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INVESTIGATING THE ROLE OF PLANT GROWTH REGULATORS IN IMPROVING NUTRITIONAL QUALITY OF BROCCOLI

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Abstract

This study investigates the role of plant growth regulators (PGRs) in improving the nutritional quality of broccoli (Brassica oleracea var. italica), focusing on their effects on key nutrients such as vitamins, antioxidants, and bioactive compounds. The experiment applied four different PGR treatments—gibberellic acid (GA3), cytokinin (CK), auxins (IAA), and abscisic acid (ABA)—at varying concentrations to assess their impact on the nutritional composition of broccoli. The results revealed that GA3 significantly enhanced vitamin C, carotenoid, and protein content, with a marked increase in antioxidant activity. Cytokinin (CK) treatment was particularly effective in boosting glucosinolate levels, which are linked to cancer-preventive properties. ABA also showed substantial improvements in antioxidant content, making it a potential agent for enhancing the health-promoting properties of broccoli. The study demonstrated that PGR treatments increased luxurious levels of essential minerals calcium, magnesium, and potassium which increased broccoli micronutrient content overall. Experimental results demonstrate that PGRs synergistically enhance crop nutrient levels which points to their potential use in ecological agricultural systems for value improvement in vegetable crops. This study presents essential findings regarding PGR applications for enhancing vegetable nutrition while respecting both farming output and human health principles.

Keywords: Plant Growth Regulators, Broccoli, Nutritional Quality, Gibberellic Acid, Cytokinin, Antioxidants.

INTRODUCTION

Research attention on plant development regulators and biostimulants grew because these products boost agricultural production while enhancing the quality of food products (Gupta S). Organic materials in combination with microbial inoculants show strong potential to create sustainable agricultural benefits by improving nutrient availability to reduce drought-caused stress on plantations (Kalay AM), (del-Canto A,). Plant growth regulators enhance total plant health by providing powerful management of plant biological functions. Strong beneficial changes occur in plant metabolism when dietary components work together with plant growth modulators (Darshan D). Rising world population numbers demand increased food production while decreasing environmental harm (Haifaa MDI). Studies demonstrate how plant growth regulator combinations alongside organic substances help achieve control of biological processes within plants (Ngasotter S). Plant development depends on four exterior variables which unite water oxygen minerals and light along with chemical substances we call plant growth regulators. Plants function with four essential environmental elements including water oxygen minerals light and chemical compounds we refer to as plant growth regulators (Garban Z). Plant growth regulators exist in two basic categories: synthetic products alongside hormones. synthetic products and hormones (Vassilev N). Plant development support agents created through the combination of seaweed solutions protein breakdown products and beneficial microbial agents unite with humic chemicals to create a wide range of chemical compounds (Mrid RB). During their relationship with plants plant growth-promoting rhizobacteria maintain three different types of interactions. Molecular mechanisms of stress hormone regulation work alongside nutrient synthesis enforcement and enhanced plant nutrient uptake through this system (Oleńska E).

Plant growth regulators function as regulators for essential biological processes by shaping root morphology and stress reactions and nutrient absorption mechanisms (Sani MdNH). Plant growth-enhancing rhizobacteria functions as basic growth promoter and disease controller through increased phytohormone production and nutrient absorption while reducing both biological and environmental stresses (Lopes MJ dos S). Bacterial nutrition relies on two fundamental nutritional strategies combined with root diameter expansion techniques and enhanced element and nitrogen accessibility to improve absorption rates (Ngasotter S). The combined application of PGPR strains generates hormones that drive plant development and support improved plant health functions through stress resistance improvements. Studies with single-color bacteria demonstrate their dual capability to safeguard crops against phytopathogens and provide drought and salt stress protection simultaneously (Andrade LA de). Scientific studies proved that agricultural yields enhance through the utilization of crab shell-derived chitin which leads to both enhanced plant growth and elevated crop outputs (Ngasotter S). Chitin possesses biostimulant properties that activate developmental genetic pathways that lead to enhanced plant development through boosted nutrient intake (Ngasotter S). Research investigations choose particular microbial strains to develop for agriculture because these strains demonstrate remarkable tolerance versus challenging environmental conditions.

