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Indole-3-Butyric Acid (IBA) as Key Drivers of Rooting Success in Dragon Fruit (*Hylocereus* Spp.) Stem Cuttings – A Review

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Abstract

Dragon fruit (*Hylocereus* spp.), a climbing cactus with significant nutritional and economic value, is primarily propagated through stem cuttings due to its efficiency and genetic uniformity. This review focuses on optimizing propagation practices, particularly the role of auxin application specifically indole-3-butyric acid (IBA) in enhancing rooting and shoot development. IBA, an exogenously applied plant growth regulator, is widely preferred over other auxins due to its superior rooting efficiency, lower toxicity, and ability to promote both primary and lateral root development. It plays a vital role in adventitious root and shoot initiation by stimulating cell division, elongation, and differentiation. This review synthesized recent findings on the mechanisms by which IBA, a key regulator of hormonal, biochemical, and physiological processes enhances propagation efficiency in dragon fruit and offers practical recommendations for sustainable propagation to ensure high-quality plant material for commercial cultivation. This review further explores the effects of different IBA concentrations on root parameters, shoot growth, and overall cutting success in dragon fruit. Additionally, the physiological and biochemical responses of stem cuttings to IBA application such as enhanced carbohydrate mobilization, enzyme activation, and phenolic compound dynamics are discussed to provide a comprehensive understanding of its mode of action. By offering practical recommendations for IBA use, this review supports the development of efficient and sustainable propagation strategies to ensure consistent, high-quality planting material for commercial cultivation in tropical and subtropical regions.

Keywords: *Hylocereus* spp., cutting success, IBA, rooting, biochemical compounds

1. Introduction

Dragon fruit (*Hylocereus* spp.), also known as pitaya, is a perennial climbing cactus native to the tropical and subtropical regions of the Americas. Its cultivation has gained substantial momentum globally, primarily due to its striking appearance, market value, and rich nutritional profile. The fruit is a good source of vitamin C, calcium, and phosphorus, and it possesses potent antioxidant properties that contribute to its increasing popularity among health-conscious consumers (Kakade, 2020; Prisa, 2022). Propagation of dragon fruit can be achieved through both sexual (seeds) and asexual (stem cuttings) methods. Although seed propagation is relatively simple, it often leads to high variability in plant characteristics because of cross-pollination, which is undesirable in commercial production systems that prioritize uniformity. Therefore, stem cuttings are the preferred method for large-scale cultivation. This method ensures genetic fidelity by preserving the desirable traits of the mother plant, thereby resulting in consistent fruit quality (Zem et al., 2015; Singh et al., 2025a). Additionally, propagation through cuttings shortens the juvenile phase, allowing earlier fruit production, which is a significant advantage for commercial growers. The success of vegetative propagation through stem cuttings, however, depends on various factors. These include the physiological status of the mother plant, time or season of propagation, handling and treatment of cuttings, humidity, ambient temperature, and the overall care given before and after planting (Chander and Kumar, 2023; Singh et al., 2025a; Singh et al., 2025b). Optimizing these variables is essential to maximize rooting efficiency and plant establishment. A widely practiced approach to enhance rooting in fruit crops is the application of plant growth regulators, particularly rooting hormones. Among these, Indole-3-butyric acid (IBA), a synthetic auxin, has proven especially effective due to its high efficacy in promoting root initiation and elongation across a wide range of horticultural crops (Pincelli-Souza et al., 2024; Nale et al., 2024; Singh, 2024). IBA is typically applied exogenously to stem cuttings to stimulate the development of primary, lateral, and adventitious roots, leading to improved plant establishment. Its superior rooting ability makes it a critical component in the propagation of high-quality planting material with desirable morphological and physiological traits (Elobeidy, 2006; Tanwar et al., 2020; Madhavan et al., 2021). While other auxins, such as naphthalene acetic acid (NAA), are also used in horticultural practices, they often exhibit higher phytotoxicity and reduced effectiveness, especially in soft or succulent cuttings like those of dragon fruit (Hartmann et al., 1990). In contrast, IBA is not only less toxic but also promotes better overall root architecture, enhancing nutrient uptake and improving post-transplant growth (Kakade et al., 2024). It facilitates stronger root systems by increasing endogenous IAA and GA_3 levels, reducing IAA oxidase activity, and elevating peroxidase activity. These biochemical changes collectively support quicker root initiation and vigorous early plant development. Moreover, IBA-treated cuttings tend to accumulate higher levels of carbohydrates and phenolic compounds, which further enhance auxin action and serve as vital energy sources for rooting processes (Denaxa et al., 2022; Singh et al., 2025b). Recent reviews by Borchetia et al. (2022) and Singh and Rani (2023) provide comprehensive insights into propagation techniques and critical factors influencing the success of dragon fruit multiplication under diverse environmental and management conditions. This review aims to explore the physiological and biochemical mechanisms through which IBA enhances rooting, assess its practical advantages over other auxins, and examine its role in improving propagation efficiency for sustainable dragon fruit production.

