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Research article

Gibberellic Acid and Salicylic Acid on the Growth and Yield of Kale under Kratky Method Hydroponic System

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Abstract: Phytohormones are organic compounds, other than nutrients, that modify plant physiological processes, act inside plant cells to stimulate or inhibit specific enzymes or enzyme systems, and help regulate plant metabolism. In this work, the effectiveness of foliar application of gibberellic acid (GA3) and salicylic acid (SA) on the growth and yield of kale cultivated in a hydroponic system was evaluated. The study was conducted in a completely randomized design to determine the effectiveness of gibberellins and salicylic acid. The study demonstrated that the addition of 25 ppm GA3 + 200 ppm SA stimulated plant growth and enhanced yield. GA3 + SA treatments enhanced various morphological traits. Plant height is 37.77cm ± 0.08, fresh weight at 54.05g ± 0.44, root weight at 17.35g ± 0.21, whole plant at 71.41g ± 0.34, number of leaves at 11.73 ± 0.03, TSS and TA at 1.07 ± 0.02 and 0.56 ± 0.03, respectively. The application of growth hormones had a significant influence on all evaluated plant growth parameters, demonstrating that the combined application can markedly enhance overall plant growth and development. This highlights the potential of growth regulators as practical tools for optimizing physiological processes and improving crop performance in a hydroponic system.

Keywords: Hydroponic system; gibberellins; salicylic acid; kale

1. Introduction

The green, leafy vegetable kale *(Brassica oleracea* L.*)* belongs to the Brassicaceae family, a cabbage-like plant characterized by its non-heading, green leaves. Evidence indicates that this plant is grown in the early spring and has been used as a food crop since approximately 2000 B.C., but it only gained attention from the scientific community in recent years [1-2]. Kale has become a prominent crop within the Brassicaceae family due to its nutritional value and agronomic importance [3]. Kale gained popularity due to its sulfur-containing Phytonutrient that encourages good health [4]. They are an excellent source of nutrients and other health-promoting Phytochemicals such as glucosinolates, polyphenols, and carotenoids, which are important for antioxidant activity [5]. Recently, consumers' awareness of the value of eating nutritious meals has increased [6-11]. This is related to consumers' understanding that consuming more vegetables may lower the chance of developing cancer and other degenerative illnesses [12-13]. Lately, consumers' awareness of the importance of a nutritious diet has led them to consistently choose vegetables due to their numerous nutritional benefits consistently. For this reason, the demand for vegetables is steadily increasing, which affects the need for higher yields. In addition, kale has gained increasing economic importance in recent years, marked by a rise in both its cultivation and consumption [14]. To meet the increasing demand for vegetables, it has become essential to boost the yield of vegetable crops using environmentally friendly strategies that are easy to implement, economical, and friendly [15-19].

Plant growth regulators are used to enhance horticultural products, promoting plant growth and yield in various crops, reducing flower and fruit drop, increasing production per unit area and time, stimulating the translocation of photosynthesis, and leading to better retention of flowers and fruits [20-22]. Gibberellic acid is a key component of plant regulators used in agriculture. It promotes the processes of cell division, elongation, and expansion, which stimulate plant growth [23]. This phytohormone is one of the most produced and used GAs associated with these processes. [24]. Gibberellins (GAs), typically synthesized in roots, young leaves, and embryos, play a key role in fruit growth and the formation of seedless fruit. Moreover, sufficient application of GAs can lead to increased plant height [25]. They induce the transcription of genes needed for cell elongation and cell division during growth [26].

Salicylic acid (SA) plays a crucial role in various aspects of plant development, including promoting flowering, stimulating root growth, aiding seed germination, and enhancing ion uptake during root growth and development. [27]. Moreover, SA is a phytohormone essential for plant metabolic functions and defensive mechanisms [28]. Modulates plant growth and development, promotes flowering, and strengthens the plant defense system [29]. Gibberellins and salicylic acid may significantly influence various metabolic processes, including chlorophyll synthesis and breakdown, assimilate transport, nitrogen metabolism, and redistribution. As previously mentioned, these effects can vary significantly depending on the species, developmental stage, application method, dosage, and cultivation practices. Despite extensive research on GA_3 and SA in many horticultural crops, limited studies have examined their combined effects on kale, particularly under hydroponic cultivation systems, where nutrient dynamics and plant responses may differ from those in soil-based production. Moreover, little is known about how varying concentrations of these phytohormones influence both growth and biochemical quality attributes of kale. Therefore, this study aimed to investigate the impact of foliar application of gibberellic acid and salicylic acid on the growth and yield of kale cultivated in a hydroponic system.

