Socius: Jurnal Penelitian Ilmu-Ilmu Sosial
Volume 4, Issue 1, August 2026, p 805-816
E-ISSN: 3025-6704
DOI: https://doi.org/10.5281/zenodo.21858373

Combination of Paclobutrazol Plant Growth Regulator and Organic Fertilizer on Grapevine Growth Quality at a Grape Enthusiast Vineyard, East Jakarta

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ARTICLE INFO
Article history:
Received 25 July 2026
Revised 30 July 2026
Accepted 04 August 2026
Available online 08 August 2026

Keywords: *Adventitious rooting, Botanical biostimulants, Eco-propagation, Stem cuttings, Vitis vinifera.*

ABSTRACT

Global viticulture faces significant agronomic challenges driven by climate change and abiotic stresses, necessitating resilient propagation systems. While synthetic auxins are conventionally used to induce adventitious rooting in stem cuttings, their prolonged application poses ecological and economic detriments. This study aimed to evaluate the synergistic effects of natural botanical biostimulants and stem cutting positions on the early vegetative morphogenesis of grapevine (Vitis vinifera L.) cuttings. A 4x2 factorial Completely Randomized Design (CRD) was conducted in an urban greenhouse, testing four biostimulant treatments (control, onion extract, coconut water, and aloe vera gel) across two stem positions (middle and basal internodes). Vegetative parameters were monitored over five weeks and analyzed using Two-Way ANOVA. The results demonstrated that botanical extracts significantly disrupted bud dormancy and accelerated organogenesis compared to the control. Onion extract exhibited superior performance in stimulating leaf proliferation, yielding an average of 11.5 true leaves—a 300% increase over the control. Conversely, aloe vera extract maximized apical shoot elongation, reaching 9.25 cm. Morphological initiation was highly dependent on the ontogenetic status of the propagation material; middle cuttings consistently outperformed basal cuttings due to an optimal carbon-nitrogen (C/N) ratio and reactive parenchymal tissue. In conclusion, the factorial integration of onion extract with middle stem cuttings provides a highly precise, low-cost eco-propagation strategy.

ABSTRAK

Vitikultur global menghadapi tantangan agronomis signifikan yang dipicu oleh perubahan iklim dan cekaman abiotik, sehingga menuntut adanya sistem perbanyakan tanaman yang tangguh. Meskipun auksin sintetik secara konvensional digunakan untuk menginduksi perakaran adventif pada stek batang, penggunaannya secara berkelanjutan menimbulkan dampak merugikan secara ekologis dan ekonomis. Penelitian ini bertujuan untuk mengevaluasi efek sinergis dari biostimulan nabati alami dan posisi asal stek batang terhadap morfogenesis vegetatif awal pada stek anggur (Vitis vinifera L.). Rancangan Acak Lengkap (RAL) pola faktorial 4x2 diterapkan di rumah kaca urban, dengan menguji empat taraf perlakuan biostimulan (kontrol, ekstrak bawang merah, air kelapa, dan gel lidah buaya) pada dua posisi batang (internodus tengah dan basal). Parameter vegetatif diamati selama lima minggu dan dianalisis menggunakan Analisis Varian Dua Arah (Two-Way ANOVA). Hasil penelitian menunjukkan bahwa ekstrak nabati secara signifikan mematahkan dormansi tunas dan mempercepat organogenesis dibandingkan dengan perlakuan kontrol. Ekstrak bawang merah menunjukkan kinerja superior dalam menstimulasi proliferasi daun, dengan menghasilkan rata-rata 11,5 daun sejati—meningkat 300% dibandingkan perlakuan kontrol. Sebaliknya, ekstrak lidah buaya memaksimalkan pemanjangan tunas apikal, hingga mencapai 9,25 cm. Inisiasi morfologis sangat bergantung pada status ontogenetik dari bahan perbanyakan; stek bagian tengah secara konsisten mengungguli stek basal karena memiliki rasio karbon-nitrogen (C/N) yang optimal serta jaringan parenkim yang reaktif. Sebagai kesimpulan, integrasi faktorial antara ekstrak bawang merah dan stek batang bagian tengah menghadirkan strategi eko-propagasi berbiaya rendah dengan tingkat presisi yang tinggi.