2. Introduction to Indole-3-Butyric Acid (IBA)

Indole-3-butyric acid (IBA) is a naturally occurring plant hormone belonging to the auxin family. Auxins are pivotal in regulating various physiological processes, including cell elongation, division, and differentiation. IBA, in particular, is renowned for its effectiveness in promoting adventitious root formation in plant cuttings, making it a cornerstone in horticultural propagation practices. For many years, IBA was regarded as a "synthetic auxin" due to its ability to mimic auxin-like effects, including root initiation, stem curvature, and leaf epinasty (Zimmerman and Wilcoxon, 1935). It serves as the active ingredient in plant propagation products like Rootone®, widely used to promote adventitious rooting in stem cuttings. However, subsequent research revealed that IBA is not merely synthetic but also occurs naturally as an endogenous compound in various plant species (as reviewed by Korasick et al., 2013).

2.1. *Chemical structure and properties of IBA*

Indole-3-butyric acid (IBA) is a white to tan powder or crystalline solid with a slight characteristic odour. IBA has a chemical structure similar to that of indole-3-acetic acid (IAA) $C_{10}H_9NO_2$ (Formula weight: 175.19), another naturally occurring auxin, but with a butyric acid side chain (Figure 1a and 1b). This structural similarity allows it to mimic IAA's functions while offering greater stability and persistence in the plant system. The molecular formula of IBA is $C_{12}H_{13}NO_2$ (Formula weight: 203.24), and its stability under various conditions makes it particularly suitable for commercial and agricultural applications.

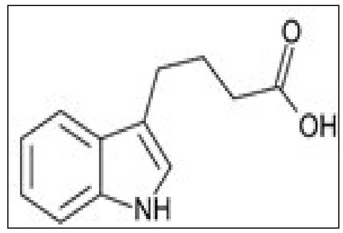

Figure 1a: Indole-3-butyric acid (IBA)

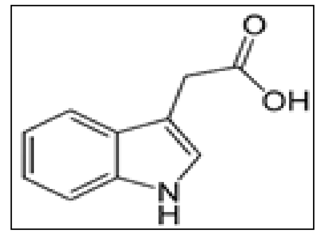

Figure 1b: Indole-3-actic acid (IAA)

Indole-3-butyric acid (IBA) is stable when stored at 2–8°C and should be kept in a cool place. It has a melting point of 121–125°C and a density of 0.60 g cm^{-3} at room temperature. A 1% IBA solution in water has a pH of 3.54. Although it is non-combustible, IBA decomposes under fire, releasing toxic fumes such as NOx, carbon monoxide, and carbon dioxide. IBA is practically insoluble in chloroform but dissolves in alcohol, ether, and acetone . For aqueous applications, IBA is typically first dissolved in methanol and then diluted with water (Jemaa et al., 2011). The sodium salt form of IBA is water-soluble and both water-soluble and water-insoluble IBA products are available (Kroin, 2008). IBA degrades upon exposure to light (Nor Aini et al., 2009).

