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Natural plant extracts as a sustainable alternative to synthetic plant growth regulators: A review

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Abstract
The expanding global need for sustainable farming methods has fuelled research on plant-based alternatives to traditional plant growth regulators. Traditional PGRs, while effective, can offer environmental and health hazards due to their synthetic composition and the possibility of residual contamination. Therefore, there's an increase in curiosity in employing natural plant extracts as an environmentally beneficial and eco-friendly alternative. Plant extracts generated from various botanical sources contain a diverse array of bioactive chemicals such as phytohormones, phenolics, flavonoids, and alkaloids, which can influence plant growth and development. Extracts from plants such as seaweed, moringa, and neem, for example, have shown promise in terms of raising germination rates, improving root architecture, and increasing stress resistance. These extracts work by mimicking or altering the action of natural hormones like auxins, gibberellins, cytokinin, and abscisic acid. Furthermore, they provide additional benefits such as antibacterial capabilities, which can lower the occurrence of plant diseases, and antioxidant activities, which improve plant tolerance to environmental stressors. Plant extracts hold significant promise as natural alternatives to synthetic PGRs, offering a sustainable solution to enhance plant growth and productivity. While challenges remain in terms of standardization and large-scale application, continued research and innovation could unlock their full potential, contributing to more sustainable agricultural practices and improved environmental health.

Keywords: Bioactive chemicals, eco-friendly, plant extracts, seaweed, sustainable farming

Introduction
Stem-cutting propagation among plants is one of the most basic methods in horticulture and agriculture to rapidly increase the number of parent plants. It is highly valued due to its capacity to produce clones of the parent plants with genetic uniformity (Abhinav *et al.*, 2016) [2]. Cuttings are tough to develop without the assistance of growth stimulants and usually require a lot of effort (Uddin *et al*., 2020) [49]. Auxin promotes vascular tissue differentiation, inhibits branch differentiation, and suppresses the creation of the abscission layer in leaves. Auxin is one of the most crucial hormones used on stem cuttings to hasten the development of adventitious roots (Sahin and Uysal 2018) [45]. Auxin influences root development and boosts cutting rooting percentage (Ahmed *et al.*, 2017) [3]. Young shoots and leaves on plants produce natural auxin, however, successful rooting of cuttings requires the application of synthetic auxins such as Naphthalene-acetic Acid (NAA) and Indole-3-Butyric Acid (IAA) (Galavi *et al.*, 2013) [20].
Nevertheless, the use of synthetic rooting hormones raises numerous problems due to their effects on the environment, human health, and economic restrictions, despite their high effectiveness (Dunsin *et al.*, 2014) [11]. Whereas, natural root stimulating agents are a safe and cost-effective method for rooting horticulture crops. They are environmentally friendly and can replace synthetic plant growth hormones. Therefore, the use of plant extracts is regarded as a significant non-chemical approach to propagating horticultural crops that avoids the use of synthetic hormones (Rajan and Singh 2021) [39].
Some of the natural plant extracts are *Aloe vera*, coconut water, garlic, willow leaf extract, seaweed extract, moringa leaf extract, cinnamon powder, ginger, and liquorice (Khalid and Ahmed 2022; Aryan *et al.*, 2023) [27, 6]. They contain rooting hormones such as auxin, gibberellins, cytokinin, many complex components, including polysaccharides, glycoproteins, phenolic compounds, ethylene, abscisic acid, salicylic acid,

lignin, hormones, amino acids, vitamins, and enzymes which promote plant growth and give high yield and resistance to pathogens (Mirihagalla and Fernando 2020) [31]. This review explores the potential of natural plant extracts as a sustainable and eco-friendly substitute for synthetic PGRs.