2. Methodology

2.1 Location

The study was conducted in the greenhouse of Cebu Technological University-Barili Campus, Cagay, Barili, Cebu, Philippines, from December 2024 to February 2025. It is situated at approximately 10° 8' North, 123° 32' East, on the island of Cebu, and is located approximately 8.5 kilometers away from the proper market. Elevation at these coordinates is estimated at 145.2 meters or 475.4 feet above mean sea level.

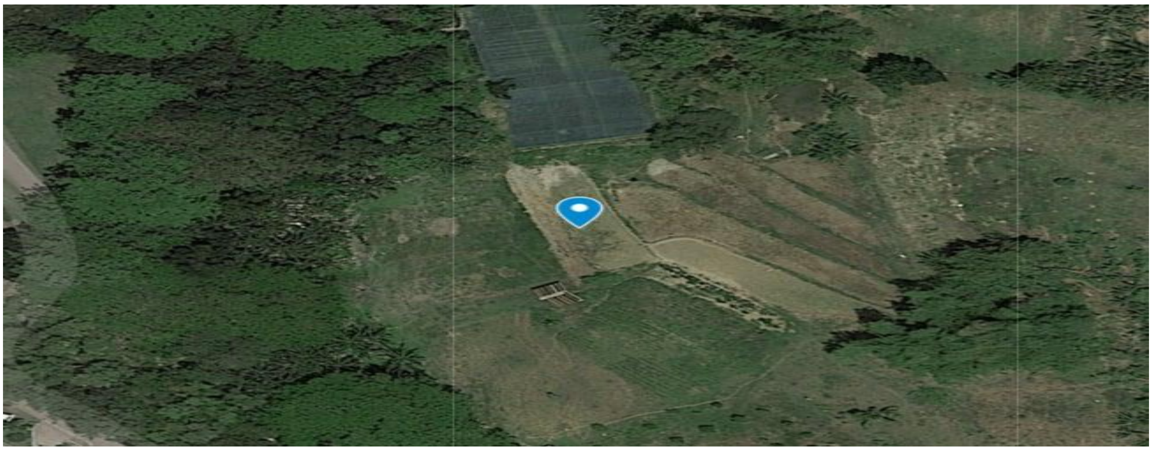

Figure 1. Location of the study within Cebu Technological University-Barili Campus

2.2 Experimental Design and Treatments

The experiment was laid out in a Completely Randomized Design (CRD) with six treatments and ten samples per treatment, replicated three times, with a spacing of 17cm per cup. The following were the treatments used in the study.

T0- Recommended Rate (Nutrient Solution)

T1- RR + 25ppm GA3

T2- RR + 200ppm SA

T3- RR + 25ppm GA3 + 200ppm SA

T4- ½ RR + 25ppm GA3 + 200ppm SA

T5- ½ RR + 50ppm GA3 + 400ppm SA

2.3 Materials and Area Preparation

The experiment area was disinfected prior to the establishment of the study to ensure the cleanliness and sanitation of the screenhouse. The Kratky hydroponic method was used, and for the establishment, bamboo racks were made. The greenhouse environment was maintained to provide optimal growing conditions for kale, ensuring a minimum of 6–8 hours of light exposure daily. The greenhouse temperature was recorded at 23–26 °C, and relative humidity (RH) was maintained between 50% and 70% using misting systems. Environmental conditions were continuously monitored to ensure consistent and reproducible greenhouse conditions throughout the experimental period.

2.4 Sample Size and Randomization

An a priori power analysis was performed to ensure that the replication was adequate to detect treatment effects. Using $\alpha = 0.05$, power = 0.80, and assuming a medium effect size (Cohen's f = 0.25) for a one-way ANOVA with six groups, the minimum required sample size was 159 plants (≈ 27 plants per treatment). The experiment provided 180 plants (30 per treatment), thus exceeding the required number and ensuring sufficient statistical power. Randomization was applied at the level of experimental units. Treatments were assigned to plants within the screenhouse using a computer-generated random number sequence, ensuring that each treatment had an equal chance of being allocated to any planting position. This procedure minimized systematic bias and ensured independence among treatment observations.

2.5 Media Sterilization and Seed Sowing

The planting medium used was cocopeat, which was sterilized with hydrogen peroxide (H_2O_2) for 24 hours to eliminate unwanted microorganisms. Following thorough cleaning and disinfection of the screenhouse, the sterilized medium was placed in seedling trays where seeds were sown and subsequently covered to promote germination.