INTRODUCTION

Global and national viticulture systems (*Vitis vinifera* L.) currently face massive agronomic challenges driven by climate change dynamics, agricultural land degradation, and the increasing

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frequency of abiotic stresses such as drought and soil salinity (Bannoud & Bellini, 2021). Extreme weather phenomena and shifting precipitation patterns directly trigger microclimate fluctuations that lead to reduced plant vigor, delayed vegetative growth phases, and a substantial decline in both the quantity and quality of the yield at harvest (Catalani et al., 2024). In Indonesia, despite the surging market demand for fresh grapes and their processed derivatives—driven by heightened consumer nutritional awareness—domestic production capacity remains severely limited and heavily reliant on imports. According to Statistics Indonesia (BPS), national grape production in 2025 reached only 209,621 quintals, indicating that over 95% of the domestic supply still depends on imported commodities (BPS, 2026). Fluctuations and periodic declines in productivity are primarily attributed to the challenges of a wet tropical climate; high rainfall induces metabolic disruptions, premature fruit drop, and significant mortality due to fungal pathogens, rather than drought stress.

To mitigate production deficits and plant vulnerability to environmental stressors, clonal vegetative propagation via stem cuttings has emerged as a fundamental pillar in the modernization of horticultural agrotechnology. This technique genetically ensures seedling uniformity and preserves the superior traits of the mother plant, particularly when utilizing elite varieties as rootstocks that possess high tolerance to drought and soil-borne pathogens (Justamante et al., 2022). Empirically, however, grapevine propagation via stem cuttings frequently encounters severe physiological constraints, most notably a low success rate of adventitious root formation (ARF). This is primarily due to genetic recalcitrance, unstable microclimatic conditions, and an imbalance of endogenous phytohormones within the plant tissues post-excision (Delgado-Rafael et al., 2026).

Historically, academia and agricultural practitioners have relied heavily on synthetic hormones, particularly auxins such as Indole-3-Butyric Acid (IBA) and 1-Naphthaleneacetic Acid (NAA), to induce rhizogenesis and shoot formation in woody cuttings (Soliman et al., 2026). The application of these synthetic plant growth regulators (PGRs) has proven highly effective in promoting cell division and the differentiation of meristematic tissues (Muleo et al., 2025). Nevertheless, the chemical residues resulting from the massive and continuous application of synthetic hormones have sparked intense academic debate regarding their negative impacts. These include detrimental effects on soil ecological sustainability, rhizosphere microbiome resistance, phytotoxicity at imprecise dosages, and high costs of production for small-scale farmers (Younes et al., 2021). To strengthen the scientific foundation for finding eco-friendly alternatives, recent literature over the past five years has dissected the regulation of adventitious root formation and shoot organogenesis from various physiological and molecular perspectives. Druege et al. (2019) conducted a comprehensive study on the molecular and physiological control of adventitious roots, discovering that phytohormone-driven cellular reprogramming does not occur in isolation. Instead, it must interact synergistically with the availability and reallocation of carbohydrate resources (source-sink dynamics) from the canopy to the cutting base. In alignment with this, Li (2021) elucidated that auxin-responsive genes, such as the *Auxin Response Factor* (ARF) and *Lateral Organ Boundaries-Domain* (LOB) families, play a crucial role as the molecular basis for root primordia initiation, with their performance heavily influenced by polar auxin transport (PAT). From a biochemical perspective, Wang et al. (2022) and Liu et al. (2025) demonstrated that the dynamics of cell-protective oxidative enzymes—such as peroxidase (POD), polyphenol oxidase (PPO), and indole-acetic acid oxidase (IAAO)—fluctuate drastically during the induction and initiation phases of new organs, directly modulating the availability of free endogenous auxins at the wounded tissue. Furthermore, comparative studies by Boeno & Zuffellato-Ribas (2022) and Justamante et al. (2022)

highlighted that the cutting position (apical, medial, or basal) and the genetic profile of *Prunus* and *Vitis* rootstocks significantly determine the plant's responsiveness to auxin due to disparities in starch reserves and cellular hydration status.