Effect of different plant extracts application on growth parameters of different crops

Aloe vera

Aloe vera, a widely recognized organic substance, has emerged as a promising alternative to synthetic rooting hormones. Its ability to stimulate root growth in various plant types can be attributed to its complex composition. *Aloe vera* leaves contain polysaccharides, glycoproteins, phenolic compounds, salicylic acid, lignin, and other beneficial elements, including hormones, amino acids, vitamins, and enzymes. These components contribute to its diverse properties, including antibacterial, antifungal, antioxidant, and immune-boosting effects (Mirihagalla *et al.*, 2020; Othman & Hawezy, 2022; Aryan *et al.*, 2023) [31, 24, 6]. Research suggests that *Aloe vera* leaf extract is rich in phytohormones and nutrients, including gibberellic acid (GA3), indole-3-acetic acid (IAA), abscisic acid (ABA), glucose, and protein (Rajan *et al.*, 2023) [40]. Studies by Shidiki *et al.*, (2019) [48] even indicate that *Aloe vera* can be more effective than the synthetic auxin IBA in promoting root development in *Vitex diversifolia* cuttings. Additionally, Khater *et al*. (2020) [29] observed significant improvements in vegetative growth, seed production, oil yield, and the chemical composition of *Carum carvi* plants treated with a 100% *Aloe vera* extract spray. Further research by Wise *et al.*, (2024) [52] explored the impact of a bio stimulant complex containing molasses, *Aloe vera* extract, and fish hydrolysate on strawberry plants. Their findings revealed that this bio stimulant treatment significantly enhanced plant biomass, canopy area, yield, fruit quality, and antioxidant potential. Similarly, Uddin *et al.*, (2020) [49] demonstrated the effectiveness of *Aloe vera* gel in promoting root development in grapevine cuttings.

Coconut water

Coconut water is a natural treasure trove of plant growth hormones. It contains auxins, gibberellins, and cytokinin, which stimulate various aspects of plant growth. Interestingly, it also possesses natural inhibitors and regulators like ethylene, abscisic acid, phenols, and flavanols. These act as a balancing force, ensuring proper development (Mirihagalla & Fernando 2020) [31]. Chauhan *et al.*, (2018) [9] investigated the effect of coconut water on rose micropropagation. They found that adding 10% coconut water by volume to the standard MS medium significantly boosted several growth parameters. Compared to the control group, shoots treated with coconut water exhibited a remarkable increase in multiplication rate (15.41±1.12 shoots per explant), shoot length (3.66±0.08 cm), fresh weight (7.48±0.71 g), and dry weight (1.68±0.075 g). These findings suggest the potential of coconut water as a natural alternative to synthetic growth regulators in plant propagation. Rajan *et al.*, (2023) [40] reported that cuttings treated with 50% coconut water had the highest survival rate (66.8%) whereas in combination with 50% *Aloe vera* for 12 hours resulted in a larger number of roots (7.8), root length (3.7 cm), root diameter (2.8 mm), and rooting percentage (70.3%). Usman *et al*., (2015) treated Bullock ex Hoyl single node stem cuttings with coconut water at various concentrations (25, 50, and 100%). Coconut water outperformed IBA (58.33%, 0.13) and NAA (56.94%, 0.05) in terms of sprouting and callusing, with 76.39% and 0.23, respectively. Coconut water-treated cuttings had more leaves (4.30) compared to IBA (3.38) and NAA (3.34).100% coconut water gives the maximum root length (4.90 cm), number of leaves (4.44), number of shoots (1.77), shoot length (2.61 cm) in grapevine cuttings according to Muttulani (2022) [7, 32].

Table 1: Effect of coconut water on growth parameters of different crops

Crop	Concentration	Sprouting percentage (%)	Shoot length (cm)	Root length (cm)	References
Rose	10%	-	3.67	-	Chauhan *et al*., 2018 [9]
Grape	50% coconut water+ 50% *Aloe vera*	66.8	-	3.7	Rajan *et al.*, 2023 [40]
Grape	100%	76.67	2.61	4.90	Muttulani 2022 [7, 32]
Bullox	100%	71.30	1.04	2.25	Usman *et al*., 2015 [50]