2.6 Nutrient Solution Preparation and Transplanting

The nutrient solution used for crop establishment was procured online and prepared according to the manufacturer's recommended formulation to ensure the provision of essential macro- and micronutrients. Transplanting of seedlings was carried out 15 days after sowing, once the seedlings had reached an appropriate stage for establishment in the growing medium. The components of the nutrient solution were the following: NPK ratio: Grow solution: 9-0-0, Bloom Solution: 0-5-7 Micronutrients (Bloom Solution): Boron (B) – 200 ppm Copper (Cu) – 40 ppm Iron (Fe) – 1850 ppm Manganese (Mn) – 200 ppm Molybdenum (Mo) – 400 ppm Zinc (Zn) – 400 ppm

2.7 pH and EC monitoring

Daily monitoring of pH and electrical conductivity (EC) was conducted using a portable 5-in-1 salinity meter, pH/TDS/Salinity/EC/Temp meter, and Water Quality Meter with a pH range of 5.5-6.5 and an EC range of 1.2-2.2.

2.8 Application of treatment and harvesting

Application of GA3 was performed at 20 and 30 days after sowing, and application of SA was conducted 3 days after transplanting and repeated four times. Harvesting was done 55 days after sowing in the morning, when leaves are larger, darker green, and tougher, with full flavor, crisp, and hydrated

2.9 Data Gathered

2.9.1 Yield and morphological characteristics

- Plant height (cm) was determined by measuring from the base of the plant to the longest leaf using a measuring tape.
- Root length (cm) was obtained by measuring from the base of the root to its end using a measuring tape.
- Plant Fresh Weight (g) was measured by using a digital scale.
- Plant Root Weight (g) was measured by using a digital scale.
- The plant's whole weight (g) was measured using a digital scale.
- The number of Leaves was gathered by counting the leaves present during harvesting

2.9.1 Physicochemical characteristics of Kale

- Total Soluble Solid (TSS). Twenty (20) grams of leaves from each sample were collected and then homogenized with H_2O (1:3w/v), and the homogenates were centrifuged at 3500 rpm for 10 minutes. The extract was used to determine the soluble solid content.
- Titratable Acidity (TA). Five milliliters of kale juice were taken, and homogenized samples were prepared from TSS, which were then diluted with 45 milliliters of distilled water. The 50 mL extract (aliquot) was measured and transferred into an Erlenmeyer flask and a beaker. Two drops of 1% phenolphthalein indicator were added. This was titrated with 0.1% NaOH until a pale pink color was achieved using a Cordial 1642TF Glass burette.

2.10 Statistical Analysis

The data was analyzed using the analysis of variance (ANOVA) in CRD to evaluate significant differences among treatments. The data was processed using the STAR software. A post hoc Test using Tukey's Honestly Significant Difference (Tukey’s HSD) test was performed to determine significant differences among treatment means.

3. Results and Discussion

3.1 Growth and Yield

At the time of harvest, 55 DAS, the height of kale plants was significantly influenced by the combined application of 25 ppm gibberellic acid (GA_3) and 200 ppm salicylic acid (SA). This specific treatment led to noticeably taller plants compared to the control group, indicating a positive synergistic effect of GA_3 and SA on plant height. These findings are consistent with those reported by [12], [30], who also observed increased plant height under similar treatment concentrations.

The increase in plant height was accompanied by a substantial rise in fresh weight, particularly due to the enhanced development of the above-ground (epigeal) parts of the kale plants [12]. This indicates that the hormonal treatment not only stimulated vertical growth but also contributed to a greater accumulation of biomass in the shoot system. However, despite the notable changes in shoot development, there was no statistically significant difference in root length among the various treatments, as shown in Table 1.

In contrast, root weight did exhibit significant variation, suggesting that while the length remained relatively constant, the density or mass of the roots was affected by the treatments. The highest root weight was recorded in treatment 3, which exceeded that of all other treatments by a statistically significant margin. This implies that treatment 3 fostered conditions that promoted more robust root development, potentially enhancing the plant's ability to absorb water and nutrients.

Moreover, when evaluating the overall biomass, plants subjected to treatment 3 demonstrated the most significant total plant weight, clearly distinguishing themselves from other treatments. This significant increase in whole plant biomass further supports the conclusion that treatment 4 provided optimal conditions for both shoot and root growth, thereby maximizing overall resource utilization and physiological efficiency in kale grown under hydroponic conditions.