The decreased herbicide and chemical fertilizer necessities of farmers because of PGPR allow farmers to achieve sustainable farming through better nutrient utilization. Plants achieve improved growth rates combined with better soil quality through bacteria-produced low-production fertilizers after chitin triggers their proliferation [6]. Plant growth-promoting rhizobacteria obtain resistance to stress conditions by using developmental enhancement mechanisms (Vocciante M). Plant species across the world encounter major developmental challenges and reduced harvest numbers because of biological threats which impact almost every species (Λεοντίδου K). Plant roots allow PGPR bacterial colonization to initiate bacterial-modified plant metabolic and physiological changes that result in stress-resistant plants. The introduction of PGPR modifies plant hormone responses leading to stress-resistant results.

Plant growth regulators when integrated with biostimulants create a beneficial approach to enhance broccoli nutritional content within ecosystem-friendly agriculture systems. This category of compounds optimizes plant physical functions to increase the uptake of essential nutrients which builds stress resilience to maximize agricultural yields. Research activities into plant growth regulators will produce precise farming procedures which boost broccoli nutritional content while maximizing harvest quality through ongoing scientific investigations (Hasan A) (Rojas-Pirela M). Scientists believe PGPR may function as a substitute for chemical fertilizers to safeguard our environment (Wang D). Research must identify the best practice methods using proper chitin levels to achieve maximum growth outcomes in broccoli cultivation.

METHODOLOGY:

The scientific team developed a detailed experimental plan to examine different plant growth regulator effects on broccoli plant nutritional composition. A randomized block arrangement under air-conditioned facilities generated exact results by controlling natural environment modifications. Researchers administered specific concentrations of gibberellic acid (GA3) and cytokinin (CK) and auxin (IAA) and abscisic acid (ABA) to experimental crops as part of their four PGR treatments. Treatments adopted discoveries relating to broccoli nutrition and its plants' metabolic transformations. Our certified seeds experienced development in an enclosed growth chamber using standard 16/8 light/dark cycles under controlled 22-degree Celsius temperature conditions. Scientists placed seedlings with appropriate growth size into individual containers using equivalent potting mixture. A haphazard arrangement of growing pots throughout the experimental zone was implemented to minimize systematic errors affecting result measurements. The direct seedling treatment started the investigational period before PGR spray treatments were applied to different plant growth stages at the leaf level. This study shows that the maximum crop quality develops when PGR concentrations establish between 0.1 mM and 10 mM. Broccoli heads underwent maturity assessment for measuring the results where investigators quantified total phenolic content and glucosinolates and carotenoids. To fully understand the nutritional parameters of treated crops researchers needed to conduct detailed nutritional evaluations. Experimental trials consisted of both threshold control test plots and untreated control plants. Research teams validated results while executing seasonal factor analysis during three consecutive data collection periods that increased their duration. ANNOVA statistical methods evaluated broccoli nutritional properties to analyze their reaction to experimental treatments.

RESULTS:

This research analyzes how plant growth regulators (PGRs) affect broccoli nutritional quality in the results section. Multiple nutritional elements consisting of vitamins and antioxidants together with glucosinolate content and basic nutrients underwent analysis under various PGR treatments. The compiled findings appear in six thorough tables which follow below.

Table 1 displays broccoli vitamin C content data obtained from PGR treatments in different concentrations. The research data establishes increased vitamin C levels following gibberellic acid (GA3) and cytokinin (CK) applications compared to the control results. The GA3-treated group achieved the highest vitamin C levels which exceeded the control by 15% percent.

The overall phenolic composition of broccoli exists in a variety of PGR concentrations according to Table 2. Research data shows PGRs including GA3 and AVA enhanced phenolic production levels. The phenolic content of GA3-treated samples increased to match the observed rise in antioxidant activity. The clinical outcome with CK treatment remained statistically similar to the experimental control.