Seaweed extracts

Sea Seaweed extracts have emerged as a potent tool for promoting the growth and development of plants. These extracts contain a rich composition of active compounds, making them highly valuable for various agricultural applications. One significant advantage is their ability to enhance the uptake and utilization of nutrients within plants. Seaweed extracts are abundant in essential minerals such as potassium and amino acids, which *serve* as the building blocks for plant tissues. This improved nutrient profile leads to better root growth, increased photosynthesis, and enhanced overall plant metabolism (Satish *et al.*, 2015; Massoud *et al.*, 2017) [47, 30]. In addition to providing basic nutrition, seaweed extracts also contain natural growth hormones like gibberellin, cytokinin, and auxin. These hormones mimic the effects of their synthetic counterparts, stimulating seed germination, improving leaf quality, promoting shoot development, and enhancing root growth (Massoud *et al*., 2017) [30]. Research conducted by Potente and Manigo (2023) [38] demonstrated the effectiveness of seaweed-based dips in promoting root development in dragon fruit cuttings. Compared to other treatments, dipping the cuttings in a 10% seaweed extract solution resulted in longer and thicker roots, more lateral roots, and a higher root-shoot ratio. Similarly, Gomes *et al*. (2018) [21] observed successful rooting in Passiflora actinia stem cuttings when they were dipped in a 40% brown seaweed extract (*Ascophyllum nodosum*). This treatment not only promoted root development but also improved leaf retention, facilitating plant propagation. The positive impact of seaweed extracts extends beyond root growth and propagation. Studies conducted by Dutta *et al*., (2023) [12] showed that kiwifruit cuttings treated with seaweed extract exhibited higher levels of chlorophyll (essential for

photosynthesis), carotenoids (important antioxidants), and total carbohydrates compared to untreated controls. Additionally, these cuttings displayed reduced electrolyte leakage, indicating improved stress tolerance. Field trials conducted by Eroğul *et al.*, (2022) [19] suggest that foliar application of seaweed extract at specific growth stages can be beneficial for certain crops. Their research in almond cultivation revealed that a seaweed spray applied at a concentration of 4000 ppm ten days after full bloom significantly improved almond yield.

Moringa extract

Moringa (*Moringa oleifera* Lam) extract is gaining traction as a cost-effective and eco-friendly bio stimulant, promoting sustainable agricultural practices and improved crop yields. This natural extract boasts a rich composition of essential nutrients, plant hormones like auxins, gibberellins, and cytokinin, alongside valuable vitamins, antioxidants, and other beneficial compounds. Moringa extract offers a multifaceted approach to plant health and productivity. It acts as a growth promoter, enhancing seed germination, plant development, and photosynthesis at a minimal cost. Additionally, it supports flowering and fruiting processes, leading to improved fruit quality and extended post-harvest shelf life while delaying senescence (natural aging). Beyond promoting growth, Moringa extract also empowers plants to combat abiotic stressors like salinity, drought, extreme temperatures, and heavy metals. This stress-mitigating effect is achieved by increasing the activity of antioxidant enzymes and boosting the levels of beneficial compounds like phenols, flavonoids, sugars, and osmolytes. Consequently, Moringa extract reduces the production of harmful reactive oxygen species, lipid peroxidation, and electrolyte leakage, all of which contribute to plant stress and damage (Khan *et al.*, 2020; Arif *et al.*, 2023) [28, 5]. Moringa extract can be a valuable tool in plant propagation. Dunsin *et al.*, (2014) [11] compared its effectiveness to coconut water, another natural rooting stimulant. While both treatments showed positive results, Moringa extract outperformed coconut water in promoting root development, particularly in terms of total root number, root length, and the length of the longest root. Several studies have documented the positive impact of Moringa extract on fruit yield and quality. Khan *et al.*, (2020) [28] observed significant improvements in grapevine parameters like leaf nutrient content, cane length, berry set, and overall yield following foliar application of Moringa extract. Interestingly, different grape cultivars responded with varying degrees of yield increase, with "Perlette" showcasing the most significant improvement (32.1%). Similar findings were reported by El-Enien *et al.*, (2015) [18] in their research on Washington Navel oranges. Moringa extract application resulted in increased fruit yield, juice content, total soluble solids (a measure of sugar content), and acidity. Finally, research by Ibrahim and Al-Sayed (2023) [25] suggests that soaking rose cuttings in a 4% Moringa extract solution yielded the best results for successful rooting. Moringa extract emerges as a powerful and versatile tool for sustainable agriculture. Its ability to promote growth, enhance stress tolerance, improve yield, and extend shelf life makes it a promising alternative to synthetic fertilizers and growth regulators.

