupakan tanaman hias yang memiliki keindahan pada daun dengan berbagai corak. Perbanyakan tanaman ini secara vegetatif menggunakan daun seringkali menghadapi masalah seperti bahan stek yang mudah kering, busuk, dan kematian, sehingga memerlukan penambahan zat pengatur tumbuh (ZPT) untuk mendukung pertumbuhannya. Penelitian ini bertujuan untuk menentukan kombinasi terbaik antara jenis bahan stek dan konsentrasi ZPT komersial dalam pertumbuhan stek daun begonia bintang merah. Penelitian ini menggunakan rancangan acak lengkap (RAL) faktorial dengan dua faktor, yaitu jenis bahan stek (daun utuh dan daun irisan) dan konsentrasi ZPT (250 ppm, 300 ppm, 350 ppm, dan 400 ppm), yang masing-masing diulang tiga kali. Hasil penelitian menunjukkan bahwa kombinasi terbaik untuk jumlah daun, panjang akar, jumlah akar primer, dan persentase hidup tertinggi adalah daun utuh dengan konsentrasi ZPT 400 ppm. Sementara itu, untuk parameter waktu awal muncul tunas, perlakuan terbaik adalah konsentrasi ZPT 350 ppm. Temuan ini dapat membantu dalam meningkatkan efisiensi perbanyakan vegetatif begonia bintang merah, mengurangi tingkat kegagalan perbanyakan, dan memberikan panduan praktis bagi petani dan penghobi tanaman hias dalam memilih metode dan konsentrasi ZPT yang optimal.

INTRODUCTION

The global development of ornamental plants is a frequently discussed topic due to their significant appeal among plant enthusiasts. Ornamental plants are valued for their diverse leaf shapes, flower colors, and aesthetic structures. In both national and international markets, ornamental plants are considered one of the premier commodities with high economic value (Wisanggara et al., 2018).

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Begonia (Begoniaceae) is a notable ornamental plant in the Angiospermae group, distinguished by its varied leaf shapes, sizes, colors, and patterns. This diversity makes Begonia a popular choice among consumers seeking unique ornamental plants. The high market demand for this plant necessitates effective propagation methods to ensure adequate availability. Vegetative propagation from mature leaves is a commonly used method; however, it has notable drawbacks, such as the susceptibility of leaves to drying, rotting, and death. To address these issues, the application of plant growth regulators (PGRs) can offer a solution. PGRs are substances that stimulate various aspects of plant growth, including root, flower, and fruit development. Auxins, a class of PGRs, play a crucial role in influencing the growth and development of cuttings (Aeni et al., 2017). Rootone F, a synthetic auxin commonly used in Indonesia, is favored for its accessibility and affordability.

Previous research by Arinasa (2015) investigated the use of Rootone F in *Begonia tuberosa* Lmk. cuttings at concentrations of 0, 150, 300, and 450 mg/L. The study found that the optimal growth of cuttings occurred with Rootone F at a concentration of 300 mg/L. However, there is a need to further explore various PGR concentrations and cutting types to improve propagation outcomes for Begonia. One specific type requiring further investigation is the red star begonia (*Begonia rex-cultorum*), a member of the rhizomatous begonias group (Ginori et al., 2022).

Subsequent studies have indicated varied results regarding the efficacy of different Rootone F concentrations on different plant species. For instance, Hariyadi & Asqian (2017) found that a concentration of 600 ppm was most effective for the growth of *Mucuna bracteata*, while Gumelar & Ari (2019) reported that a 3000-ppm concentration yielded the best results for jasmine clone cuttings. Abdullah et al. (2023) determined that a 150-ppm concentration was optimal for the growth of poinsettia cuttings, and Soleha et al. (2023) observed that a 200-ppm concentration was most effective for the growth of cuttings from terminal shoots. Additionally, Silviana et al. (2022) found that 150 mg/L was optimal for the root growth of fig cuttings, while Salim et al. (2022) reported varying results for coffee cuttings based on the number of nodes and Rootone F concentration.

The existing research lacks direct comparisons of various cutting types (whole leaves versus leaf slices) and a broader range of PGR concentrations on red star begonia. This study aims to fill these gaps by evaluating the effects of different cutting types and PGR concentrations on the propagation of red star begonia. Consequently, this study is expected to provide comprehensive information on optimal conditions for enhancing the success of vegetative propagation for red star begonia.