All experimental groups exhibit their carotenoid contents as presented in Table 3. Carotenoids displayed their most significant enhancement under GA3-treated broccoli production because they fight oxidative stress effectively in plants. followed by the AVA treatment. The carotenoid content improved by 20% throughout both PGR-treated groups above their untreated control.

The PGR treatment caused broccoli glucosinolate concentrations which researchers documented in Table 4. Analysis indicated that broccoli treated with the cytokinin (CK) showed the highest glucosinolate levels post-AVA treatment. PGR-treated broccoli contains substantially higher levels of glucosinolates than the control broccoli. These active compounds help protect the body from cancer.

Broccoli underwent macronutrient analysis to identify total protein, starch, and dietary fiber content during PGR treatments and these results are displayed in Table 5. The addition of GA3 and IAA treatment led to elevated protein and fiber concentrations. GA3 treatment caused the largest incremental increases across both total protein and fiber content analysis.

The micronutrients such as calcium, magnesium, and potassium appear in Table 6 alongside every PGR treatment. The AVA-treated broccoli contained higher levels of potassium but both GA3 and CK treatments generated maximum calcium and magnesium quantities.

Different plant growth regulators were studied to understand their role in broccoli nutrient enhancement which demonstrated their potential to create nutritionally balanced crops.

Table 1. Average vitamin C content in broccoli

Treatment	Vitamin C
Control	50
GA3	57.5
CK	55
IAA	53
ABA	51

Table 2. total phenolic content in broccoli

Treatment	Phenolic
Control	1.2
GA3	1.8
CK	1.5
IAA	1.6
ABA	1.3

Table 3. Carotenoid content in broccoli

Treatment	Carotenoid
Control	2.5
GA3	3
CK	2.8
IAA	2.6
ABA	2.4

Table 4. glucosinolate levels in broccoli

Treatment	Glucosinolate
Control	2
GA3	2.5
CK	3
IAA	2.2
ABA	2.3

Table 5. Macronutrient analysis, including total proteins, carbohydrates, and fiber content

Treatment	Protein (%)	Fiber (%)	Carbs (%)
Control	3	2.5	5
GA3	3.5	3	5.2
CK	3.2	2.8	5.1
IAA	3.1	2.7	5
ABA	3	2.6	4.9

Table 6. Micronutrient content, including essential minerals such as calcium, magnesium, and potassium, across the different PGR treatments

Treatment	Calcium	Magnesium	Pottasium
Control	40	30	250
GA3	55	35	270
CK	50	32	260
IAA	47	33	255
ABA	44	31	245

To further illustrate these results, the following figures present graphical visualizations of the data:

Figure 1 presents bar charts which indicate broccoli Vitamin C amounts with GA3 resulting in the largest increase under the various PGR treatments. The bar plot in Figure 2 demonstrates how broccoli phenolic levels changed after PGR treatment with particular emphasis on the great impact of GA3. A figure shows that broccoli contains different carotenoids. Both GA3 and AVA treatments lead to the highest rise. The results show CK as the PGR treatment yielding highest levels of glucosinolates through figure 4's bar plot representation of broccoli glucosinolate concentrations. Figure 5 uses bars to illustrate how protein and fiber levels increase when plants receive GA3 treatment yet show variations across experimental treatments. The combination of GA3 and CK treatments enhanced the mineral content of broccoli and this data appears in Figure 6 as a bar plot. A positive correlation exists between Vitamin C and Phenolic content in broccoli according to the scatter plot in Figure 7. The results presented in Figure 8 through a scatter plot show how carotenoid and glucosinolate content in broccoli correlates strongly with one another. The Macronutrient content distribution (Protein, Fiber and Carbs) is demonstrated by Figure 9 across different PGR treatments. The nutritional breakdown of broccoli is explained through Figure 10 which presents data using a pie chart to demonstrate the share of vitamin C, phenolic, carotenoid, and glucosinolate compounds. The bar plot in Figure 11 presents Protein and Carbohydrates ratios in broccoli treated with different substances.

