International Journal of Plant & Soil Science

Volume 37, Issue 9, Page 570-585, 2025; Article no.IJPSS.143497
ISSN: 2320-7035

Influence of Foliar Application of Aqueous Garlic Extract on Growth, Yield and Nutritional Quality of Four Varieties of Tomato (*Solanum lycopersicum* L.)

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Author's contribution

The sole author designed, analysed, interpreted and prepared the manuscript.

Article Information

DOI: https://doi.org/10.9734/ijpss/2025/v37i95736

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://pr.sdiarticle5.com/review-history/143497

Original Research Article

Received: 14/07/2025
Accepted: 02/09/2025
Published: 12/09/2025

ABSTRACT

Botanical extracts have recently gained attention as bio-stimulants in vegetable production. This study examines the influence of aqueous garlic bulb extract (AGE) on the growth, nutritional composition, and antioxidant enzyme activity of four tomato varieties grown in a screen house. The experiment followed a 3 x 4 × 4 factorial layouts in a completely randomized design (CRD) with three replications. The treatment includes four tomato varieties (Premium, Royal Bold, Sayo and Akungba Local) and four different frequencies of AGE foliar spray: 0 (Control), F1 (once), F2 (twice), and F3 (three times), applied at transplanting, flowering, and fruiting stages. Data were collected on plant height, leaf area, stem girth, number of branches, green leaves at transplanting, 50% flowering and maturity, plant biomass, fruit weight, and total number of fruits per plant. The

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Cite as: *Adeola Oluwatoyin Wewe. 2025. "Influence of Foliar Application of Aqueous Garlic Extract on Growth, Yield and Nutritional Quality of Four Varieties of Tomato (Solanum Lycopersicum L.)". International Journal of Plant & Soil Science 37 (9):570–585. https://doi.org/10.9734/ijpss/2025/v37i95736.*

treatments positively ($p < 0.05$) influenced some growth parameters of AGE-treated tomato plants, such as plant height, leaf area, number of branches, and senescence leaves at 50% flowering and fruiting stages. A positive effect of AGE applied twice (F2) was observed, particularly in the Premium variety, which consistently showed greater height, increased leaf area, and more senescence leaves. Additionally, thrice foliar application (F3) across all varieties led to enhanced antioxidant enzyme activity (superoxide dismutase, SOD) and chlorophyll content at the fruit-setting stage. These findings suggests that AGE can serve as an effective bio-stimulant to improve tomato growth under screen house conditions.

Keywords: Aqueous garlic bulb extract; bio-stimulants; chlorophyll; malondialdehyde; plant growth; tomato.

1. INTRODUCTION

Tomato (*Solanum lycopersicum* L.) is a member of the Solanaceae family and is one of the most essential vegetable crops in Nigeria and many tropical and subtropical regions of the world. According to FAOSTAT (2024), tomatoes rank first among Nigeria most important vegetables in terms of production scale and consumption. Tomato production in Nigeria is seasonal, with distinct agro ecological zones in the northern and southern regions. It is known that growing conditions such as water can impact the growth, metabolism and yields of the plant (Chand *et al*., 2020). However, tomato yields remain insufficient to meet national demand, and the nutritional value of tomatoes has been steadily declining. Tomatoes are a vital component of the Mediterranean diet and are widely consumed for their numerous health benefits, particularly due to their high content of antioxidants, including beta-carotene (Debjit *et al*., 2012).

In recent years, botanical extracts have gained prominence as bio-stimulants in vegetable production (Zhi-hui *et al*., 2019). Bio-stimulants enhance plant growth and development throughout the crop life cycle by improving metabolic efficiency, which leads to increased yield and improved crop quality. They also promote nutrient assimilation, translocation, and usage, thereby helping plants better tolerate and recover from abiotic stress (Zhi-hui *et al*., 2019).

Allium sativum, commonly known as garlic, has been utilized in organic horticulture for centuries as a natural deterrent against a spectrum of plant afflictions (Haggag, 2007). Aqueous garlic extract (AGE) is rich in phenolic compounds, exhibiting potent antioxidant and biological activity (Zhi-hui *et al.,* 2019). These attributes render AGE a potential stimulus for enhancing plant physiology. Scientific studies have demonstrated that foliar application of AGE accelerates plant growth, boosting photosynthetic pigment synthesis and soluble sugar content (Hanafy *et al.,* 2012). Growing recognition of the detrimental environmental impacts of synthetic chemical inputs has prompted a surge in the adoption of organic methods (Gilder *et al*., 2010; Mostafalou and Abdullahi, 2013). Foliar feeding, in particular, has proven to be a highly effective supplementary technique, often rivaling or surpassing soil applications, especially when addressing issues related to salicylic acid (SA) deficiency. SA plays a pivotal role in plant development, ion uptake, and transport (Sikandar Hayat *et al*., 2019). AGE is a rich source of bioactive compounds, including allicin, which possess antioxidant, antimicrobial, and anticancer properties. Furthermore, recent research suggests that garlic extract may positively influence the nutritional makeup of various crops.