MATERIALS & METHODS

The research was conducted from May to August 2023 in a greenhouse located in Claket Village, Pacet District, Mojokerto Regency (7°40'32"S, 112°34'2"E), at an altitude of 950 meters above sea level and an average temperature of 24°C. Materials included whole and sliced leaves of red star begonia sourced locally and Rootone F (PT. Rhone-poulenc Agrocarb, Indonesia). Rootone F contains napthalene acetamide (NAA) 0.067%, 2-methyl-1-napthalene acetamide (NAD) 0.013%, 2-methyl-1-naphthalene acetate 0.33%, and indole butyric acid (IBA) 0.057%. NAA is a synthetic auxin commonly used in research, particularly for plant cuttings (Yan et al., 2014).

The experimental design was a completely randomized design (CRD) with two factors and three replications. The first factor was the type of cutting material: whole leaves and leaf slices. The second factor was the concentration of PGR: 250 ppm, 300 ppm, 350 ppm, and 400 ppm. This resulted in eight treatment combinations, each with three samples, totaling 72 polybags. Data were analyzed using ANOVA, and significant interactions were further analyzed with the LSD test at the 5% significance level.

The planting medium was prepared by mixing husk and compost in a 2:1 ratio and filling the polybags to three-quarters full (Rohadi et al., 2023). Cutting materials were mature, healthy leaves from the lower nodes of the mother plant (Efendi

& Intan, 2018; Siska & Puji, 2019). Propagation was performed using whole leaves and leaf slices, with leaf slices cut radially from the base through three veins (Ginori et al., 2022). Each cutting was soaked in PGR (prepared by dissolving 0.25 g, 0.3 g, 0.35 g, or 0.4 g of NAA in 1 L of distilled water) for 30 minutes. Planting was performed by making a hole 5 cm deep in the planting medium; leaf slices were placed upright, and whole leaves were laid flat (Cahyadi et al., 2017). Maintenance included watering twice daily, weeding by hand, and weekly spraying with Gandasil-D leaf fertilizer (1 g/L) (PT. Kalatham, Indonesia), as followed previous study (Aulia et al., 2022).

Observation parameters included the time of shoot emergence (days after planting, DAP), the number of leaves at 49 to 91 DAP recorded at two-week intervals, root length at 91 DAP, the number of primary roots at 91 DAP, and the percentage of live cuttings (Siska & Puji, 2019). The percentage of live cuttings was calculated using the formula as described by (Fitri et al. 2021) :

$$\text{Percentage of live cuttings} = \frac{\text{Number of live cuttings}}{\text{Number of cuttings planted}} \times 100\% \qquad (1)$$

RESULTS & DISCUSSIONS

Table 1 presents the ANOVA summary for all observed parameters, highlighting the effects of different cutting materials and PGR immersion on the early growth of red star begonia plants. The parameters observed include the time of initial shoot emergence, the number of leaves at different stages (49, 63, 77, and 91 days after planting, DAP), the length of the longest root, and the number of primary roots.

Table 1. Summary of ANOVA for all observed parameters on the growth of red star begonia (n = 72)

Treatment	F Table		Initial shoot emergence	No. of leaves -----DAP----				Longest root length	No. of primary roots
	5%	1%		49	63	77	91		
B	4.49	8.53	0.93 ns	6.26*	0.35ns	4.62*	2.54ns	0.31ns	21.80**
Z	3.24	5.29	3.28*	4.09*	1.98ns	8.28**	9.56**	4.19*	8.92**
B × Z	3.24	5.29	1.94 ns	9.22**	4.39*	14.59**	11.88**	4.61*	10.46**
LSD 5%			6.98	0.65	1.42	1.16	1.38	2.12	1.44

Note: B = cutting material, Z = PGR concentration, ns: not significant, * = significant at 5%, ** = highly significant at 1%

Table 1 shows the summary of the ANOVA results for all observed parameters, highlighting the effects of cutting materials and PGR immersion on the early growth of red star begonia plants. The results (see Table 1) indicate an interaction between the combination treatments of leaf cutting materials and PGR immersion for the parameters of the number of leaves, the longest root length, and the number of primary roots. However, no interaction was observed for the parameter of the initial shoot emergence time.