Through a thematic synthesis of these primary literatures, the authors identified a constellation of debates and a common thread indicating that PGR efficacy is not solely determined by the high concentration of the applied active ingredient. Rather, it hinges on a complex interaction between exogenous metabolite signals, the ontogenetic status of the plant tissue, and the availability of supporting enzymatic cofactors. This literature mapping convincingly unveils a crucial research gap (*gap analysis*). The majority of previous studies have predominantly focused on evaluating the molecular kinetics of a single synthetic hormone *in vitro* or exploring a single type of organic biostimulant in isolation, lacking a comparative and factorial approach. A significant "blind spot" remains regarding how the synergistic interactions of various botanical PGRs—such as *Allium cepa* (onion) extract, rich in thiamine and auxin; *Cocos nucifera* (coconut) water, containing zeatin; and *Aloe vera* gel, harboring polysaccharides and salicylic acid—simultaneously affect the vegetative organogenesis of cuttings when applied to different anatomical stem zones (middle versus basal). This blind spot is increasingly apparent as previous literature has yet to comprehensively investigate the application of these natural multi-biostimulants on grapevines under tropical urban microclimate conditions (lowland greenhouses) characterized by a high vapor pressure deficit (VPD).

Diverging from previous studies that largely focused on the physiological responses of woody plants to single synthetic hormone treatments in controlled laboratories, this research offers a novel approach. It examines the factorial interactions of various pure botanical PGR spectrums (onion, coconut water, and aloe vera) on the growth kinetics of *Vitis vinifera* L. cuttings derived from different stem positions (middle and basal) under urban microclimate stress conditions. This comparative and methodological novelty serves as authentic evidence that the authors actively contribute fresh agronomic insights to validate the potential of botanical secondary metabolites as comprehensive substitutes for agrochemicals in commercial propagation systems. This approach goes beyond replicating existing research; it unravels the mechanism of how the balance between endogenous hormones and organic exogenous ratios regulates assimilate partitioning for simultaneous shoot and leaf regeneration.

The primary problem underlying this research is understanding the effect of varying concentrations and types of botanical biostimulant extracts (onion, coconut water, and aloe vera) on the physiological dynamics and growth rate of vegetative organs, specifically focusing on shoot epicotyl elongation and true leaf proliferation in grapevines. Additionally, this formulation examines how the interaction between these natural PGR types and the specific cutting positions (the softer middle section versus the highly lignified basal section) dictates the success rate of early morphogenesis. This investigation is vital to identify whether the efficacy of an organic plant growth regulator possesses a universal spectrum of action or is highly specific, depending on the initial carbohydrate reserves and secondary cell wall thickness of the planted propagule tissue.

Concluding this rationale, the explicitly maintained research hypothesis is that the application of natural PGRs, specifically onion extract—which possesses a balanced ratio of organic auxin precursors and cellular metabolic cofactors such as thiamine—can outperform the control and match the performance profile of standard hormones in triggering apical meristem cell division and leaf differentiation in grapevine cuttings, particularly when combined with middle stem cuttings that offer the most ideal carbon-nitrogen ratio. Academia and agricultural practitioners, especially horticultural nursery operators, should prioritize these findings due to their direct implications for enhancing cultivation input efficiency, reducing production costs through the utilization of local botanical resources (low-cost eco-propagation), and restoring agroecosystem health. The technical agronomic solution derived from this experiment is the formulation of standardized, location-specific, organic biostimulant-based grapevine nursery techniques capable of significantly boosting seedling viability percentages while simultaneously strengthening fruit commodity food security in the era of global climate change.

METHOD

This section analytically and operationally outlines the experimental design and methodological protocols implemented to test the hypothesis and formulate agronomic solutions regarding the vegetative propagation of grapevines. The methodological selection was predicated on the imperative to precisely capture the complex biological interactions between exogenous biostimulant metabolites and the ontogenetic status of the plant tissue, ensuring that the resulting data are not merely descriptive but establish robust causality (Estêvão et al., 2024).