2.2. *Mechanism of action*

IBA's primary function is to regulate the initiation and development of adventitious roots. It is metabolized into Indole-3-acetic acid (IAA) within plant tissues, triggering auxin-responsive genes that regulate cellular and developmental processes. Its mechanism involves promoting cell elongation, division, and differentiation, which are critical for root initiation. IBA significantly enhances the formation of root primordia by stimulating meristematic cell activity at the cutting base, ensuring robust adventitious root emergence. This process is complemented by the hormone's influence on vascular differentiation, which improves water and nutrient uptake, crucial for plant establishment and growth.

3. Effect of IBA on Rooting, Shoot Growth and Cutting Success in Dragon Fruit

3.1. *Effect of IBA concentrations on root parameters*

IBA-derived auxin plays a pivotal role in multiple aspects of root development, including the regulation of root apical meristem size, elongation of root hairs, initiation and growth of lateral roots, and the formation of adventitious roots (Frick and Strader, 2018).

3.1.1. Number of roots

Dragon fruit has a strong natural rooting ability and can root effectively without auxin treatment; however, the application of IBA enhances rooting, resulting in better and more uniform root development (Elobeidy, 2006). The number of roots is a critical determinant of the successful establishment and subsequent growth of dragon fruit cuttings, as it directly influences nutrient and water uptake. Seran and Thiresh (2015) reported the highest average number of roots (19.3) per cutting in IBA 8000 ppm, statistically at par with IBA 6000 ppm, while untreated cuttings recorded the least (7 roots). Similarly, Ahmad et al. (2016) observed the maximum root number in dragon fruit cuttings treated with IBA 100 ppm and the minimum in the control plot. Chhetri et al. (2021) recorded the highest number of roots (27.6) per cutting in cuttings treated with IBA 5000 ppm. General trends indicate that optimal IBA concentrations and environmental factors significantly enhance root development. Siddiqua et al. (2018) found the maximum number of roots (46.88) in cuttings treated with IBA 7000 ppm, while control cuttings had the minimum. Similarly, Dharani et al. (2023) found the highest number of roots per cutting in dragon fruit treated with IBA 6000 ppm (16.28), with a combination of 25 cm cuttings and IBA 6000 ppm yielding the maximum root number (20.17). Studies also show that IBA treatments at lower concentrations can be effective. Raut et al. (2022) reported the highest root number (55.15) in IBA 2000 ppm-treated cuttings, followed by IBA 2500 ppm (50.34). Pandey et al. (2022) observed a similar trend, with the maximum root number (41.76) recorded in cuttings treated with IBA 4000 ppm, statistically at par with IBA 2000 ppm (40.96). Recent study by Singh et al. (2025) showed higher number of roots in white dragon fruit cuttings treated with IBA 1000 ppm. These findings underscore the consistent positive effect of IBA on root induction in dragon fruit cuttings, with variations attributed to cutting length, collection time, and environmental conditions.

3.1.2. Root length

The length of roots is a vital parameter for the successful establishment of dragon fruit cuttings as it directly impacts water and nutrient uptake, contributing to overall plant vigour. Root elongation is influenced by multiple factors, including the application of growth regulators like IBA and environmental conditions. Seran and Thiresh (2015) reported the maximum root length of 22 cm in dragon fruit cuttings treated with IBA 8000 ppm, statistically at par with IBA 6000 ppm (21.3 cm). Similarly, Ahmad et al. (2016) observed the longest roots in IBA 100 ppm-treated cuttings, while untreated cuttings had the shortest roots. Dhruve et al. (2018) also documented the longest root length (22.93 cm) under IBA 6000 ppm treatment. General trends highlight that optimal concentrations of IBA consistently promote greater root elongation across studies.