The interaction between the cutting materials and PGR concentrations significantly affected the number of leaves at 63, 77, and 91 DAP, the length of the longest root, and the number of primary roots, as indicated by the highly significant ($p < 0.01$) and significant ($p < 0.05$) F-values. The findings suggest that optimizing the combination of cutting materials and PGR concentrations can enhance the vegetative propagation success of Red star begonia by improving key growth parameters. Further analysis through the Least Significant Difference (LSD) test at a 5% significance level was conducted to elucidate specific treatment effects and interactions on each observed parameter.

Time of shoot emergence

The ANOVA results indicate that there was no significant interaction between the type of cutting material and the PGR concentration on the time of shoot emergence. This parameter did not show significant differences with respect to the type of cutting material. However, the PGR treatment did show significant differences. The time of shoot emergence is presented in Table 2.

Table 2. Time of shoot emergence in different cutting type and PGR concentrations (n = 3). Data are means ± SD

Treatment	Time of shoot emergence (DAP)
Cutting type	
Whole leaf	61.92 ± 8.67
Leaf slices	58.74 ± 10.59
LSD 5%	Ns
PGR concentration	
250 ppm	68.00 ± 8.35 b
300 ppm	62.08 ± 5.69 ab
350 ppm	55.28 ± 11.65 a
400 ppm	55.94 ± 7.65 a
LSD 5%	6.98

Note: Numbers followed by the same letter within the same column indicate no significant difference at the 5% LSD test; ns = not significant; DAP = days after planting.

Table 2 shows that the time of shoot emergence for the 350 ppm PGR treatment (55.28 DAP) was not significantly different from the 400 ppm (55.94 DAP) and 300 ppm (62.08 DAP) treatments. The 250 ppm concentration significantly differed from the 350 ppm and 400 ppm treatments, with shoot emergence occurring at 68.00 DAP.

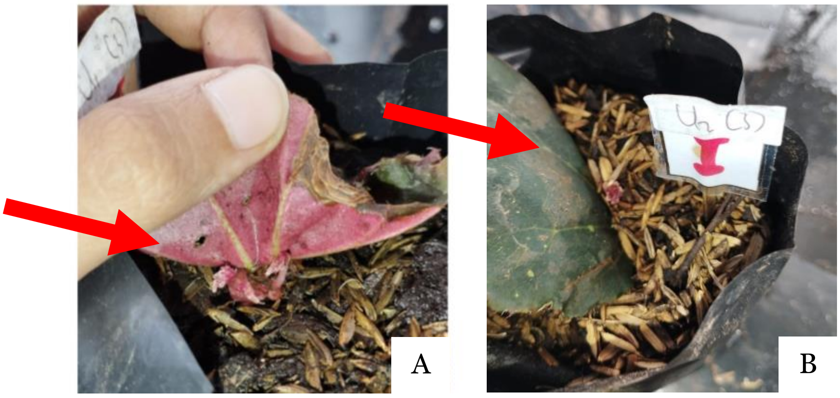

Figure 1. Shoot emergence in cutting types: (A) whole leaf (B) leaf slices

The PGR concentration treatment revealed that 350 ppm induced the fastest shoot emergence. This indicates that this concentration is optimal for the plant's requirements. Soaking the cuttings in PGR at optimal levels accelerates root growth due to osmosis and diffusion, where water enters the cells, increasing cell water content and also increasing the levels of IAA, NAA, and IBA. The increased auxin content, such as NAA, a synthetic auxin, significantly influences plant metabolism processes, thus regulating plant growth processes like root formation, cell elongation, and xylem and phloem tissue differentiation. Good root growth facilitates quicker photosynthesis by providing water and minerals from the cuttings, leading to faster cell division and quicker shoot formation. Plant growth regulators are hormones needed by plants in addition to nitrogen and carbohydrates, with the addition of PGR serving as an optimal growth regulator supplement to support plant growth.