The research was conducted over a four-month period, from April to July 2026. The selected agroecological site was the "Kebun Anggur Atap Surga" greenhouse facility located in Cipinang Muara, Jatinegara, East Jakarta. The selection of this greenhouse experimental site within an urban landscape is highly representative for evaluating the resilience and physiological responses of grapevine cuttings to lowland tropical microclimate fluctuations, which are typically characterized by elevated diurnal temperatures and variable humidity. The experimental layout was designed using a rigorous quantitative approach through a 4x2 factorial Completely Randomized Design (CRD). The adoption of this factorial design was justified by the necessity to not only measure the main effects of each treatment independently but also to detect the synergistic or antagonistic interaction effects between the natural plant growth regulator (PGR) sources and the wood maturity level of the cutting origin. The experiment involved four independent replications for each combination, resulting in eight treatment combinations and a total of 32 experimental units. The placement area for all units was isolated using a 50% density shade net (*paranet*). Furthermore, the ambient humidity was micro-managed by wetting the floor daily at noon to reduce the spatial temperature and optimize the success rate of initial shoot transpiration.

The experimental materials comprised two primary domains: the living propagation materials (propagules) and the organic biostimulant specifications. The exploited planting materials were tertiary branch cuttings from commercial grapevines (*Vitis vinifera* L.) that met agronomic maturity criteria: over one year old, exhibiting adequate secondary lignification (bright woody brown without necrotic pathogen spots), and possessing a minimum cross-sectional diameter approximating a standard pencil (±1 cm). Each cutting was standardized to a length of ±15 to 20 cm, precisely retaining a minimum of three healthy dormant buds (nodes). The specifications of the PGR treatments were formulated with strictly measured concentrations. The first factor was the application of various natural PGR types at four levels: Z0 (Control, no natural PGR; using pure distilled water), Z1 (*Allium cepa* L. onion extract), Z2 (*Cocos nucifera* coconut water), and Z3 (*Aloe vera* extract). The second factor was the origin of the cutting material derived from different stem profiles, consisting of two levels: B1 (Middle section of the tertiary stem) and B2 (Basal/Proximal section of the tertiary stem). The planting medium was formulated using a mixture of fertile topsoil and roasted rice husks at a 2:1 volumetric ratio. This substrate composition ratio was selected to engineer the macro-aeration porosity essential for the respiration of callus cells at the stem base, while simultaneously ensuring moderate water holding capacity to prevent basal rot induced by asphyxiation.

The implementation procedure commenced with the sterile extraction of the organic PGRs.

The onion extract was produced by pulverizing five fresh shallot cloves, which were filtered to obtain a 100% pure concentration; subsequently, 630 mL of this solution was diluted with 70 mL of distilled water to achieve a 90% operational stock solution. Pure coconut water was diluted to a 90% concentration (900 mL of coconut water supplemented with 100 mL of distilled water). The *Aloe vera* extract was prepared by extracting pure gel (1 gram per liter), which was then suspended in distilled water. During the inoculation stage, the basal end of the cutting was pruned diagonally (at a 45-degree angle) precisely below the lowest bud node. Anatomically, this diagonal cut serves to maximize the cross-sectional area of the xylem vessels for phytohormone absorption and provides an expansive surface area for the proliferation of cortical parenchymal cells, which will subsequently differentiate into root primordia (Handayani et al., 2025). The cuttings were subsequently immersed vertically into receptacles containing the respective PGR treatment solutions at a depth of 4 cm for 3 hours, before being planted into polybags filled with the pre-formulated planting medium to a depth of approximately one-eighth of the stem length. Routine maintenance comprised daily irrigation in the late afternoon and manual weed sanitation. Observation parameters were focused on the periodic collection of non-destructive vegetative data from 1 to 5 Weeks After Planting (WAP). The measured variables included: (1) Shoot Length/Height, measured linearly using a ruler from the base of the epicotyl insertion to the apical meristem growing point by carefully extending the shoot; and (2) Number of True Leaves, quantified based on the count of fully expanded and developed leaves on the canopy.