Chhetri et al. (2021) demonstrated that cuttings treated with IBA 6000 ppm yielded the longest roots (26.6 cm). Rodrigues et al. (2021) observed maximum root length in cuttings taken during summer (17.13 cm). These findings reaffirm the role of IBA in enhancing root length. Wadhekar et al. (2022b) found IBA 7000 ppm produced the longest roots (12.50 cm), statistically at par with IBA 6000 ppm (11.67 cm). Raut et al. (2022) observed the highest root length (20.62 cm) in cuttings treated with IBA 2000 ppm, followed by IBA 2500 ppm (18.70 cm). Ali et al. (2022) recorded the longest roots (14.79 cm) in cuttings treated with IBA 7000 ppm, closely followed by IBA 6000 ppm (13.42 cm). Additionally, environmental factors and cutting techniques influence outcomes. Chhetri et al. (2023) observed the longest roots (29.60 cm) in cuttings treated with IBA 7000 ppm after a slant cut. Dharani et al. (2023) found that cuttings treated with IBA 6000 ppm exhibited the maximum root length of 13.83 cm, and IBA 6000 ppm achieved a root length of 17.64 cm in another study. In white dragon fruit cuttings, 1000 ppm IBA resulted in the longest root length, reflecting improved carbohydrate metabolism and root elongation (Singh et al., 2025). These studies collectively emphasize the importance of IBA in optimizing root length, a key factor in establishing robust and healthy dragon fruit plants.

3.1.3. Fresh and dry weight of root

The fresh and dry weights of roots are critical indicators of root system development, influencing the successful establishment and growth of dragon fruit cuttings. These parameters highlight the efficiency of treatments, particularly rooting hormones like IBA, in enhancing root mass and plant health. Seran and Thiresh (2015) observed the maximum fresh weight (2.96 g) and dry weight (0.90 g) in roots of dragon fruit cuttings treated with IBA 8000 ppm. Other IBA concentrations, such as 2000, 4000 and 6000 ppm, showed no significant differences. Ahmad et al. (2016) recorded the highest fresh (2.7 g) and dry (0.8 g) weights in cuttings treated with IBA 100 ppm, while untreated cuttings had the lowest values. Similarly, Dhruve et al. (2018) noted that IBA 6000 ppm-treated cuttings exhibited the maximum fresh weight (1.83 g) and dry weight (0.58 g) of roots, followed by IBA 4000 ppm-treated cuttings. The trend of improved root weight with higher IBA concentrations is evident in other studies. Siddiqua et al. (2018) also observed the highest fresh (2.28 g) and dry weights (0.67 g) in cuttings treated with IBA 7000 ppm, while untreated cuttings had the least. Root mass can also be influenced by environmental factors and cutting techniques. Chhetri et al. (2021) standardized IBA treatments and cutting lengths, finding that IBA 6000 ppm resulted in maximum fresh (2.49 g) and dry weight (0.64 g) of roots. Ali et al. (2022) highlighted IBA 7000 ppm as the most effective treatment, resulting in fresh and dry weights of 1.96 g and 0.98

g, respectively. Consistency in results across various studies underscores the role of IBA in enhancing root weight. Pandey et al. (2022) reported the highest fresh weight (2.22 g) and dry weight (0.59 g) under IBA 4000 ppm, followed by IBA 2000 ppm treatments. Raut et al. (2022) recorded similar trends, with IBA 2000 ppm producing the highest fresh weight (2.09 g) and dry weight (0.61 g). Chhetri et al. (2023) found that fresh weight peaked at 1.78 g in cuttings collected in June, exposed to the interior wood portion, and treated with IBA 5000 ppm, while untreated cuttings showed minimal root mass. In fig cv. Brown Turkey the highest number of roots per cutting (69.5), along with increased root fresh weight (4.9 g) and dry weight (2.4 g), was recorded in IBA-treated cuttings (100 ppm) after 180 days of planting. The stimulation of root formation suggests that IBA promotes cell division and elongation in root primordia, Chander and Kumar (2023). In white dragon fruit cuttings, 1000 ppm IBA increased the fresh and dry weight of roots, showing significant enhancement of root biomass accumulation (Singh et al., 2025). Application of IBA at 2500 ppm by quick dip method was found most effective in enhancing root biomass of hardwood cuttings in common fig, resulting in the highest fresh weight (12.72 g) and dry weight (4.75 g) of roots per cutting (Nale et al., 2024). These findings collectively reinforce the importance of rooting hormones, particularly IBA, in promoting better root development, ensuring successful establishment and nutrient uptake for dragon fruit cuttings.