The formation of leaves begins with the division of shoots stimulated by hormones, leading to the emergence of axillary shoots at the leaf base. The bud cells then undergo tissue changes, developing into new organs, including leaves. The more new shoots that emerge, the more leaves will form (Fitriani, 2014). The addition of PGR, which contains auxin hormones, aims to stimulate root initiation, leading to root formation. Well-formed roots in the cuttings are expected to encourage initial growth, absorb nutrients and water efficiently, and facilitate photosynthesis. According to Ramadani & Setiono (2021), a well-developed root system enhances nutrient absorption, thus promoting plant growth. PGR, an auxin-type PGR containing active compounds like IBA and NAA, is used for cell elongation and differentiation, accelerating cell division in plant cells, resulting in faster shoot and leaf growth. Tamba et al. (2019) stated that the application of auxin at the initial planting stage can accelerate the formation of shoots, leaves, and lateral root growth, thereby enhancing the photosynthesis process in the cuttings. According to Adiwirman et al. (2020), good root growth and development can be stimulated by the addition of auxin hormones, facilitating shoot growth in plants.

Number of leaves

The interaction between leaf cutting material and PGR treatment significantly influenced the number of leaves observed from 49 DAP to 91 DAP. Table 3 provides the number of leaves for each treatment combination.

Table 3. Number of leaves from 49 to 91 DAP under different cutting types and PGR concentrations (n = 3). Data are means ± SD

Treatment	Number of leaves (count) - DAP -			
	49	63	77	91
Whole leaf (B1)				
PGR 250 ppm (Z1)	0.00 ± 0.00 a	1.67 ± 0.29 a	3.67 ± 1.20 a	5.50 ± 1.32 a
PGR 300 ppm (Z2)	0.00 ± 0.00 a	2.33 ± 1.15 abc	3.89 ± 0.84 ab	5.72 ± 0.95 a
PGR 350 ppm (Z3)	0.00 ± 0.00 a	2.61 ± 1.40 abc	4.78 ± 1.50 b	7.22 ± 1.84 b
PGR 400 ppm (Z4)	1.33 ± 0.58 b	5.00 ± 0.33 d	8.33 ± 1.00 d	10.78 ± 1.02 d
Leaf slices (B2)				
PGR 250 ppm (Z1)	0.00 ± 0.00 a	2.00 ± 1.73 ab	3.39 ± 0.67 a	5.56 ± 0.51 a
PGR 300 ppm (Z2)	1.17 ± 0.76 b	3.28 ± 0.25 bc	4.28 ± 0.25 ab	6.06 ± 1.55 ab
PGR 350 ppm (Z3)	2.00 ± 1.00 c	3.44 ± 1.17 cd	6.44 ± 0.38 c	9.22 ± 0.51 c
PGR 400 ppm (Z4)	1.00 ± 0.58 b	1.78 ± 1.68 a	3.22 ± 1.07 a	5.44 ± 0.51 a
LSD 5%	0.65	1.42	1.16	1.38

Note: Numbers followed by the same letter within the same column indicate no significant difference at the 5% LSD test; ns = not significant; DAP = Days after planting.

At 49 DAP, the highest average number of leaves was observed in the combination of leaf slices with 350 ppm PGR. This combination showed the quickest shoot emergence, resulting in faster root formation due to the smaller planting surface, which facilitated quicker root development. At 63, 77, and 91 DAP, the highest average number of leaves was found in the combination of whole leaves with 400 ppm PGR. In contrast, the combination of leaf slices with 400 ppm PGR had the lowest average number of leaves. The whole leaf with 400 ppm PGR treatment had a longer shoot emergence time because the initial growth phase focused on root development, delaying shoot emergence.

The highest number of leaves in this combination occurred because the greater root growth enhanced nutrient absorption, providing more resources for photosynthesis and creating a larger photosynthetic surface area. Optimal auxin hormone levels in whole leaf cuttings maximized root formation. Sufficient photosynthetic resources facilitated rapid growth, from shoot formation to leaf development. According to Shofiana et al. (2013) in Darise (2023), auxin hormones stimulate epidermal cell walls, causing cell division that activates proton pumps (H^+ ions) in the plasma membrane, lowering the pH around the cell wall to 4.5 from 7 (normal pH), breaking hydrogen bonds between cellulose fibers. This results in cell wall loosening, reducing cell wall pressure, and causing cell elongation. Low pH also activates specific cell wall enzymes that degrade various proteins or polysaccharides, leading to cell enlargement and division.

Figure 2. Leaf growth in different cutting types

Table 4. Longest root length under different cutting types and PGR concentrations (n = 3). Data are means ± SD

PGR Concentration	Longest root length (cm) Cutting type: Whole Leaf	Longest root length (cm) Cutting type: Leaf Slices
250 ppm	12.38 ± 0.37 ab	12.79 ± 3.19 abc
300 ppm	12.51 ± 2.16 abc	14.36 ± 1.40 bc
350 ppm	14.57 ± 1.80 c	18.03 ± 0.61 d
400 ppm	18.14 ± 0.74 d	11.72 ± 1.72 a
LSD 5%	2.12	

Note: Numbers followed by the same letter within the same column indicate no significant difference at the 5% LSD test; ns = not significant.