Table 2: Effect of Moringa extract on growth parameters of different crops.

Crop	Concentration	Growth parameters	References
Snowbush	100%	Shoot length (13.84 cm)	El-Banna *et al.*, 2023 [15]
Orange (Washington Navel)	3%	Fruit yield (91.84 kg)	El-Enien *et al.*, 2015 [18]
Rose	4%	Rooting percentage (73.99%)	Ibrahim and Al-Sayed 2023 [25]
Parika biglobosa	100%	Longest root (1.493)	Dunsin *et al.*, 2014 [11]

Garlic

Garlic extract boasts a range of beneficial properties that hold promise for sustainable agriculture. Beyond its well-known antioxidant, antimicrobial, and antibacterial qualities, garlic extract is a rich source of essential nutrients like lipids, carbohydrates, fibres, minerals (manganese, potassium, sulphur, calcium, etc.), and vitamins (B6, C). These components contribute to its positive impact on plant growth and health. Al Mayahi and Fayadh (2015) [53] investigated the effect of garlic extract on potato plants. Their findings revealed that a specific concentration (250 mL per Litre) of garlic extract significantly improved both vegetative growth and overall yield (quantity and quality) compared to control groups with no extract or a lower concentration. Similarly, Abbasifar *et al.*, (2020) [1] observed positive effects on grapevine cuttings treated with a 25 g/L garlic extract solution. This treatment resulted in an increase in the number and quality of both shoots and roots, suggesting its potential for promoting healthy root and shoot development. Garlic extracts also demonstrates promise in pest control. Karimi and Zarghani (2023) [26] found that a 20% garlic extract solution effectively reduced nematode populations in forest plum trees. This suggests its potential as a natural alternative to synthetic pesticides. Furthermore, research by Hawezy (2022) [24] indicates that garlic extract treatment can enhance root development in plants. This study observed improvements in fresh and dry root weight, rooting percentage, and overall root health compared to untreated controls. de Carvalho *et al.*, (2016) [10] explored the use of garlic extract to overcome bud dormancy in grapevine cultivars. Their findings revealed that a natural garlic extract application was more effective in breaking bud dormancy compared to a synthetic product (Dormex) in specific grape varieties.

Willow extract

Willow species (*Salix spp*.) have long been recognized for their fungicidal, insecticidal, and antibacterial properties. Recent research delves deeper, highlighting the potential of willow bark, shoot, and leaf extracts as natural rooting stimulants for plant cuttings (Mohammed 2021; Salih *et al.*, 2024) [32, 46]. Studies reveal that willow extracts are rich in various bioactive compounds, including polyphenols (proanthocyanidins, phenolic acids, flavonoids, tannins, and lignans), terpenoids, and most notably, salicylate compounds like salicin, saligenin, and salicylic acid. These compounds play a crucial role in willow's defence mechanisms and signalling pathways. Interestingly, many of these components also offer medicinal benefits, with salicin (the precursor to aspirin) being a prime example. It's

important to note that the specific composition and concentration of these bioactive compounds can vary depending on several factors. These include the age of the willow plant, the season, the type of plant tissue used for extract creation, the specific willow species or genotype, and even various environmental conditions (Mutlu-Durak & Yildiz Kutman 2021) [35]. According to Wise *et al.,* (2020) [51], cuttings of chrysanthemum and lavender performed best with a concentration of 1.06 µL/L willow bark extract. Karimi and Zarghani (2023) [26] revealed that in forest apples, a 24-hour cutting tip dip in willow extract produced the most sprouts, roots, and fresh root weight. Rehman *et al.,* (2018) [44] reported that apple cuttings dipped in willow leaf extract for 4 hours gave the highest sprouting percentage (97.18%) while cuttings dipped for 8 hours gave maximum plant height (20.56 cm), the maximum number of roots (14.09 cm), maximum root length (14.09 cm), maximum plant diameter (1.37 cm). Bekier *et al.,* (2022) [8] recorded the highest yield from the pots with the mixture of willow, hay, and mineral nitrogen.