3.2. Effect of IBA concentrations on shoot parameters

3.2.1. Shoot emergence

The emergence of shoots is a crucial step in the propagation of dragon fruit. Studies have shown that the application of auxins, particularly IBA, significantly influences the time taken for shoot emergence. Various studies highlight the significant role of IBA in enhancing sprout emergence and growth in dragon fruit cuttings. Similarly, Dhruve et al. (2018) found the earliest sprout emergence (43 days) with 6000 ppm IBA, followed by 4000 ppm. Wadhekar et al. (2022) observed the quickest shoot initiation in 14.83 days with 7000 ppm IBA, closely followed by 6000 ppm (15.33 days). Raut et al. (2022) demonstrated that treatment with 2000 ppm IBA resulted in sprouting within 36.99 days, whereas the longest duration (51.90 days) was observed with 500 ppm IBA. Dharani et al. (2023) reported that IBA at 6000 ppm led to sprouting in 8.26 days, significantly reducing the time required compared to untreated controls. Malik et al. (2023) found that IBA at 8500 ppm, combined with a soil, sand, and vermicompost mixture, minimized sprouting time (17.87 days), while untreated cuttings took the longest. Chander and Kumar (2023) found that fig cuttings with 1000 ppm IBA significantly enhances rooting success, shoot growth, and overall biomass accumulation. In white dragon fruit cuttings, 1000 ppm IBA significantly reduced the time to shoot emergence, attributed to enhanced nutrient mobilization (Singh et al., 2025). These findings demonstrate that IBA treated cuttings are generally more effective in significantly reducing the time to sprout emergence compared to lower concentrations or untreated controls. The ability of IBA to stimulate root and shoot initiation through enhanced cell division and elongation makes it a crucial factor in optimizing dragon fruit propagation.

3.2.2. Number of shoots

The number of shoots emerging from a cutting is a direct indicator of the physiological vigour and overall health of the plant, reflecting its ability to support robust growth. Numerous studies have demonstrated that auxin concentration, particularly IBA, plays a pivotal role in regulating shoot emergence in dragon fruit cuttings by promoting cell division and differentiation at the cutting's nodal regions. Studies emphasize the critical role of IBA in promoting number of shoot emergence in dragon fruit cuttings. Siddiqua et al. (2018) reported the highest number of shoots per cutting (2.4) with 7000 ppm IBA, while untreated controls produced the least (1.4). Dhruve et al. (2018) observed the maximum shoots (4.0) in cuttings treated with 6000 ppm IBA, significantly outperforming the control. Similarly, Wadhekar et al. (2022) recorded 2.5 shoots per cutting with 7000 ppm IBA, followed by 2.2 shoots with 6000 ppm. Raut et al. (2022) demonstrated that IBA at 2000 ppm resulted in 4.7 sprouts per cutting, comparable to 4.51 sprouts with 2500 ppm. Ali et al. (2022) found that IBA at 7000 ppm influenced the highest number of sprouts per cutting (2.67). Dharani et al. (2023) observed the maximum shoots per cutting (3.7) in dragon fruit treated with 6000 ppm IBA, whereas untreated cuttings produced the fewest. Malik et al. (2023) reported the highest number of sprouts (3.1) with 8500 ppm IBA in a soil, sand, and vermicompost mixture, with untreated cuttings showing the lowest sprout count. Number of Shoots: In white dragon fruit cuttings, 1000 ppm IBA promoted the highest number of shoots per cutting, demonstrating a direct positive influence on shoot proliferation (Singh et al. 2025a). These findings underline that IBA application enhances the number of shoots per cutting, with higher concentrations generally yielding superior results. Auxins like IBA are crucial in stimulating cell division and shoot proliferation, making them essential for optimizing propagation practices in dragon fruit cultivation.