An increased number of leaves accelerates subsequent plant growth, as more leaves provide more sites for photosynthesis and improve root systems. Photosynthesis occurs exclusively in leaves, making them crucial for plant growth. According to Khadijah (2021), increased cell division activity in young shoots leads to more shoots because auxin hormones are vital for meristematic growth. Wibowo (2022) states that shoot formation is driven by cell division and elongation in the shoot apex. Nutrients activate meristematic cells in the plant's shoot tip, enhancing photosynthesis in leaves and promoting shoot growth. Purba et al. (2018) assert that leaves play a key role in photosynthesis. A greater number of leaves indicates increased photosynthesis and assimilate content.

Longest root length

The study showed a significant effect of cutting material and PGR concentration on the longest root length. Table 4 illustrates the average longest root length for each treatment combination.

Figure 3. Measurement of the longest root length

The combination of whole leaf cuttings and 400 ppm PGR yielded the longest root length (18.14 cm), indicating it as the most effective treatment. Conversely, leaf slices combined with 400 ppm PGR resulted in the shortest root length (11.72 cm). Whole leaf cuttings with 400 ppm PGR benefit from a larger photosynthetic surface area compared to leaf slices. The lack of extensive cutting also facilitates quicker root growth, leading to longer roots. Whole leaf cuttings absorb PGR more efficiently during immersion, ensuring optimal auxin levels that promote root elongation. This combination allows auxin in PGR to be absorbed effectively, loosening epidermal cells in the roots and facilitating easier root emergence, thus increasing both root length and quantity. Rapid photosynthesis in whole leaf cuttings increases the demand for photosynthetic materials, prompting the roots to seek more nutrients and water from the growing medium, resulting in longer roots compared to other treatments.

According to Tamba et al. (2019), optimal auxin concentrations, tailored to the plant's requirements, promote root elongation. Auxin moves from the apical meristem to the basal parts of the plant, accumulating carbohydrates that drive root formation. The lowest average root length was observed in the leaf slices with 400 ppm PGR, likely due to toxicity from excessive PGR, which exceeded the optimal limit for root growth, thereby inhibiting root development. High osmotic pressure in the leaves and excessive PGR within the cuttings contributed to this result. Rahmawati et al. (2021) noted that while auxin at certain concentrations promotes cell elongation, excessive auxin can inhibit root elongation and stunt stem growth. Auxin is vital for plant growth and development, particularly for the root and shoot systems. Indole-3-acetic acid (IAA), a type of auxin, is easily absorbed by plants due to its chemical structure, which closely resembles natural plant auxin.

Number of primary roots

The study revealed a notable effect of cutting material and PGR concentration on the number of primary roots. The number of primary roots for each treatment combination is presented in Table 5. Table 5 shows that the highest average number of primary roots was observed in the whole leaf cuttings treated with 400 ppm PGR (14.56 roots), which was not significantly different from the whole leaf cuttings with 350 ppm PGR (13.89 roots). The lowest average number of primary roots was found in the leaf slices treated with 400 ppm PGR (7.89 roots), which was not significantly different from the leaf slices with 250 ppm PGR (9.44 roots).

Table 5. Number of primary roots for different cutting types and PGR concentrations (n = 3). Data are means ± SD

PGR concentration	Number of primary roots (count) Cutting type	
	Whole Leaf	Leaf Slices
250 ppm	9.56 ± 2.22 bc	9.44 ± 1.84 ab
300 ppm	10.11 ± 0.38 c	10.11 ± 0.38 c
350 ppm	13.89 ± 0.38 e	11.67 ± 0.58 d
400 ppm	14.56 ± 1.26 e	7.89 ± 0.69 a
LSD 5%	1.44	

Note: Values followed by the same letter within the same column indicate no significant difference at the 5% LSD test; ns = not significant.