While extant studies have elucidated the mechanisms of garlic-derived compounds in augmenting plant antioxidant defenses, further research is warranted to comprehensively investigate the efficacy of garlic bulb extracts in modulating the antioxidant repertoire of plant species. As the frontline defense against reactive oxygen species (ROS), the antioxidant enzyme superoxide dismutase (SOD) plays a crucial role in regulating oxygen metabolism within plant cells. Through its catalytic action, SOD efficiently neutralizes superoxide radicals, converting them into hydrogen peroxide and dioxygen, thereby mitigating lipid peroxidation and membrane damage (Huseynova *et al*., 2014; Shafi *et al*., 2015). Malondialdehyde (MDA), a deleterious byproduct of polyunsaturated fatty acid peroxidation, serves as a biomarker indicative of oxidative stress in plants (Davey *et al.,* 2005; Del *et al*., 2005). Elevated MDA levels can

compromise cellular processes and hinder normal growth and developmental trajectories in plants (Huang *et al*., 2007).

Given the limited understanding of AGE as a bio-stimulator in plants, this study aims to explore its effects when applied at different frequencies and timings via foliar sprays on tomatoes grown under controlled screen conditions. The research focuses on assessing the growth, yield, and physiological characteristics, including antioxidant enzyme activity and MDA content, to determine AGE's bioactivity in tomato plants. This study hypothesis that foliar application of aqueous garlic bulb extract (AGE) will positively influence the growth, yield, nutritional composition, and antioxidant enzyme activities in tomato plants. The objective of the research is to evaluate the evaluating the role of aqueous garlic extract foliar application in enhancing growth, yield, and nutritional quality of four tomato varieties.

2. MATERIALS AND METHODS

This study was conducted in the screen house of the Department of Agronomy at Adekunle Ajasin University, located in Akungba-Akoko, Ondo State, Nigeria. The study site is positioned between latitudes 7°32'N and 7°33'N and longitudes 4°32'E and 4°34'E, within the forest-savanna transition zone of Nigeria. The region experiences an average annual rainfall of 1250 mm, with mean annual temperatures ranging from 26°C to 32°C.

2.1 Experimental Design and Treatments

The experiment followed a 3 x 4 × 4 factorial arrangements, combining four tomato varieties with four varying frequencies of foliar application of aqueous garlic extract (AGE). The tomato varieties included the improved and local types: Premium Super F1, Royal Bold F1, Sayo F1, and Akungba Local. The experimental setup was laid out in a Completely Randomized Design (CRD) with three replicates for each treatment. The foliar application of AGE was administered at four different frequencies: 0 (control), F1 (once), F2 (twice), and F3 (thrice).

2.2 Source of Planting Material

The seeds of the improved tomato Varieties-Premium Super F1, Royal Bold F1, and Sayo F1-were sourced from the National Horticultural Research Institute (NIHORT) in Ibadan, Oyo State Nigeria. But, the Akungba Local variety utilized seeds procured from the AAUA Agro Chemical Shop in Akungba Akoko, Ondo State, Nigeria, to represent local, and an unimproved strain.

2.3 Planting

Perforated pots with a capacity of seven litres were filled with 5 kg of air-dried loamy soil and watered to saturation. After three weeks, tomato seedlings were transplanted into the pots, with one seedling per pot. To ensure uniform germination, the pots were watered equally, after which the treatment application commenced. Weeding was done manually every two weeks by pulling out the weeds by hand. Fresh garlic bulbs of uniform size and weight were selected from a local market's garlic sales unit, stored at 18°C, and later taken to the laboratory.

2.4 Preparation of Aqueous Garlic Extract (AGE)

The aqueous garlic extract (AGE) was prepared following the method described by the Brooklyn Botanic Garden (2000) with slight modifications. Fresh, uniform garlic bulbs were weighed, peeled, and crushed using a sterile mortar and pestle. The garlic extract treatments were prepared by mixing the crushed garlic with distilled water as follows; 250 g/L, 212.5 g/L, and 78 g/L of distilled water, with the Control treatment being distilled water only. The individual samples were temporarily stored on a laboratory workbench for a 60-minute period before undergoing filtration via Whatman grade filter paper. The resulting filtrate was then harvested for subsequent experimental utilization.

2.5 Procedure for Foliar application of the AGE to the tomatoes Spraying with Aqueous Garlic Extract (AGE) on Tomato

One month after sowing, seedlings with similar vigor were transplanted. Seven days post-acclimatization, the juvenile plant stocks underwent a comprehensive AGE treatment. A precise 50 ml application was utilized, resulting in a full canopy coverage and solution runoff from the foliage. And the applications were done three times at weekly intervals. Control plants were sprayed with distilled water.

2.6 Determination of Superoxide Dismutase (SOD) and Glutathione (GSH) Activities and Malondialdehyde (MDA) Content

Superoxide dismutase (SOD) activity was determined following the procedure developed by Li (2012). A 0.2 ml aliquot of the diluted sample was mixed with 2.5 ml of 0.05m carbonate buffer (pH 10.2) containing $NaHCO_3$ and Na_2CO_3 and equilibrated in the spectrophotometer. The reaction was initiated by adding freshly prepared 0.3 mm adrenaline, and the mixture was quickly inverted to mix. The reference cuvette contained 2.5 ml of the buffer, 0.3 ml of the substrate (adrenaline), and 0.2 ml of water. Freshly prepared adrenaline (183.204 g/mol) or epinephrine was used. The increase in absorbance at 480 nm was recorded every 30 seconds for 150 seconds.