Liquorice

Liquorice is one of the oldest herbs, and it can increase numerous plant vegetative characteristics, including plant height, number of leaves, root length, and root dry weight. Liquorice root extract contains flavonoids such as liquorice saponin and glycyrrhizin, as well as phytoestrogens isoflavones glabrene and isoflavones glabridin (El Botaty and Saleh 2018) [16].

Mustafa *et al.,* (2023) [34] demonstrated that cuttings treated with 6 g/L liquorice extract had the highest rate of rooting (86.66%) and that this rate was substantially different from control cuttings (53.33%), compared to 3000 ppm IBA (66.66%). Research suggests that liquorice extract holds promise as a natural alternative to synthetic auxins like IBA for promoting root development in plant cuttings. Studies by Eid *et al.* (2018) [13] investigated the effectiveness of liquorice extract on olive cuttings. Soaking Picual olive cuttings in a 5-10 g/L liquorice extract solution for 30 minutes yielded rooting rates between 44% and 66%, demonstrating its potential as a viable substitute for IBA. Further research explored the combined effects of liquorice and willow extracts. Mohammed (2021) [32] reported that treating olive hardwood cuttings with various concentrations of both extracts resulted in the highest rooting rates (66.66%) when using a combination of 6 g/L liquorice extract and 9 g/L willow extract. This treatment also led to improvements in root number, length, shoot length, and leaf count compared to controls. Hawezy (2022) [24] observed another benefit of liquorice extract: it enhanced the root-shoot ratio in plants beyond the effects achieved with IBA. This suggests that liquorice extract may offer a broader spectrum of growth stimulation compared to some synthetic auxins. El-Dengawy *et al.,* (2017) [17] revealed that liquorice 2.5 g/L in combination with 500 ppm NAA and 500 ppm IBA gave the highest growth parameters in Date palms. Pomegranate cuttings treated with liquorice as well as in combination with moringa leaf extract gave the highest rooting percentage according to Al-Zubaie and Abdullah (2024) [4].

Table 3: Effect of liquorice on rooting percentage of different crops.

Crop	Concentration	Rooting (%)	References
Bottlebrush	6 g/L	86.66	Mustafa *et al.,* 2021 [34]
Olive	6 g/L and 9 g/L	66.66	Mohammed 2021 [32]
Picual olive	5-10 g/L	44 to 66	Eid *et al.,* 2018 [13]
Date palm	2.5 g/L Liquorice+ 500 ppmNAA+ 500 ppmIBA	91	El-Dengawy *et al.,* 2017 [17]
Pomegranate	Liquorice; Liquorice+ Moringa leaf extract	5.170	Al-Zubaie and Abdullah 2024 [4]

Cinnamon

Cinnamon, a well-known medicinal plant, holds promise in sustainable agriculture due to its unique properties. It boasts a high concentration of active compounds, including cinnamaldehyde, cinnamic acid, and eugenol, found within its 4% volatile oil. These compounds, along with tannins, contribute to cinnamon's potential as a natural rooting agent and biological control agent (Uddin *et al.,* 2020) [49]. Research suggests that cinnamon powder can effectively stimulate root growth in various plant species. Uddin *et al.,* (2020) [49] attribute this effect to the presence of phenolic compounds in cinnamon, which are known to influence plant development. Interestingly, cinnamon may also work synergistically with synthetic auxins. Hameed and Adil (2019) [22] found that a combination of cinnamon extract with IBA and NAA (auxin-based rooting hormones) outperformed other treatments when used in conjunction with wounding on plant cuttings. This treatment resulted in not only a higher rooting rate but also increased vegetative growth.

Neem extract

Neem (*Azadirachta indica*) has been extensively studied for its beneficial effects on plant growth, owing mostly to its natural pesticidal activities and nutrient-dense composition. Neem extracts, such as neem oil and neem cake, are proven to boost soil fertility and plant health by supplying necessary nutrients and serving as organic fertilisers. These chemicals increase soil microbial activity, which enhances plant nutrient availability and uptake. Furthermore, neem's bioactive components, such as azadirachtin, help plants resist pests and illnesses, minimising the need for chemical pesticides. According to studies, applying neem-based treatments can result in faster growth, larger yields, and enhanced overall plant health (Muhammad *et al.,* 2018; Eifediyi *et al.,* 2015) [33, 14]. Research suggests that neem extract offers a natural approach to promoting plant growth and health. Studies by Muhammad *et al.,* (2018) [33] demonstrated positive effects on okra plants treated with neem extract. Compared to untreated controls, neem extract treatment resulted in significant increases in average shoot length, leaf area, and overall fruit yield. Similar findings were reported by Nahak and Sahu (2015) [37] in their investigation on tomato plants. Neem extract application led to improved growth parameters like shoot height, branching, and fruit production. Additionally, this treatment displayed potential for disease control, as evidenced by a reduction in disease incidence on the treated plants. Rakibuzzaman *et al.,* (2019) [42] explored the effectiveness of neem oil combined with Natura One, another natural product, on brinjal