3.2.3. Shoot length

The length of shoots serves as a critical indicator of the vigour and potential growth of nursery plants, including dragon fruit. Several studies have highlighted the influence of Indole-3-butyric acid (IBA) treatments in enhancing shoot growth in dragon fruit cuttings. Optimal IBA concentrations have been shown to significantly promote shoot elongation, reflecting improved plant vigor and establishment potential. This underscores the pivotal role of auxin treatments in nursery management practices. Seran and Thiresh (2015) reported maximum shoot length (9.5 cm) in cuttings treated with IBA at 6000 ppm, followed by 4000 ppm (7.3 cm), while untreated cuttings exhibited the least growth (4.3 cm). Similarly, Dhruve et al. (2018) observed the longest shoot length (23.9 cm) in cuttings treated with IBA at 6000 ppm, with 4000 ppm producing slightly shorter shoots.

Chhetri et al. (2021) observed the highest shoot growth (28.9 cm) in cuttings treated with 5000 ppm IBA. Raut et al. (2022) found that cuttings treated with IBA at 2000 ppm recorded maximum shoot length (31.7 cm), followed by 2500 ppm (29.5 cm). Several researchers have also studied shoot growth at different intervals. Wadhekar et al. (2022a) recorded maximum shoot lengths at 30, 60, and 90 days after planting (2.6, 8.4 and 17.5 cm, respectively) in cuttings treated with 7000 ppm IBA. Similarly, Ali et al. (2022) noted shoot lengths of 3.8, 9.0 and 20.2 cm at the same intervals for cuttings treated with 7000 ppm IBA, followed by 6000 ppm. Malik et al. (2023) reported the highest average shoot lengths per cutting (4.47, 13.40 and 25.65 cm) in cuttings treated with IBA at 8500 ppm, with the longest shoots measuring 6.35, 14.65, and 27.53 cm at these intervals. Dharani et al. (2023) observed that cuttings treated with IBA at 6000 ppm achieved significantly higher shoot growth (12.9, 33.1 and 59.7 cm at 30, 60 and 90 days, respectively). The treatment with 6000 ppm IBA consistently produced the highest shoot lengths (20.9, 42.2 and 75.5 cm) at these intervals. In white dragon fruit cuttings, 1000 ppm IBA resulted in the maximum shoot length, likely due to improved water and nutrient uptake facilitated by enhanced root growth (Singh et al., 2025). These findings consistently highlight the significant role of IBA concentrations in promoting shoot elongation in dragon fruit cuttings, with variations depending on time after planting.

3.2.4. Fresh and dry weight of shoot

The fresh and dry weight of the shoots provide insights into the overall growth and biomass accumulation of the young nursery plants. The fresh and dry weights of shoots are crucial parameters for assessing the growth and vigour of dragon fruit cuttings, as they indicate the plant's biomass accumulation and overall health. Seran and Thiresh (2015) recorded the highest fresh weight of shoots (10.3 g) in cuttings treated with IBA at 6000 ppm, which was statistically at par with 4000 ppm, while untreated cuttings showed the least weight. A similar trend was observed in dry weight, where the maximum value (0.6 g) was recorded in IBA 6000 ppm-treated cuttings, and the minimum (0.2 g) in untreated cuttings. Dhruve et al. (2018) also reported maximum shoot weights, both fresh (112.1 g) and dry (9.5 g), under IBA 6000 ppm treatment.

General trends suggest that larger cuttings and optimal IBA concentrations result in greater biomass accumulation. Rodrigues et al. (2021) demonstrated that longer cuttings (40 cm) collected during winter showed superior fresh and dry mass compared to shorter cuttings collected in summer. Raut et al. (2022) reported maximum fresh weight (47.77 g) in cuttings treated with IBA at 2000 ppm, which was statistically at par with 2500 ppm (46.27 g) and 3000 ppm (44.70 g). Similarly, dry weights were highest under IBA treatments of 2000 ppm (8.39 g), followed by 2500 ppm (7.37 g) and 3000 ppm (7.24 g). Wadhekar et al. (2022a) observed that IBA at 7000 ppm resulted in maximum fresh weight (56.67 g), statistically at par with IBA 6000 ppm. The dry weight followed a similar trend, with the highest value (11.3 g) in IBA 7000 ppm-treated cuttings, comparable to 6000 ppm (11.10 g). In white dragon fruit cuttings, 1000 ppm IBA maximized shoot fresh and dry weights, indicating increased biomass accumulation due to enhanced shoot development (Singh et al. 2025). These findings consistently underscore the effectiveness of IBA treatments in enhancing the fresh and dry biomass of dragon fruit cuttings across various studies.