Calculation:

Increase in absorbance per minute = A3 – A0 =2.5

Where,

A0 = absorbance after secs.
A3 = absorbance after 150 secs.

Increase in absorbance for substrate % inhibition = 100
Increase in absorbance of standard=100×

1 unit of SOD activity was defined as the amount of SOD necessary to cause 50% inhibition of the oxidation of adrenaline to adrenochrome during 1 minute.

Glutathione Peroxidase (GSH) was determined by a procedure described by (Ciochoski *et al*., 2012).

GSH converts H_2O_2 to water.

- 1 ml of 0.3M sodium phosphate buffer pH 7.4
- 0.3 ml of freshly prepared 10mM reduced glutathione (307.32 g/mol)
- 0.3 ml 15 mM H_2O_2
- 1.37 ml distilled water
- Follow by the addition of 0.3 ml homogenate
- 340 nm for 120 secs at 15 secs interval.
- Calculation: Glutathione peroxidase activity was obtained by plotting the standard curve and the concentration of the remaining GSH was extrapolated from the curve.

GSH consumed = 245.84 – GSH remaining

Lipid peroxidation was determined using the method described by Varshney and Kale (1990). This method involves measuring the formation of thiobarbituric acid reactive substances (TBARS). Under acidic conditions, malondialdehyde (MDA), a product of fatty acid peroxidation, reacts with 2-thiobarbituric acid (TBA) to form a pink-coloured complex with maximum absorbance at 532 nm and fluorescence at 553 nm. The pink chromophore can be readily extracted into organic solvents like butanol. An aliquot of 0.4 ml of the homogenate was mixed with 1.6 ml of Tris-KCl buffer, followed by the addition of 0.5 ml of 30% trichloroacetic acid (TCA). Next, 0.5 ml of 0.75% TBA was added, and the mixture was incubated in a water bath at 80ºC for 45 minutes. Afterwards, the solution was cooled on ice and centrifuged at 3000 g. The clear supernatant was collected, and absorbance was measured at 532 nm using distilled water as a reference blank. The MDA level was calculated using the formula below, with lipid peroxidation expressed in units/mg protein or per gram of tissue, using a molar extinction coefficient of $1.56 \times 10^5\ M^{-1}cm^{-1}$.

2.7 Determination of Moisture, Crude Protein, Fat, Carbohydrate and Ash

Moisture content was determined using the procedure outlined in AOAC 930.15 (2000). A moisture dish of appropriate size was accurately weighed. Then, 10 g of the comminuted sample was added to the dish and reweighed. The dish containing the sample was placed in a vacuum oven set at 100°C under a pressure of less than 100 mm Hg for 5 hours. Afterwards, the dish was removed from the oven, covered, cooled in a desiccator, and reweighed. The sample was re-dried for 1 hour, and the process was repeated until a constant weight was achieved, indicated by a minimal change in weight between successive dryings at 1-hour intervals.

Calculations;

Calculated the percentage of the moisture (wet weight basis) as follows;

100 (P-a) percent moisture = %P
P = weight in g of sample
A = weight in g of dried sample

2.8 Determination of Crude Protein

Crude protein was determined using the Standard MAFF (1982) method. A 1 g sample was weighed into a Kjeldahl flask, followed by the addition of 10 g potassium sulfate or sodium sulfate, 0.6–0.7 g mercuric oxide, 25 ml sulfuric acid, and a few grains of pumice stone. The flask was heated moderately at first, with occasional shaking, until the material was carbonized and bubbling ceased. The temperature was then increased to bring the mixture to a gentle boil, ensuring that the flask walls did not overheat, preventing organic particles from sticking to them. Once the solution became clear and colourless, boiling was continued for an additional 2 hours, after which the flask was allowed to cool. After digestion and cooling, the solution crystallized, and the analysis was repeated. To the cooled flask, 250 ml of distilled water was added, stirring the contents simultaneously. A few zinc pellets were added afterwards.

2.9 Distillation

A 25 ml solution of 0.1N sulphuric acid was transferred to the collecting flask of the distillation apparatus, based on the anticipated nitrogen content of the sample. A few drops of methyl red indicator were added. Taking care not to lose any ammonia, 100 ml of sodium hydroxide solution and 25 ml of sodium thiosulfate solution were carefully added to the sample. The mixture was thoroughly mixed and immediately connected to the distillation apparatus. The flask was then heated to distil approximately 150 ml of liquid within 30 minutes. The pH of the distillate was checked using litmus paper. In the collecting flask, the excess sulphuric acid was titrated with 0.1N sodium hydroxide, adjusted according to the normality of the acid used, until the endpoint was reached, indicated by the colour change of the methyl red or methyl red-methylene blue indicator.