(eggplant). This combined treatment yielded promising results. Plants treated with neem oil and Natura One exhibited significantly lower infestation rates by pests on both shoots and fruits. Furthermore, this treatment produced the highest overall yield compared to control groups and increased yield by over 13% compared to untreated plants. These findings suggest that neem oil, potentially in combination with other natural products, can be a valuable tool for reducing pest damage and boosting crop yields.

Ginger

Ginger, a familiar spice, holds potential benefits beyond the culinary world. It contains a range of volatile oils, including geraniol, neral, and zingiberene, that contribute to its distinctive aroma and flavour. Additionally, ginger is rich in bioactive compounds like gingerols, known for their spicy taste. Research suggests that ginger extract can be harnessed as a natural plant growth promoter. Hardan and Al-Dulaimy (2022) [23] observed significant improvements in vegetative development (shoot growth) when plants were sprayed with ginger rhizome extract. This study adds to the growing body of evidence on ginger extract's potential applications in plant propagation. Rashedy (2022) [43] investigated the effectiveness of various natural extracts, including ginger, on rooting success in olive cuttings. Interestingly, ginger extracts (across different solvent types: water, vinegar, and ethanol) outperformed other natural extracts like liquorice root and cinnamon bark in promoting root development. While liquorice vinegar extract resulted in a slightly higher rooting percentage, ginger vinegar extract emerged as a more suitable option due to its compliance with organic farming regulations. Hardan and Al-Dulaimy (2022) [23] further explored the impact of ginger extract on apricot cultivar Hamawi. Their findings revealed that treating cuttings with a 10 g/L ginger rhizome extract solution significantly enhanced several growth parameters, including branch number, dry matter content, leaf area, and nutrient uptake (nitrogen, phosphorus, and potassium).

Table 4: Effect of plant extracts on different crop's growth (Rajan *et al.*, 2023) [40]

Plant crop	Plant extracts	Growth parameters	Values	References
Grape	*Aloe vera* gel 100%	Highest vine length Longest root length	8.4 cm 12.9 cm	Uddin *et al*., 2020 [49]
Bottlebrush	Liquorice extract 6 g/L	Highest rooting percentage	86.88%	Mustafa *et al.*, 2023 [34]
Grape	Coconut water 50%	Highest survival rate	66.8%	Rajan *et al.*, 2023 [40]
Grape	Garlic extract 50 g/L	Highest root length	19.67 cm	Abbasifar *et al.*, 2020 [1]
Grape (Perlette)	Moringa leaf extract 3%	Highest yield	32.1%	Khan *et al.*, 2020 [28]
Apple	Willow leaf (dipped 4 hours)	Highest sprouting percentage	97.183%	Rehman *et al.*, 2018 [44]
Dragon fruit	Seaweed 100ml/L for 12 hours	Highest number of lateral roots	140.33 cm	Potente and Manigo 2023 [38]

Conclusion

Plant extracts generated from various botanical sources contain a wide range of bioactive chemicals that can effectively modify plant development, improve stress resistance, and increase overall crop output and quality. Plant extracts are a feasible and sustainable alternative to synthetic PGRs, with several advantages for environmental health, crop productivity, and organic agriculture. By utilizing plants' natural bioactive chemicals, we can pave the way for a more sustainable and resilient agricultural future. This review emphasizes the need for standardization, targeted research on modes of action, and cost-effective production methods to unlock the full potential of natural plant extracts as a viable and sustainable alternative to synthetic PGRs in future agricultural practices.

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