Table 6. Percentage of living cuttings for different cutting types and PGR concentrations

PGR concentration	Percentage of living cuttings (%) Cutting type	
	Whole leaf	Leaf slices
250 ppm	78 ± 0.58	89 ± 0.58
300 ppm	89 ± 0.58	89 ± 0.58
350 ppm	100 ± 0.00	100 ± 0.00
400 ppm	100 ± 0.00	78 ± 0.58

The synthetic auxin in PGR stimulates the endogenous auxin produced by the pineapple plant's root organs. This auxin is transported to the base of the cutting, where it accelerates cell differentiation. The larger the cutting's cross-sectional area, the higher the number of roots formed (Pongoh et al. 2021). Whole leaf cuttings treated with 400 ppm PGR produced a high number of roots due to the broad base of the cuttings, which allowed more primary roots to grow effectively with the auxin present in PGR. According to Yuliawan (2019), a larger cutting base surface area results in a higher number of roots.

The combination of whole leaf cuttings and 400 ppm PGR yielded the most roots, suggesting better growth potential compared to other treatments. A higher number of roots optimizes nutrient transport from the growing medium to the leaves, promoting optimal growth. This also correlates with longer petioles and more leaves due to the increased nutrient uptake facilitated by a larger photosynthetic area. Nitrogen absorbed by the roots influences leaf growth, as chlorophyll formation during photosynthesis depends on healthy leaf development (Hazmi, 2021). According to Najoan et al. (2022), a higher number of roots enhances nutrient and water absorption, which supports physiological processes that maintain a balance between shoot growth and development.

Percentage of living cuttings

The percentage of living cuttings was calculated from nine data points per treatment, as shown in Table 6. The data in Table 6 indicate that the highest survival rate of begonia leaf cuttings, 100%, was achieved with the whole leaf and 350 ppm and 400 ppm PGR treatments, as well as with the sliced leaf at 350 ppm. The lowest survival rate, 78%, was observed in the whole leaf cuttings treated with 250 ppm PGR and in the sliced leaf cuttings treated with 400 ppm PGR.

PGR soaking treatment promotes endogenous hormones in the cuttings by adding exogenous auxins. Optimal PGR concentrations provide the conditions necessary for stimulating faster growth. The criteria for living cuttings include the presence of roots and emerging shoots. According to Masli et al. (2019), the presence of roots indicates a higher likelihood of survival, whereas cuttings without roots are more likely to perish. Root growth is crucial for determining the viability of cuttings, as it enables nutrient absorption from the growing medium. Latief et al. (2015) stated that auxins in PGR, a plant growth regulator (PGR), stimulate new shoot and bud formation. Auxins in PGR increase cell permeability, cell wall flexibility, hydrogen and potassium ion exchange, break certain hydrogen bonds, and synthesize proteins needed for growth. These processes lead to the renewal and differentiation in the apical meristem and coleoptile, forming growth points and shoot primordia (Fora, 2022).

The lowest survival rates were seen with the whole leaf cuttings at 250 ppm and the sliced leaf cuttings at 400 ppm. In the former case, the auxin supply was insufficient for optimal growth, while in the latter, the hormone application exceeded the optimal range, inhibiting growth. Additionally, unhealed wounds on the sliced cuttings could delay growth. Growth regulators are effective at specific concentrations but can inhibit growth and metabolic processes if applied excessively (Rokhmah, 2020). Mudaningrat & Nada (2021) added that excessive PGR application can damage plant tissues, causing leaf drop, yellowing, and eventually death. According to Shofiana et al. (2013), inappropriate PGR application can lead to auxin overproduction, increasing ethylene production, which reduces leaf number and size and causes leaf drop, contrary to auxin effects (Febriandy et al., 2021).

CONCLUSION

This study explored the impact of different leaf cutting materials and PGR concentrations on the growth and survival of begonia cuttings, a crucial topic for optimizing propagation techniques in horticulture. Our findings indicate that whole leaf cuttings treated with 400 ppm PGR resulted in the highest number of leaves and the longest roots, highlighting the benefits of larger cutting surfaces and optimal auxin levels. While some may argue that lower concentrations or different cutting methods could yield similar results, our data clearly demonstrate the superiority of the specified treatments in enhancing growth parameters and survival rates. This research underscores the necessity of selecting appropriate cutting materials and hormone concentrations to maximize propagation success. Future research should investigate the long-term effects of these treatments and their applicability to other plant species. Implementing these findings can significantly improve propagation efficiency and success in horticultural practices.

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