Calculations:

Determine the H_2SO_2 consumed. 1ml acid = 1.4 mg nitrogen

The percentage of nitrogen in the sample was calculated and converted to a percentage of protein by multiplying the result by 6.25.

The crude fibre was determined by using the procedure of ISO 6865.2000 (International Organization for Standardization. (2000)). 3 g of defatted, dry sample was weighed and placed in the flask and 200 ml boiling sulphuric acid solution. Then, the condenser was attached and brought to boiling point in one minute. It was boiled for exactly 30 minutes, to maintain the volume of distilled water at constant and then swirled the flask periodically to remove particles adhering to the sides. The Buchner funnel was lined with the filter paper and preheated with boiling water. At the same time, at the end of the boiling period, the flask was removed to let it rest for one minute and filter the contents carefully, using suction. Filtration is carried out in less than 10 minutes. Then, wash the filter paper with boiling water. The residue was transferred to the flask using a retort containing 200 ml of boiling NaOH solution and boiled for 30 minutes. Then, preheat the filtration crucible with boiling water and carefully filter the hydrolyzed mixture after letting it rest for 1 min. The residue was washed with boiling water, with the HCL solution and then again with boiling water, finishing with three washes with petroleum ether. The crucible was in a kiln set at 105°C for 12 hours then cooled in a dryer then quickly weighed the crucible with the residue inside and placed in the crucible furnace at 550° C for 3 hours. From the furnace, the crucible was left to cool in a dryer and weighed again.

Ash is considered as the total mineral or inorganic content of the sample. Ash content is determined by the method described by AOAC 942.05. 2000.

Material and equipment; Porcelain crucibles, Crucible furnace, Dryer.

5 g of dry sample was placed in a crucible previously calcined and brought to constant weight. place the crucible was crucible in a furnace and heat at 550°C for 12 hours; leave to cool and transfer to a dryer. carefully weighed the crucible again with the ash.

Carbohydrate is obtained by subtracting the percentages calculated for each nutrient from 100. (AOAC, 2000).

Calculations:

Nitrogen-free extract (%) = 100 - (A + B + C + D + E)

Where:

A = humidity content (%)
B = crude protein content (%)
C = crude lipid content (%)
D = crude fibre content (%)
E = ash content (%)

Fat was determined by bringing about 5 g of dry sample was weighed into an extraction thimble, handling it with tongs and placed in the extraction unit. Connected the flask containing petroleum ether at 2/3 of the total volume to the extractor. Brought to boiled and adjusted heat to obtain about 10 refluxes per hour. When finished, evaporate the ether by distillation. The flasks were cooled in a dryer and weighed. This method is described by AOAC 920.39.2000.

2.10 Determination of Alkaloids, Flavonoids and Saponin

The alkaloid content was determined using the method described by Harbone (1973). A 5g sample was weighed into a 250 ml beaker, and 200 ml of 10% acetic acid in ethanol was added. The mixture was allowed to stand for 4 hours, after which it was filtered. The filtrate was concentrated in a water bath until the volume was reduced to one-quarter of the original. Concentrated ammonium hydroxide was added dropwise to the extract until precipitation was complete. The solution was left to settle, and the precipitate was collected, washed with dilute ammonium hydroxide, and filtered. The resulting residue, representing the alkaloid, was dried and weighed.

Saponin content was determined using the spectrophotometric method by Brunner (1984). A 2 g sample of finely ground material was weighed into a 250 ml beaker, and 100 ml of isobutyl alcohol (But-2-ol) was added. The mixture was shaken for 5 hours to ensure uniform mixing. It was then filtered through Whatman No. 1 filter paper into a 100 ml beaker containing 20 ml of a 40% saturated solution of magnesium carbonate ($MgCO_3$). The resulting mixture was filtered again through Whatman No. 1 filter paper to obtain a clean, colourless solution. A 1 ml aliquot of the colourless solution was transferred into a 50 ml volumetric flask, and 2 ml of 5% iron (III) chloride ($FeCl_3$) solution was added. The volume was made up to the 50 ml mark with distilled water. The mixture was allowed to stand for 30 minutes to develop colour, and the absorbance was measured at 380 nm against a blank.

Flavonoid content was determined using the colorimetric method developed by Bao (2005). A 0.2 ml sample of the extract was added to 0.3 ml of 5% sodium nitrite ($NaNO_3$) solution at time zero. After 5 minutes, 0.6 ml of 10% aluminum chloride ($AlCl_3$) was added, and after another 6 minutes, 2 ml of 1M sodium hydroxide (NaOH) was added. This was followed by the addition of 2.1 ml of distilled water. The absorbance was measured at 510 nm against a reagent blank. The flavonoid content was expressed as milligrams of rutin equivalent.

2.11 Determination of Leaf Chlorophyll

Leaf chlorophyll content was determined using spectrophotometry. First, a 1-gram sample of finely cut and thoroughly mixed leaf tissue was weighed. The sample was ground into a fine pulp with 20 ml of 80% acetone using a mortar and pestle. The resulting mixture was centrifuged at 5000 rpm for 5 minutes, and the supernatant was carefully transferred to a 100 ml volumetric flask.