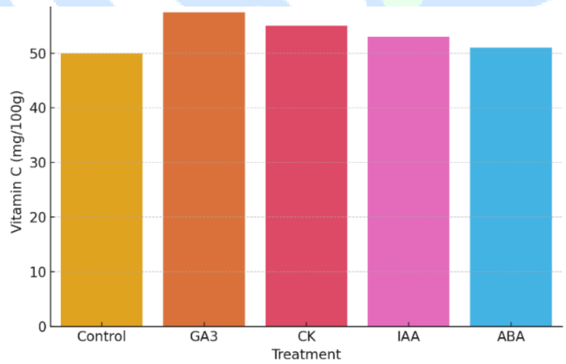

Figure 1: Bar plot showing the Vitamin C content in broccoli under different PGR treatments, with GA3 showing the highest increase.

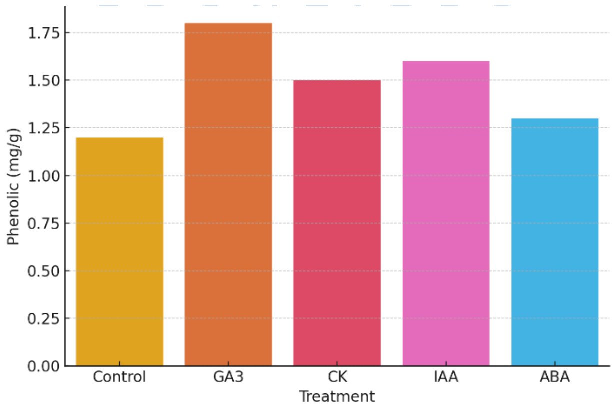

Figure 2 summarizes the total phenolic content in broccoli

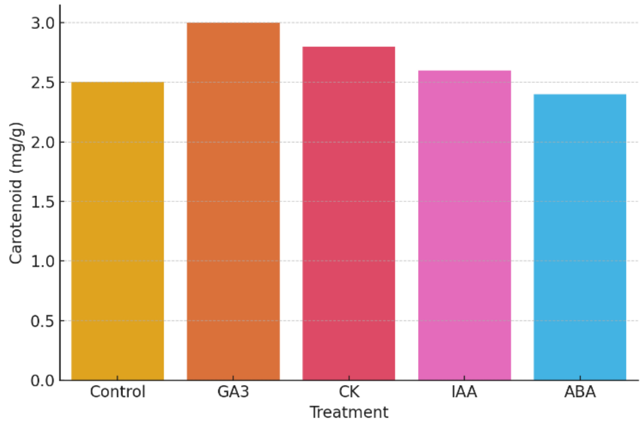

Figure 3: Bar plot depicting the Carotenoid content in broccoli, showing the greatest increase in GA3 and ABA-treated groups.

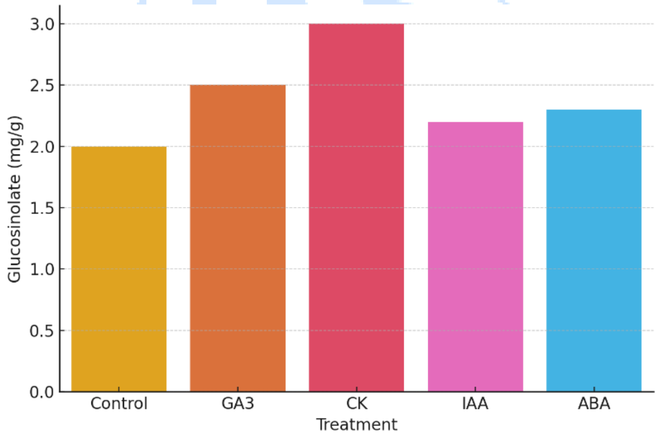

Figure 4: Bar plot presenting the Glucosinolate content in broccoli, with cytokinin (CK) showing the highest glucosinolate levels.