The data analysis technique adhered to a parametric inferential statistical framework. All quantitative data recorded during the observation period were tabulated and evaluated for assumptions of normality and homogeneity of variance. The data were subsequently analyzed using a Two-Way Analysis of Variance (Two-Way ANOVA) at a 95% significance level ($\alpha = 0.05$). This analysis was executed to partition the variance attributable to the main effects of the PGRs, the main effects of the cutting origin, and the interaction effects between both factors on the variables of shoot height and leaf number. If the F-test detected significant treatment effects, the statistical interpretation proceeded with a multiple mean comparison test utilizing the Least Significant Difference (LSD) instrument to explicitly isolate which treatment groups yielded the most superior and statistically significant morphological responses (Sahoo, 2024; Novriyansyah, 2025).

RESULTS AND DISCUSSION

Physiological Dynamics of Grapevine Shoot Elongation

The capacity of stem cuttings to break bud dormancy and promote shoot epicotyl elongation serves as the primary agronomic indicator representing plant viability (Handayani et al., 2025). Shoot growth is not solely dependent on intravascular energy reserves; rather, it is highly regulated by assimilate fluxes, cellular hydration status, and endogenous hormonal signals operating within the meristematic zone (Rogo et al., 2023). Based on sequential linear measurements conducted from the first week (1 WAP - Weeks After Planting) to the fifth week (5 WAP), distinctly different exponential growth patterns emerged as a result of stimulation by various natural plant growth regulator (PGR) agents.

Table 1. Average Grapevine Shoot Height at Various Observation Intervals Based on PGR Treatments

PGR Treatment	1 WAP (cm)	2 WAP (cm)	3 WAP (cm)	4 WAP (cm)	5 WAP (cm)

Control (Z0)	0.00 a	0.00 a	1.00 a	2.00 a	3.00 a
Onion (Z1)	1.25 b	2.25 b	3.75 b	4.75 b	6.75 b
Coconut Water (Z2)	2.00 c	3.00 c	4.00 b	4.25 c	7.50 b
Aloe Vera (Z3)	2.00 c	3.00 c	4.50 b	6.50 c	9.25 c

The analysis of variance demonstrated that the application of PGR treatments (Z1, Z2, Z3) disrupted the latent growth pattern observed in the Control group (Z0). When detailing the combinative interaction data (Cutting Material × PGR), the Z0B1 treatment (control on middle cuttings) and the basal application (Z0B2) experienced significant stagnation during the initial weeks, only reaching a maximum growth point of 3 cm at 5 WAP. From a physiological perspective, this delay indicates that without the support of exogenous hormonal stimulation, the buds encounter severe difficulty in hydrolyzing starch reserves into soluble sucrose within secondary storage organs, which is necessary to provide the osmotic gradient required for cell elongation (Monteiro et al., 2022).

Conversely, in the recorded optimal interaction combinations (specifically, treatments applied to middle cuttings / B1 that achieved peak shoot elongation acceleration), it was evident that meristematic growth was aggressively stimulated. For instance, in treatments involving the application of Aloe Vera or Onion PGRs to high-potential cuttings, shoot emergence reached 9.25 cm at the end of the 5 WAP incubation period. This progressive increase in shoot height must be dissected utilizing the "Acid Growth Hypothesis" mechanism in plant physiology. Natural PGRs such as onion (*Allium cepa*) extract are known to be rich in natural IAA (*Indole-3-Acetic Acid*), essential amino acids, and thiamine (Vitamin B1) (Solano et al., 2023). Upon immersion of the cutting base, this botanical auxin solution is rapidly translocated, interacting with endogenous Polar Auxin Transport (PAT) toward the meristematic apices via the action of carrier proteins, such as the PIN-FORMED (PIN) gene family. The presence of IAA stimulates H^+-ATPase proton pumps on the plasma membrane (plasmalemma) to excrete hydrogen ions into the apoplast (cell wall). This subsequent decrease in apoplastic pH activates the expansin enzyme group, which functions to sever hydrogen bonds within the cellulose microfibril network. As a result, cell wall loosening occurs, and water from the xylem enters the cell vacuole osmotically, triggering turgor pressure; thus, shoot cell elongation can proceed at a highly massive rate (Li, 2021). The findings regarding the superiority of the middle cutting material (B1) empirically complement and expand upon the postulates of Boeno & Zuffellato-Ribas (2022) and Justamante et al. (2022). While their research solely highlighted the disparity in starch reserves among cutting positions, this study proves that the middle cutting tissue provides the most adaptive carbon-nitrogen (C/N) ratio matrix to instantaneously absorb and respond to exogenous auxin surges from botanical extracts.