3.3. Effect of IBA concentrations on cutting success

Cutting success, often assessed through survival and shooting percentages, is a critical determinant of the propagation potential in dragon fruit. These metrics reflect the effectiveness of treatments, environmental conditions, and cutting techniques in establishing healthy plants.

Dhruve et al. (2018) reported the highest survival percentage (90.26%) in cuttings treated with IBA 6000 ppm, significantly outperforming other concentrations and the control group. Ringphawan and Alila (2019) achieved a remarkable 100% survival rate in 15 cm cuttings treated with 1000 ppm IBA, even after a year of planting, demonstrating the long-term benefits of optimal IBA concentrations. Raut et al. (2022) highlighted the superior performance of IBA 2000 ppm, which achieved a maximum survival rate of 95.87%, comparable to IBA 2500 ppm. The lowest survival rate was observed in cuttings treated with a 500 ppm IBA solution. Similarly, Wadhekar et al. (2022) noted the highest shooting percentage in cuttings treated with IBA 7000 ppm, which was statistically similar to the IBA 6000 ppm treatment, with untreated cuttings showing the lowest shooting percentages. Ali et al. (2022) demonstrated the influence of IBA on survival rates, with IBA 7000 ppm yielding a maximum survival percentage of 94.43%, statistically at par with IBA 6000 ppm. They observed the highest success (96.66%) in 20 cm cuttings, followed by 15 cm cuttings (87.75%). Notably, 100% survival was recorded in combinations like IBA 7000 ppm+20 cm cutting and IBA 6000 ppm+20 cm cutting, emphasizing the synergy between cutting length and hormone concentration. Malik et al. (2023) observed a 100% survival rate in cuttings treated with IBA 8500 ppm, followed by 93.33% for IBA 4500 ppm, while untreated cuttings showed the lowest survival percentage (60%). Dharani et al. (2023) recorded the highest survival percentage (93.42%) in 25 cm cuttings treated with IBA 6000 ppm, although the interaction between length and treatment showed no significant difference. Lengthwise, 25 cm cuttings demonstrated maximum survival (85.39%), and treatment-wise, IBA 6000 ppm proved to be the most effective (79.22%). IBA application at 1000 ppm resulted in the highest cutting success rate (68.6%) and enhanced bud sprouting (2.4 buds per cutting), demonstrating its role in improving vegetative propagation efficiency in fig cv. Brown Turkey (Chander and Kumar, 2023). In white dragon fruit cuttings, 1000 ppm IBA achieved the highest cutting success rate, demonstrating its effectiveness in promoting successful propagation (Singh et al., 2025). These findings underline the crucial role of IBA concentration in enhancing the success of dragon fruit cuttings. The consistency of results across different studies further validates the use of rooting hormones as a reliable strategy for successful propagation.

3.4. Physiological and biochemical effects of IBA on dragon fruit stem cuttings

3.4.1. Effect of IBA concentrations on hormonal content

Enhanced endogenous hormone levels, particularly indole-3-acetic acid (IAA) and gibberellic acid (GA_3), play a crucial role in root initiation and development. Auxins, such as indole-3-butyric acid (IBA), are widely used to stimulate root formation by influencing endogenous hormone levels. Increased IAA content at the time of root initiation has been reported in several plant species. Stefancic et al. (2007) observed a significant rise in IAA levels during root initiation in cherry rootstock 'GiSela 5', suggesting its critical role in early root development. Similarly, Abo El-Enien and Omar (2018) found that IBA-treated cuttings exhibited significantly higher GA_3 concentrations than untreated controls, reinforcing IBA's role in modulating hormonal activity to enhance rooting responses. In white dragon fruit cuttings, the application of 1000 ppm IBA significantly elevated endogenous IAA and GA_3 levels, positively influencing root initiation and subsequent growth. Cuttings treated with 1000 ppm IBA showed a 60% higher IAA content compared to the control. Additionally, GA_3 content was 40.63% higher per mg ml^{-1} during the root initiation phase, following a similar trend to IAA. These findings highlight the role of IBA in regulating key plant hormones to enhance root induction and establishment (Singh et al., 2025b).