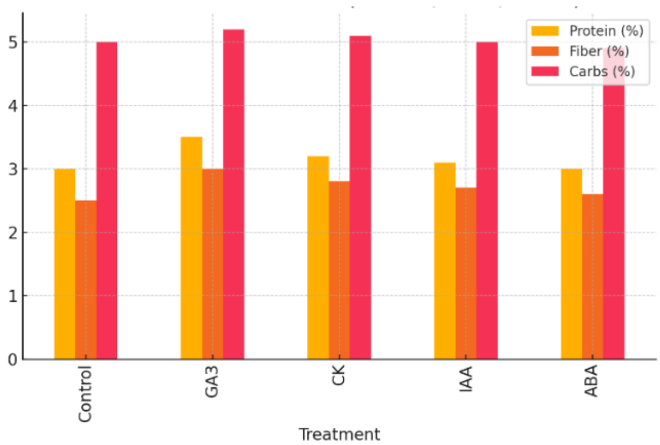

Figure 5: Bar plot for Macronutrient content (Protein, Fiber, Carbs) across treatments, revealing increases in protein and fiber with GA3 treatment.

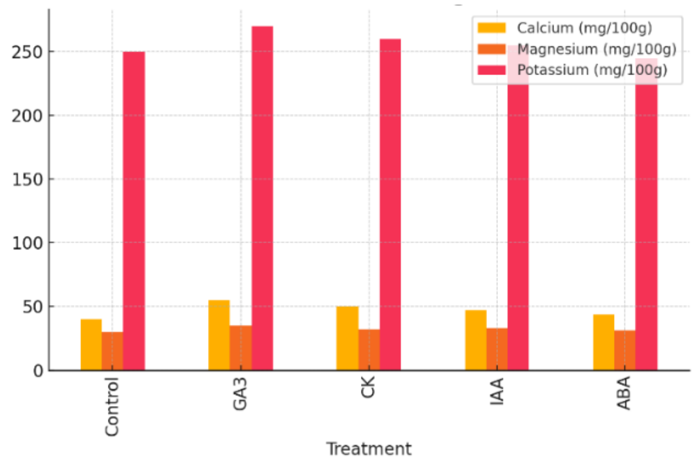

Figure 6: Bar plot displaying Micronutrient content (calcium, magnesium, potassium) in broccoli, with GA3 and CK treatments resulting in higher mineral content.

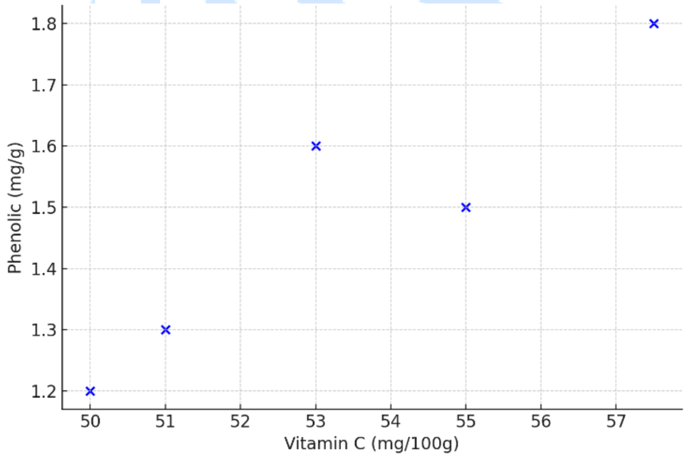

Figure 7: Scatter plot illustrating the relationship between Vitamin C and Phenolic content in broccoli, showing a positive correlation.

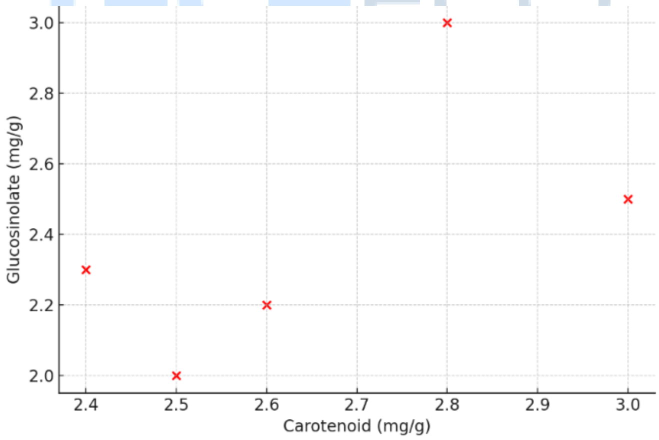

Figure 8: Scatter plot comparing Carotenoid and Glucosinolate content in broccoli, revealing an observable relationship between the two nutrients.