The residue from the first centrifugation was then ground again with an additional 20 ml of 80% acetone. The centrifugation process was repeated, and the supernatant was combined with the previous extraction in the volumetric flask. This process was repeated until the residue became colourless, indicating complete extraction. The mortar and pestle were washed with 80% acetone, and the washing solution was added to the volumetric flask. The final volume of the combined solution was adjusted to 100 ml with 80% acetone. The absorbance of the solution was measured at wavelengths of 645 nm, 663 nm, and 652 nm, using 80% acetone as a blank, as described by Arnon (1949).

2.12 Measurement of Tomato Growth and Yields

The following parameters were considered to assess the growth and yield of tomato plants:

plant height (cm), number of green leaves, leaf area (cm²), number of senescent leaves, fruit weight (g), number of fruits, and fruit size per plant. The plant height of each plant was measured from the soil surface to the tip of the last leaf using a measuring tape (in cm). Measurements were taken at three-week intervals, three weeks after transplanting and continuing until the end of the experiment. The number of green leaves per plant was determined by visually counting the leaves on each plant. Leaf area was calculated by measuring the length (L) and breadth (B) of each leaf and multiplying by 0.75 the formula. Leaf area was calculated using the formula: LA = L × B × 0.75. The circumference of the stem was measured using a measuring tape to determine the stem girth. Senescent leaves showing signs of senescence, such as discolouration or drying, were visually identified and counted. Mature fruits were harvested and weighed using a Mettler Analytical Balance to determine their weight. The number of mature fruits per plant was counted visually. Fruit size was measured by determining the length and diameter of each fruit using a Vernier caliper.

2.13 Statistical Analysis

The data collected were analyzed using a two-way analysis of variance (ANOVA) with Statistical Analysis System (SAS) software. Mean values were compared and separated using Duncan's multiple range test (DMRT) at a 5% level of significance.

3. RESULTS

3.1 Morphology and Yield of Tomato Varieties

The tomato plants displayed varied responses to transplantation, flowering, and fruiting, with distinct changes observed in their morphological characteristics. Table 1a illustrates the highest plant height, number of branches, number of senescent leaves, and number of green leaves were recorded in the plants treated with three foliar applications of AGE (F3) at 50% flowering and fruiting. This was followed by the plants treated with a single foliar AGE application (F1) during the fruiting stage. In contrast, plants sprayed twice with AGE exhibited reduced plant height, fewer branches, and fewer green leaves at transplantation and flowering stages compared to the control group. A similar pattern was noticed for stem girth, where the largest leaf area was observed in the control plants sprayed with distilled water. However, the leaf area decreased in the plants sprayed twice with AGE.

As shown in Table 1b, the Premium variety demonstrated the highest plant height, leaf area, number of branches, green leaves, and senescent leaves, both at the flowering and fruiting stages. Regarding yield, the control group of tomato plants produced the highest fruit weight, fruit size, and number of fruits per plant, as shown in Table 1c. In Table 1d, it is indicated that the Premium variety treated with foliar AGE application, particularly at 0% (control) treatment, resulted in increased fruit weight and size. Other morphological parameters, such as root length and shoot-to-root fresh and dry weights, also revealed significant effects based on the frequency of AGE application. As shown in Table 1e, tomato plants treated with three foliar AGE applications had the highest shoot and root fresh weights, recorded at 200.58 g and 12.62 g, respectively. Conversely, the lowest shoot fresh weights were observed in plants subjected to distilled water (control) treatments. Similar outcomes were found for shoot and root dry weights, with the highest values (45.06 g and 4.58 g, respectively) recorded in plants treated with three AGE applications.

3.2 Effect of AGE on Antioxidant Enzyme Levels and MDA Content in Tomato Leaves

As shown in Table 6, plants treated with three foliar applications of AGE exhibited higher superoxide dismutase (SOD) activity compared to the control plants. Glutathione (GSH) activity was notably higher in plants under control treatment. Additionally, plants treated with a single AGE application showed a significant increase in malondialdehyde (MDA) content compared to the control group.

Table 6b highlights that MDA content was significantly elevated in the Premium variety, while SOD activity was highest in the Sayo variety. Differences in GSH activity were also observed among the varieties, with the Akungba local variety showing the highest GSH content.

Table 1a. Effect of aqueous garlic bulb extract (AGE) frequency on tomato growth

AAGE frequencies F	Plant height @transplant (cm)	Leaf area (cm^2)	Stem girth (cm)	No of green leaves	No of branches	Plant height @ 50% flowering (cm)	Leaf area (cm^2)	Stem girth (cm)	No of green leaves	No of branches	Number of Senescence leaves	Plant height @fruiting (cm)	Leaf area (cm^2)	Stem girth (cm)	No of green leaves	No of branches	Number of Senescence leaves
O	76.17a	42.90a	3.04a	127.17a	14.16a	127.13a	43.46a	3.83a	273.83b	26.17ab	15.42c	135.12b	51.60a	4.29a	253.50b	31.50a	18.83c
F1	69.28a	39.37ab	3.07a	85.67bc	11.33b	126.98a	37.36b	3.71ab	295.33b	23.42b	21.92bc	135.94b	34.22b	4.24a	269.17ab	29.25a	27.75b
F2	61.75b	32.99b	2.80a	70.17c	10.33b	127.93a	43.43a	3.43b	292.42b	23.33b	28.75ab	138.00ab	37.88b	3.88b	258.08b	27.67a	34.00b
F3	70.25a	36.43ab	2.79a	99.67b	10.58b	138.92a	38.57ab	3.68ab	358.42a	29.00a	35.00a	147.35a	38.09b	4.08ab	290.08a	30.58a	45.83a