These observations align closely with previous research by Sun et. al [30], which also reported that the application of salicylic acid led to a marked improvement in both plant height and total biomass accumulation.

The consistency between these findings reinforces the potential of GA_3 and SA, especially in combination, as effective growth enhancers in leafy vegetables such as kale.

Table 1. Growth and Yield parameters of kale plants applied with gibberellic acid (GA3) and Salicylic acid (SA).

Treatments	Plant Height (cm)	Fresh Weight (g)	Root Length (cm)	Root Weight (g)	Whole Plant (g)
Control (Nutrient Solution)	35.73 ± 0.32^{bc}	51.95 ± 0.50^{b}	35.30 ± 0.40^{a}	14.96 ± 0.51^{b}	66.91 ± 0.30^{c}
Nutrient Solution + 25ppm GA3	36.27 ± 0.03^{b}	51.85 ± 0.33^{b}	36.37 ± 0.29^{a}	15.77 ± 0.54^{ab}	68.34 ± 0.22^{b}
Nutrient Solution + 200ppm SA	35.53 ± 0.08^{c}	51.66 ± 0.35^{b}	35.17 ± 0.14^{a}	15.39 ± 0.43^{b}	67.04 ± 0.11^{bc}
Nutrient Solution + 25ppm GA3 + 200ppm SA	37.77 ± 0.08^{a}	54.05 ± 0.44^{a}	35.90 ± 0.26^{a}	17.35 ± 0.21^{a}	71.41 ± 0.34^{a}
½ Nutrient Solution + 25ppm GA3 + 200ppm SA	28.37 ± 0.03^{d}	43.20 ± 0.09^{c}	27.40 ± 0.25^{b}	8.53 ± 0.21^{c}	51.73 ± 0.29^{d}
½ Nutrient Solution + 50ppm GA3 + 400ppm SA	23.23 ± 0.08^{e}	26.51 ± 0.13^{d}	22.27 ± 0.12c	7.11 ± 0.18^{c}	33.62 ± 0.31^{e}
CV (%)	0.78	1.29	0.49	5.03	0.80

Values with the same letter are not significantly different ($p>0.05$).

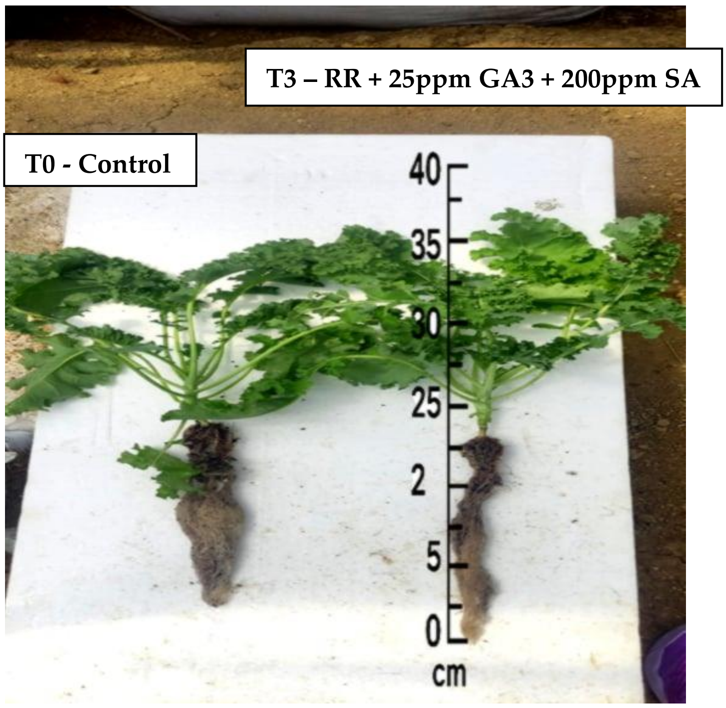

Figure 2. Comparing the yield using the control (nutrient solution) alongside the combination of Nutrient Solution + 25ppm GA3 + 200ppm Salicylic Acid (SA)

3.2 Number of Leaves, Total Soluble Solids, and Titratable Acidity

The number of leaves produced by kale plants was significantly influenced by the different treatments, as illustrated in Table 2. Among all the treatments, Treatment 3 yielded the highest number of leaves, with an average of 11.37, which was statistically significantly greater than the other treatments. This notable increase in leaf count under Treatment 3 suggests that the specific combination of applied substances played a crucial role in promoting vegetative growth. These findings align with those reported by [31], who demonstrated that the application of GA_3 enhances vegetative growth through mechanisms such as increased cell division and cell elongation. The exogenous application of GA_3 promotes the division, elongation, and proliferation of shoot cells, which collectively contribute to accelerated plant growth and development, particularly in the formation of new leaves.