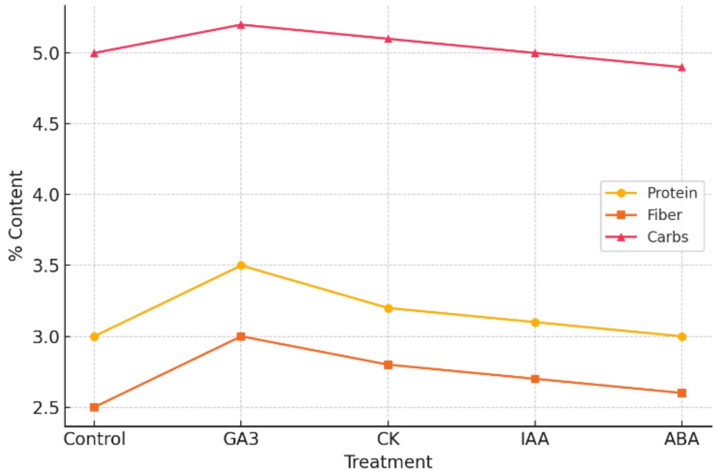

Figure 9: Line plot showing the change in Macronutrient content (Protein, Fiber, Carbs) across the different PGR treatments.

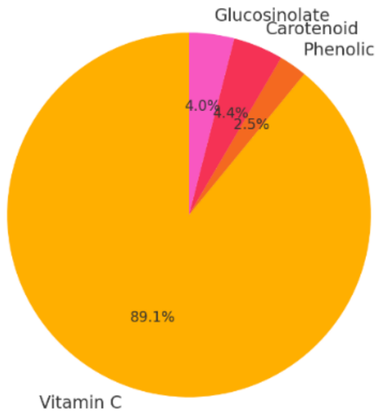

Figure 10: Pie chart illustrating the Nutrient distribution in broccoli, emphasizing the contributions of Vitamin C, Phenolic, Carotenoid, and Glucosinolate.

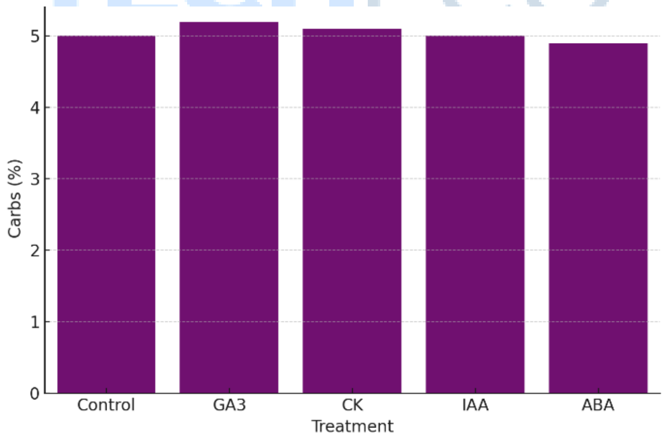

Figure 11: Bar plot comparing Protein and Carbohydrates in broccoli across treatments, showing the balance between the two macronutrients.

DISCUSSION:

The current study aimed to evaluate plant growth regulator effects on broccoli nutritional content by investigating vitamin C along with phenolic content and carotenoids and glucosinolates with macronutrients and micronutrients and produced significant findings which support PGR treatments as broccoli nutritional enhancers (Syed RU). This study contributes new findings to existing research about PGR's impact on nutritional value and plant growth (Coves S). Research findings demonstrated that the administration of gibberellic acid consistently produced significant increases in broccoli's vitamin C and phenolic compounds (Syed RU). The results reinforce similar studies that demonstrate gibberellins generate improvements in antioxidant and secondary metabolite production across multiple crop species. Results demonstrate an increase in carotenoids when broccoli plants receive treatment with both GA3 and AVA. Broccoli's antioxidant capabilities increase through the abscisic acid-mediated promotion of carotenoid synthesis which occurs during stress reactions. The health benefits of these molecules reinforce the intriguing results of cytokinin treatment on glucosinolate levels since they indicate targeted PGR applications can increase specific beneficial molecules in broccoli (Renna M). Studies show that macronutrient and micronutrient profiles increase when using GA3 and CK treatments to produce broccoli output of potentially higher nutritional value.