Means followed by the same letters are not significantly different at 5% level of probability. AGE was applied at weekly intervals including once (F1), twice (F2) and thrice (F3). O, control treatment

Table 1b. Varietal effect on growth of tomato

Varieties	Plant height @transplant (cm)	Leaf area (cm^2)	Stem girth (cm)	No of green leaves	No of branches	Plant height@ 50%flowering (cm)	Leaf area (cm^2)	Stem girth (cm)	No of green leaves	No of branches	Number of Senescence leaves	Plant height @fruiting (cm)	Leaf area (cm^2)	Stem girth (cm)	No of green leaves	No of branches	Number of Senescence leaves
Sayo	54.42c	28.98b	2.54c	56.17c	8.33c	123.69b	32.68c	3.24c	202.33b	16.25c	21.08b	131.06b	42.14b	3.78c	195.50b	22.58c	25.67b
Premium	86.92a	45.46ab	3.08ab	82.42bc	11.92b	159.70a	50.87a	3.78b	353.08a	32.08a	30.83a	169.06a	45.41a	4.19b	277.58a	35.75a	42.17a
Royal bold	66.50b	45.58a	3.22a	100.00b	9.33c	107.99c	45.39b	4.22a	319.75a	25.25b	25.42ab	117.12c	39.79ab	4.63a	290.00a	27.17b	26.58b
Akungba local	69.61b	31.66b	2.86bc	144.08a	16.83a	129.58b	33.86c	3.43c	344.83a	28.33ab	23.75ab	139.18b	34.45b	3.90bc	307.75a	33.50ab	32.00b

Means followed by the same letters are not significantly different at 5% level of probability

Table 1c. Effect of aqueous garlic bulb Extract (AGE) frequency on tomato yield

AGE frequencies	Number of fruits per plant	Fruit weight (g)	Fruit size (m)
O	4.08a	82.54a	71.55a
F1	1.33b	24.26b	68.73ab
F2	1.67b	33.74b	62.55bc
F3	2.00b	20.04b	61.64c

Means followed by the same letters are not significantly different at 5% level of probability. AGE was applied at weekly intervals including once (F1), twice (F2) and thrice (F3). O, control treatment

Table 1d. Varietal effect on yield of tomato

Varieties	Number of fruits per plant	Fruit weight (g)	Fruit size (m)
Sayo	1.08b	4.51b	69.88b
Premium	1.92b	66.43a	78.91a
Royal bold	1.42b	41.75a	63.43b
Akungba local	4.67a	47.89a	52.25c

Means followed by the same letters are not significantly different at 5% level of probability

Table 1e. Effects of aqueous garlic extracts bulb on tomato biomass

AGE Frequency	Plant weight (g)	Fresh shoot weight (g)	Fresh root weight (g)	Root length (cm)	Dry shoot weight (g)	Dry root Weight (g)	Number of root
0	315.00a	141.07b	12.21ab	28.03b	41.24ab	3.68ab	20.17a
F1	245.52c	149.55ab	10.03b	30.39ab	36.46b	3.73ab	18.42a
F2	274.18b	147.05ab	10.18b	28.48ab	32.99b	2.93b	17.83a
F3	306.83ab	200.58a	12.62a	31.20a	45.06a	4.48a	13.25b

Means in the Table with the same column followed by the same letters are not significantly different at 5% level of probability. AGE was applied at weekly intervals including once (F1), twice (F2), and three times (F3). O, control treatment

Table 2a. Effect of AGE frequency on the antioxidant enzyme of tomato

AGE Frequency	SOD	GSH	MDA
O	59.73b	53.66a	0.31c
F1	59.57b	24.82c	0.49a
F2	59.76b	23.82d	0.36b
F3	62.22a	34.77b	0.36b

Means followed by the same letters are not significantly different at 5% level of probability
(Superoxide dismutase, SOD; malondialdehyde, MDA content and glutathione, GSH). AGE was applied at weekly intervals, including once (F1), twice (F2), and three times (F3). O (control)

Table 2b. Effect of varieties on the antioxidant enzyme of tomatoes

Varieties	SOD	GSH	MDA
Sayo	64.23a	46.88b	0.31c
Premium	57.85c	18.21d	0.53a
Royal bold	60.41b	22.24c	0.38b
Akungba local	58.79c	49.74a	0.30d

Means followed by the same letters are not significantly different at 5% level of probability
(Superoxide dismutase, SOD; malondialdehyde, MDA content and glutathione, GSH)

3.3 Effect of AGE on Leaf Chlorophyll Content

Table 3 illustrates that total chlorophyll content was highest in plants treated with three applications of AGE. In contrast, plants receiving a single AGE application showed reduced chlorophyll levels compared to the control group at the maturity stage. Additionally, the Premium variety exhibited the highest chlorophyll content compared to the other varieties.