3.4.2. Effect of IBA concentrations on biochemical contents

Phenolic compounds and carbohydrates play a crucial role in root initiation and development in plant cuttings. Phenolic compounds, as key secondary metabolites, influence various physiological processes, including auxin regulation, by acting as cofactors that enhance its activity. Higher phenol content has been observed in the basal portions of cuttings, contributing to improved rooting responses. Denaxa et al. (2022) reported that some phenolic compounds act as competing substrates for indole-3-acetic acid (IAA) oxidase, thereby improving auxin stimulus and promoting root initiation.

Similarly, carbohydrates serve as essential energy sources for cell division and root formation, with their concentration increasing in response to auxin treatment. This process may occur through the activation of hydrolyzing enzymes or by enhancing carbohydrate translocation towards the cutting base (Denaxa et al., 2012). da Costa et al. (2013), emphasizing the role of carbohydrates in enhancing bud sprouting and metabolic processes. In white dragon fruit cuttings, the application of 1000 ppm IBA significantly increased phenol (1.3 mg g^{-1} FW) and carbohydrate (41.9%) content, highlighting their positive role during root initiation (Singh et al., 2025b). The higher carbohydrate content likely provided the necessary energy for root development, coinciding with the high rooting ability in treated cuttings.

Enzymatic activities play a critical role in root initiation, influencing the balance between root-promoting and root-inhibiting processes. IAA oxidase and peroxidase (POD) are key enzymes involved in auxin metabolism and root formation. Higher IAA oxidase activity has been associated with reduced root initiation, while increased peroxidase activity is linked to enhanced root formation. The presence of phenolic compounds is known to regulate these enzymatic activities by acting as competing substrates for IAA oxidase, thereby reducing its activity and preserving auxin levels. Husen et al. (2017) reported a strong correlation between increased peroxidase activity and root-related processes such as cell division and primordium formation in mulberry, highlighting its importance in root initiation. In white dragon fruit cuttings, the application of 1000 ppm IBA significantly influenced enzymatic activity during root initiation (Singh et al., 2025b). IAA oxidase activity was higher (101.4 Δ OD min^{-1} g^{-1} FW) in control cuttings, indicating its negative impact on root formation, whereas peroxidase activity (21.7 U min^{-1} mg^{-1} FW) was significantly higher in IBA-treated cuttings. The increased peroxidase levels in the rooting zone suggest its role in root development, likely due to its involvement in cofactor formation essential for root initiation.

Chlorophyll content is a key indicator of photosynthetic efficiency and plant health. The application of IBA enhances chlorophyll synthesis by improving nutrient uptake and metabolic activity, supporting better rooting and growth. Increased chlorophyll levels have been linked to enhanced vegetative development in various plant species. In white dragon fruit cuttings, 1000 ppm IBA significantly increased total chlorophyll content. The highest levels were recorded in 30 cm IBA-treated cuttings, with 6.4 mg g^{-1} in March and 6.1 mg g^{-1} in July, while control cuttings showed lower values (4.5 mg g^{-1} in March and 3.9 mg g^{-1} in July). The significant increase underscores IBA's role in promoting chlorophyll synthesis, contributing to improved rooting and overall plant growth (Singh et al., 2025b).

4. Conclusion

Indole-3-butyric acid significantly enhances root and shoot development in dragon fruit cuttings by improving root number, length, biomass, and shoot vigour. IBA also modulates endogenous hormones, notably increasing IAA and GA_3 levels, which are crucial for root initiation. Biochemically, it elevates phenolic and carbohydrate contents that support auxin activity and provide energy for root formation. Enzymatically, IBA reduces IAA oxidase and increases peroxidase activity, both favourable for rooting. Factors such as cutting length, collection timing, and environmental conditions further affect propagation success. This review synthesized existing research on optimal IBA concentrations and cutting techniques to promote efficient and sustainable propagation strategies for dragon fruit cultivation.

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