On the other hand, Treatments 5 and 6 exhibited a significantly lower number of leaves. This reduction can likely be attributed to the use of half-strength nutrient solutions in these treatments. Inadequate nutrient availability, particularly deficiencies in macronutrients such as nitrogen, phosphorus, and potassium, limited the plants' ability to sustain active vegetative growth. Restricted access to essential nutrients negatively affected leaf initiation and expansion, which reduced overall vegetative performance. Tan et al [32] similarly reported that kale cultivated with half-strength solution exhibited lower biomass accumulation and plant height compared to full-strength treatments, highlighting the direct relationship between nutrient sufficiency and growth outcomes.

Table 2. Physicochemical characteristics of kale plants applied with gibberellic acid (GA3) and Salicylic acid (SA).

Treatments	No. of leaves	Total Soluble Solid Context (TSS)	Titratable Acidity (TA)
Control (Nutrient Solution)	9.71 ± 0.38^{b}	0.86 ± 0.02^{b}	0.42 ± 0.003^{b}
Nutrient Solution + 25ppm GA3	9.57 ± 0.03^{b}	0.86 ± 0.01^{b}	0.42 ± 0.01^{b}
Nutrient Solution + 200ppm SA	9.37 ± 0.03^{b}	0.83 ± 0.02^{bc}	0.46 ± 0.008^{b}
Nutrient Solution + 25ppm GA3 + 200ppm SA	11.73 ± 0.03^{a}	1.07 ± 0.02^{a}	0.56 ± 0.03^{a}
½ Nutrient Solution + 25ppm GA3 + 200ppm SA	7.40 ± 0.15^{c}	0.74 ± 0.01^{d}	0.33 ± 0.01^{c}
½ Nutrient Solution + 50ppm GA3 + 400ppm SA	7.10 ± 0.05^{c}	0.77 ± 0.01^{cd}	0.32 ± 0.02^{c}
CV (%)	3.31	3.07	7.13

Values with the same letter are not significantly different ($p>0.05$).

In addition to leaf count, the soluble solid content in kale leaves also varied significantly across the treatments. The nutrient solution with 200ppm SA again stood out, showing the highest accumulation of soluble solids. This indicates that this treatment was particularly effective in enhancing the concentration of sugars and other soluble compounds in the plant tissues, contributing to improved taste and nutritional quality. These results are consistent with those of [30], who also observed increased soluble solid content following the application of salicylic acid and gibberellic acid. Furthermore, the study revealed apparent differences in titratable acidity among the treatments, highlighting the measurable influence of hormonal applications on the organic acid levels in kale grown under hydroponic conditions. These variations suggest that the hormonal combinations not only affected vegetative traits but also had a significant impact on the biochemical composition of the plants, potentially altering flavor and storage properties [12,30]. Overall, the combination of GA_3 and SA, particularly in Treatment 3, proved to be the most effective in promoting both growth and quality attributes in hydroponically cultivated kale.

From an economic feasibility and practical application perspective, the integration of GA_3 and SA into hydroponic kale production offers considerable promise. The relatively low cost of applying plant growth regulators is outweighed by the yield improvements achieved, thereby improving profitability for growers. Economic evaluations of hydroponic kale systems, such as the feasibility analysis by Bafort [33], reported positive benefit–cost ratios and acceptable break-even points, confirming the viability of kale as a profitable crop when yield-enhancing strategies are employed. This suggests that the adoption of GA_3 and SA treatments can be scaled commercially to increase both productivity and profitability under sustainable hydroponic practices.

4. Conclusions

The combined application of 25 ppm GA_3 and 200 ppm SA (Treatment 3) produced the most favorable outcomes in hydroponically grown kale, significantly increasing plant height, leaf number, fresh weight, and total biomass, while enhancing biochemical attributes such as soluble solid content and titratable acidity. Although root length remained unchanged, root weight improved, indicating denser and more robust root systems. Treatments with half-strength nutrient solutions resulted in reduced leaf production due to nutrient limitations. Overall, the synergistic effect of GA_3 and SA demonstrates clear potential for optimizing both vegetative growth and quality traits. Maintaining full-strength nutrient solutions ensures optimal growth, making this approach economically feasible and suitable for scaling in commercial hydroponic kale production.

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