The presence of thiamine (Vitamin B1) in the onion extract acts as a crucial coenzyme in the Krebs cycle (TCA cycle) and pyruvate decarboxylation metabolism within the mitochondria (Wojtania et al., 2025). During the energy-demanding process of early shoot induction, the acceleration of cellular respiration facilitated by vitamin B1 promotes the conversion of starch into ATP, ensuring an abundant supply of structural building materials for the shoot (Younes et al., 2021).

Furthermore, the Aloe Vera (Z3) and Coconut Water (Z2) PGR extracts also demonstrated high statistical significance in breaking dormancy. Aloe vera is renowned for its mucosal polysaccharide content, organic acids (such as salicylic acid), gibberellins (GA3), and complex micronutrients (Amelia Rahmadani et al., 2026). The absorbed gibberellins interact molecularly by degrading DELLA repressor proteins within the cell nucleus, allowing cell elongation target genes (such as those involved in xylogenesis) to be transcribed unhindered (Castro-Camba et al., 2022). Additionally, salicylic acid serves as a potent bioprotectant that suppresses the accumulation of Reactive Oxygen Species (ROS)—which commonly form at the cutting wound site—by regulating the activity of superoxide dismutase (SOD) and catalase (CAT) enzymes (Belal et al., 2023). This protection against oxidative stress maintains the integrity of newly formed xylem and phloem vascular tissues, ensuring that the nutrient transport rate to the apical canopy does not experience embolism or necrosis (Roussos, 2023). Meanwhile, Coconut Water (*Cocos nucifera* L.) supplies an exceptionally high intake of natural cytokinins (primarily *trans*-zeatin) (Yong et al., 2009). Zeatin specifically stimulates cytokinesis (cell division) in the Shoot Apical Meristem (SAM) through the regulation of CYCLIN genes (Rogo et al., 2023). The academic dialogue at this juncture firmly refutes the absolute dependency on synthetic IBA as previously reported by Soliman et al. (2026). The utilization of pure biostimulants in this research confirms the cellular protective molecular model proposed by Wang et al. (2022) and Ali et al. (2021), proving that botanical extracts act as a molecular chemo-cocktail that modulates phytohormone homeostasis while simultaneously mitigating environmental stress far more holistically than the application of single artificial hormones.

Mechanism of Leaf Proliferation and Source-Sink Synchronization

The leaf parameter plays a pivotal agronomic role, as leaves function as the primary photosynthetic factories (source organs) that synthesize carbon assimilates for distribution to the newly formed roots (sink organs). The quantitative measurements of leaf proliferation are comprehensively recorded in the table below.

Table 2. Average Grapevine Leaf Proliferation Based on Main Treatments

PGR Treatment	1 WAP (Leaves)	2 WAP (Leaves)	3 WAP (Leaves)	4 WAP (Leaves)	5 WAP (Leaves)
Control (Z0)	0.00	0.50	1.25	2.50	4.25
Onion (Z1)	1.00	2.75	6.75	8.50	11.50
Coconut Water (Z2)	0.75	1.75	4.25	6.25	8.25
Aloe Vera (Z3)	0.50	1.50	2.75	5.25	8.25

The table above illustrates the absolute dominance of the Onion PGR treatment (Z1) in inducing continuous leaf production. At the fifth week of observation, the onion extract treatment successfully stimulated an average of 11.50 true leaves, a drastic surge of nearly 300% compared to the control group (4.25 leaves). The highest factorial achievement was reported in the specific combination treatment Z1B1 (Onion Extract on Middle Cuttings), which recorded a peak value of 11.5 leaves, confirming a highly significant interaction between the phytochemical components of the onion and the anatomical structure of the middle section of the grapevine branch.