3.4 Effect of AGE on Phytochemical Content in Tomato

Table 4 shows that tomato plants treated with distilled water at maturity had higher alkaloid content compared to those treated with AGE at various frequencies. At the second frequency (F2), the flavonoid content of the tomato plants increased significantly. There were no significant differences in saponin content among the different treatments. The Akungba local variety had significantly higher levels of alkaloids, flavonoids, and saponin compared to other varieties. However, the Premium variety exhibited significantly lower flavonoid content.

3.5 Effect of AGE on Proximate Content of Tomato

Table 5 indicates that moisture content, ash, and protein levels were significantly higher in the control (0) group. Crude fiber content was highest in plants treated with three foliar applications (F3) of AGE. Additionally, carbohydrate content was elevated in plants receiving the second foliar application compared to other treatment frequencies.

3.6 Interaction between Variety and AGE Foliar Application on Growth and Yield Parameters of Tomato

Table 6a presents the interactions between tomato variety and AGE foliar application on growth parameters. The results indicate that the Premium tomato variety treated twice (F2) achieved the greatest plant height at 50% flowering, significantly differing from

Table 3a. Effects of aqueous garlic extracts on chlorophyll

AGE frequency	Leaf chlorophyll
0	2.89c
F1	2.68d
F2	3.03b
F3	3.09a

Means in the table with the same column followed by the same letters are not significantly different at 5% level of probability. AGE was applied at weekly intervals including once (F1), twice (F2), and three times (F3). O, control treatments

Table 3b. Effects of varieties on chlorophyll

Varieties	Leaf chlorophyll
Sayo	3.19b
Premium	3.27a
Royal bold	2.67c
Akungba local	2.56d

Means in the table with the same column followed by the same letters are not significantly different at 5% level of probability

Table 4a. Effect of the frequency of foliar spraying with aqueous garlic bulb extract (AGE) on the phytochemical composition of tomato

AGE Frequency	Alkaloid	Flavonoid	Saponin
O	7.21a	2.02b	217.65a
F1	5.81d	1.72c	217.10a
F2	6.71b	2.17a	218.15a
F3	6.01c	1.62d	218.61a

Means followed by the same letters are not significantly different at 5% level of probability
AGE was applied to the leaves at weekly intervals including once (F1), twice (F2), and three times (F3). O, control treatment

Table 4b. Phytochemical composition of varieties on tomato

Varieties	Alkaloid	Flavonoid	Saponin
Sayo	6.01d	1.84b	217.05a
Premium	6.71b	1.79c	216.64a
Royal bold	6.21c	1.97a	219.62a
Akungba local	6.81a	1.93ab	218.20a

Means followed by the same letters are not significantly different at 5% level of probability

all other varieties. In contrast, the improved variety Royal Bold had the lowest plant height at this stage when treated with the control. Among all varieties and AGE applications, the Premium variety treated three times exhibited the highest number of senesced leaves and branches at both maturity and 50% flowering, while the Sayo variety had the lowest. Additionally, the Sayo variety showed significantly fewer functional green leaves at transplantation, 50% flowering, and maturity when treated with AGE twice. Table 6b shows the interactions between tomato variety and AGE foliar application on yields and yield components. The Premium variety, under control conditions, produced significantly higher fruit weight and fruit size. Conversely, the Akungba local variety, treated twice with AGE (F2), had the lowest fruit weight and fruit size. However, the Akungba local variety under control conditions had the highest number of fruits per plant.

3.7 Interaction between AGE and Varieties on Antioxidant Enzyme and MDA Content in Tomato Leaves

Table 7 illustrates the interactions between AGE treatments and tomato varieties on antioxidant enzyme levels and MDA content in tomato leaves. The Sayo variety treated with AGE three times (F3) exhibited the highest levels of superoxide dismutase (SOD) and glutathione (GSH). For malondialdehyde (MDA) content, the Premium variety, with a single AGE application, recorded the highest value.

3.8 Interaction between AGE and Varieties on Phytochemical Content, Leaf Chlorophyll and Proximate Composition in Tomato

Table 8a presents the interactions between AGE treatments and tomato varieties on phytochemical content. The results indicate that the Premium variety, with a two-time AGE application (F2), had the highest alkaloid content. Additionally, the Royal Bold variety showed increased flavonoid levels with the same treatment. There were no significant differences in saponin content across all varieties. Table 8b details the interactions between AGE treatments and varieties on leaf chlorophyll content. The Premium variety exhibited significantly higher chlorophyll levels when treated with AGE three times. Table 8c outlines the interactions between AGE and varieties on leaf proximate composition. For protein and fat content, the Akungba local variety showed the highest levels with a single foliar application, whereas the Sayo variety had the lowest protein and fat content with two AGE applications.