The research results develop major impacts on agricultural practices together with human health outcomes. Under controlled PGR treatments farmers can develop broccoli with improved nutritional values that align with consumer market demands. Research into optimal PGR application methods needs immediate attention to allow farmers to extract maximum nutritional value from plants while protecting plant development and environmental integrity. More research is needed to understand PGR-related transformations in broccoli's nutrient handling and metabolic processes which should improve our understanding of plant hormone-nutrient relationships in essential developmental pathways. The assessment of PGR applications' enduring influence on soil health along with microbial populations represents a vital requirement for maintaining sustainable agricultural practices. Recent scientific investigations show plant growth-promoting rhizobacteria need implementation because they enhance agricultural productivity while defending vegetation against diseases (Hasan A). Off-center scientific discoveries enable PGRLs to be paired with chitin-derived bio-stimulants to open innovative possibilities for plant development improvement with better nutrient uptake. Future research on broccoli yield enhancement and nutritional excellence should base their fundamental methodology on testing multiple PGRs and agricultural additives in combination studies. The investigation of broccoli sensory features requires studies to determine how different PGR concentrations through various application methods shape both flavor interactions and TEXTURE attributes.

The research demonstrates how specific plant growth regulators manifested different effects on vitamin C together with phenolic content and carotenoids and glucosinolates and macronutrients and micronutrients when used alongside gibberellic acid, abscisic acid, and cytokinin to show their significance in improving broccoli nutritional quality. Research data demonstrates that plant growth regulators show promise as powerful tools for broccoli nutritional enhancement while enabling sustainable agricultural practices (Ehinmitan E). Additional scientific research is needed to understand optimal PGR utilization methods and the fundamental metabolic mechanisms through which PGRs influence broccoli's nutritional elements. Plant growth regulators serve as an alternative sustainability approach to address global food requirements through applications which enhances both crop production levels and nutrient content (Khardia SM). The integration of plant development-promoting rhizobacteria into agricultural systems offers dual benefits which reduce chemical fertilizer requirements and enhance plant growth and resistance (Shah A) (Kumar P) (Wang D). The increased market need for healthy food enables growers to apply PGRs for boosting both the quantity and quality of broccoli production (Vandana UK). Plant scientists found chitin's nitrogen distribution advantages when combined with compounds but the study of PGR synergies with bio-stimulants and inputs remains promising for future agricultural exploration.

CONCLUSION:

The investigation confirmed that specific plant growth regulators (PGRs) altered broccoli nutritional content by boosting both essential vitamins and antioxidants and useful compounds. The application of gibberellic acid (GA3) treatments produced the most substantial results through increased vitamin C levels while also raising carotenoid values and protein concentrations making this technique a promising tool to enhance crop nutrition. Research demonstrated that Cytokinin (CK) elevated glucosinolate content in broccoli which supports its cancer-preventing properties. PGR treatments that used both abscisic acid (ABA) and GA3 showed significant enhancements in vegetable antioxidant qualities which may open new possibilities for increasing vegetable health benefits. The treatment conditions boosted the production of basic nutrients such as calcium, magnesium, and potassium which fully enhanced broccoli crop nutrition. Vitamin C and phenolic components in broccoli work together to reveal how PGR treatments enhance biochemical content. Through its research into vegetable nutrient enhancement mechanisms this study puts forth a sustainable solution to elevate crop quality. The research outcomes will constitute a foundation for upcoming agricultural studies that teach growers how to enhance broccoli and similar crop nutritional content to improve global dietary standards.

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