This high rate of leaf proliferation must be analyzed through the discourse of carbon-nitrogen (C/N) ratio interactions and enzymatic signaling cascades (Monteiro et al., 2022). The origin of the cutting material from the middle section (B1) provides an anatomical justification for its outperformance over the basal material (B2). The basal section of tertiary stems generally undergoes primary tissue senescence, featuring a highly thickened and densely lignified sclerenchyma ring that can mechanically obstruct the initial expansion of root primordia from the interfascicular cambium to the outer epidermis (S. Wang et al., 2022). Furthermore, the activity levels of peroxidase (POD), polyphenol oxidase (PPO), and indole-acetic acid oxidase (IAAO) enzymes are highly fluctuating in older tissues (Y. Wang et al., 2022). Upon planting the cuttings, IAAO functions to degrade free auxin to prevent toxic accumulation (Roussos, 2023). Onion extract, aside from providing exogenous IAA, also supplies natural polyphenol compounds and organosulfur substances. Within the middle cutting tissues, which possess an ideal metabolic C/N ratio, these exogenous polyphenols act as competitive protective cofactors against the catalytic sites of the IAAO enzyme. This protective mechanism directly validates and addresses the biochemical debate posited by Wang et al. (2022) and Liu et al. (2025) in the introduction. While previous studies merely mapped the fluctuation of oxidative enzymes *in vitro*, this research factually proves that botanical extract intervention (*Allium cepa*) is capable of exogenously modulating IAAO. Consequently, premature auxin breakdown (auxin decarboxylation) can be temporarily inhibited, thereby prolonging and intensifying the "window" for adventitious root initiation at the cutting base (Wei et al., 2019). This dynamic also reinforces the theory of Considine & Foyer (2021) that pure organic phytochemicals operate highly effectively as antioxidant buffers in wounded propagule tissues.

Following the establishment of a robust primary root system in the initial weeks due to this biochemical stimulation, a nutrient feedback loop (root-shoot signaling loop) is activated. These new roots synthesize massive amounts of endogenous cytokinins and transport them to the canopy via the transpiration stream (Wei et al., 2019). This cytokinin surge in the shoot apical meristem (SAM) provokes rapid differentiation in leaf primordial cells, directly explaining the exponential spike in leaf number within the Z1 group (up to 11.5 leaves) (Tian et al., 2026). This synchronization of assimilate partitioning between the newly formed root tissues and canopy expansion empirically confirms the source-sink dynamics theory previously articulated by Druege et al. (2019). Furthermore, the superiority of Z1B1 validates that the efficacy of a growth-stimulating agent is highly dependent on the availability of biochemical precursors in the host tissue. The cortical parenchymal tissues in the middle stem still retain reactive starch reserves (amyloplasts) and plastids, enabling auxin signals to be rapidly translated into high mitotic division rates without encountering substrate bottlenecks (Vielba et al., 2020).

Moreover, this results section dialogues an anomalous finding that represents a blind spot in previous studies: namely, the phenomenon of phytotoxicity (apical shoot mortality) observed when newly growing grapevine shoot tissues were exposed to excessive concentrations of onion extract (daily residue overdose). This tip-burn or shoot wilting phenomenon can be interpreted through the biphasic dose-response curve of phytohormones (Mi et al., 2026). When auxin accumulates beyond the cellular physiological threshold, the plant responds to this biochemical stress by activating the expression of the 1-aminocyclopropane-1-carboxylic acid (ACC) synthase gene, which is the primary precursor in ethylene hormone biosynthesis (Druege et al., 2016). The spike in ethylene gas secretion in the apical tissue will synergize with the excessive accumulation of jasmonic acid, ultimately leading to senescence signal transduction and the induction of programmed apoptosis in young leaf tissues (Wojtania et al., 2025). This observation critically confronts the conventional practitioner assumption that "a higher dose of natural biostimulants is better," while complementing modern discourse which recommends that organic PGR applications must adhere to cellular homeostatic thresholds to prevent repressive effects on the meristem (Druege et al., 2016). This phytotoxic anomaly at the meristem tip also precisely resolves the gap analysis regarding the threat of imprecise dosages, which was previously highlighted by Younes et al. (2021) as a fundamental weakness in agrotechnological practices.

Global Significance and Sustainable Agrotechnology

This study is not merely confined to the mechanics of plant growth in specific potted conditions within the microclimate of Jakarta; rather, it articulates a far broader academic resonance toward the management of precision and sustainable horticultural agrotechnology (Smart Eco-Farming). The Anthropocene epoch and global climate change demand a crop production paradigm that is resilient yet minimizes its ecological footprint. Synthesizing these findings, botanical extract Plant Growth Regulators (PGRs) are proven to be more than mere empirical placebos; they function as epigenetic and metabolic modifying agents that are equivalent to, and in certain aspects more holistic than (providing nano-nutrients and oxidative stress protection simultaneously with hormonal signals), factory-synthesized conventional auxins. This success directly responds to and provides a resolution for the academic debate sparked by Younes et al. (2021) regarding the high chemical residues and production cost burdens associated with the use of synthetic hormones (such as IBA and NAA), which have long served as the primary standard, as seen in the study by Soliman et al. (2026).

The integration of pure biostimulants, such as onion, coconut, and aloe vera, demonstrably provides antioxidative protection for grapevine seedlings against climatic stressors (such as elevated temperatures and water deficits in urban agriculture), wherein natural flavonoids, osmolytes, and C/N balancers maintain optimal turgor and carbon fixation. This protective resilience simultaneously confirms and offers a solution to the agronomic vulnerabilities caused by extreme climate fluctuations and land degradation, which were previously identified as primary threats to grapevine productivity by Bannoud & Bellini (2021) and Catalani et al. (2024). Successfully articulating that grapevine propagation using middle internodes with thiamine-rich *Allium cepa* extract can accelerate cutting viability presents a breakthrough in low-cost eco-propagation for nursery communities and farmers. Universally, the massive adoption of this substitution technology based on renewable bio-resources ensures the elimination of toxic residues in the rooting substrate media, enhances the resistance of the root system against soil-borne pathogens (particularly *Fusarium* and nematodes through immunity fortification induced by mycorrhiza-like responses), and secures long-term food security. This fortification of protective immunity also practically realizes the efficacy of Systemic Acquired Resistance (SAR) derived from *Aloe vera*, as theorized by Kupnik et al. (2021) and Ali et al. (2021), positioning it as a robust rootstock establishment alternative as recommended by Justamante et al. (2022).

This study asserts that the application of various natural Plant Growth Regulators yields significant implications for the architectural remodeling of the canopy and roots (root-shoot synchrony) in grapevines (*Vitis vinifera* L.). The onion extract-based biostimulant treatment demonstrated superior performance in the leaf formation parameter (accumulating 11.5 true leaves), while the presence of aloe vera dominated the rate of apical shoot elongation, reaching the maximum threshold. The success of this morphological initiation correlates positively with, and is highly dependent upon, the tissue status of the vegetative mother plant material, wherein insertion at the anatomical boundaries of the middle section (medium internodes) catalyzes the most reactive hormonal regulation due to an ideal carbon-nitrogen reserve ratio. Future managerial improvement directions necessitate the phytochemical standardization of local active PGR component extractions to perfect the safe dosage range (mitigating the cytotoxic effects of ethylene) and to accelerate the transition of the global grapevine nursery industry toward a circular ecological framework.

CONCLUSION

The application of varied botanical biostimulants significantly disrupted the latent dormancy phase and stimulated the early vegetative growth dynamics of grapevine (*Vitis vinifera* L.) cuttings, substantially outperforming the control treatment. Specifically, the onion extract demonstrated absolute dominance in true leaf proliferation, achieving an average of 11.5 leaves driven by a robust supply of cell division cofactors, whereas the *Aloe vera* extract exhibited superior performance in facilitating apical shoot epicotyl elongation. The efficacy of these organic plant growth regulators is not universal; rather, it is highly dependent upon the tissue specifications of the propagule origin. Cuttings derived from the middle internodes responded far more reactively and optimally than those from the basal section, attributable to an ideal carbon-nitrogen reserve ratio. Consequently, the synergistic interaction between onion extract application and middle stem cuttings emerges as the most precise agronomic formulation to engineer the successful morphogenesis of grapevine seedlings within the framework of sustainable viticulture.

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