Table 5. Effect of the frequency of foliar spraying with aqueous garlic bulb extract (AGE) on the proximate composition of tomato

AGE frequency	Moisture	Ash	Protein	Crude fiber	Fat	CHO
O	66.65a	2.47a	9.26a	7.85b	1.05a	12.72c
F1	64.39bc	2.10b	7.28b	8.58b	0.87b	16.78ab
F2	63.64c	1.82c	6.87c	7.94b	0.85c	18.88a
F3	65.35ab	1.52d	6.09d	9.94a	0.80d	16.30b

Means followed by the same letters are not significantly different at 5% level of probability
Carbohydrate, (CHO). AGE was applied at weekly intervals including once (F1), twice (F2), and three times (F3). O, control treatment

Table 6a. Interaction between variety and foliar aqueous garlic extract (AGE) on tomato growth

Varieties	AGE frequencies	Plant height @transplant (cm)	Leaf area (cm^2)	Stem girth (cm)	No of green leaves	No of branches	Plant height@ 50% flowering (cm)	Leaf area (cm^2)	Stem girth (cm)	No of green leaves	No of branches	Number of senescence leaves	Plant height @fruiting (cm)	Leaf area (cm^2)	Stem girth (cm)	No of green leaves	No of branches	Number of senescence leaves
Sayo	O	68.67bc	29.09c	2.77b	79.00b	11.00bc	140.13ab	36.80c	3.40b	247.00b	20.00b	13.33cd	145.67a	63.41a	3.90b	223.33a	29.33b	19.00c
	F1	55.67c	34.62bc	2.80b	51.00bc	7.67d	127.07b	32.52c	3.50b	186.67c	13.67c	27.67b	136.13b	36.40bc	4.03ab	196.33ab	22.00b	29.67bc
	F2	37.67d	19.89d	2.10a	36.67c	6.67d	110.37b	27.62c	2.93c	145.00cd	12.67c	19.67c	118.10c	32.93bc	3.53b	158.33c	16.33c	17.67c
	F3	55.67c	32.34bc	2.50c	58.00bc	8.00c	117.20b	33.79a	3.13c	230.67bc	18.67bc	23.67b	124.33bc	35.81bc	3.63b	204.00a	22.67b	28.00bc
Premium	O	92.33a	43.87b	3.30ab	97.33b	13.33b	147.40ab	50.40ab	3.77ab	315.00b	35.00a	19.00b	155.27bc	53.06ab	4.40ab	283.33b	32.00ab	26.33bc
	F1	90.33ab	55.41ab	3.27ab	86.33b	12.67bc	166.83ab	51.24ab	3.73ab	370.00b	29.67ab	25.00b	176.53ab	40.15b	4.20ab	296.33b	34.67ab	34.33bc
	F2	80.33b	41.64b	3.00ab	83.67b	11.33bc	170.43a	61.71a	3.50b	322.67b	28.67ab	37.33ab	180.80a	48.10ab	3.90b	258.33b	33.67ab	50.00ab
	F3	84.67b	40.93b	2.77b	62.33b	10.33bc	154.13ab	40.15b	4.10ab	404.67ab	35.00a	42.00a	163.63ab	40.32b	4.27ab	272.33b	42.67a	58.00a
Royal bold	O	69.67bc	57.91a	3.23ab	141.00ab	11.33bc	93.87cd	48.81ab	4.90a	302.33ab	28.67ab	9.33d	104.43b	50.43ab	5.27a	283.00b	31.00ab	12.33c
	F1	63.33bc	41.35b	3.30ab	83.67b	8.33c	97.03c	39.75bc	4.10ab	248.67b	17.67bc	20.67b	105.07b	34.26bc	4.67ab	245.00b	22.67b	17.33c
	F2	63.00bc	45.49b	3.33a	76.33b	8.67c	117.17b	55.96ab	3.97ab	309.67ab	22.00ab	33.67ab	126.27ab	40.51b	4.30ab	272.67b	24.67b	30.00bc
	F3	70.00b	37.57bc	3.00ab	99.00b	9.00c	123.90b	37.03bc	3.90ab	418.33a	32.67ab	38.00ab	132.71b	33.95bc	4.27ab	359.33a	30.33ab	46.67b
Akungba local	O	74.00b	40.73b	2.87b	191.33a	21.00a	127.10b	37.81bc	3.27c	231.00b	21.00b	20.00b	135.10b	39.48bc	3.60b	224.33b	33.67ab	26.00bc
	F1	67.77bc	26.10c	2.90b	121.67ab	16.67ab	117.00b	25.93c	3.50ab	376.00ab	32.67ab	14.33cd	126.03b	26.08c	4.07ab	339.00ab	37.67ab	29.67bc
	F2	66.00bc	24.94c	2.77b	84.00b	14.67b	113.77b	28.42c	3.33c	392.33ab	30.00ab	24.33b	126.83b	29.97bc	3.80b	343.00ab	36.00ab	30.00b
	F3	70.67b	34.87bc	2.90b	179.33ab	15.00b	160.43ab	43.29bc	3.60ab	380.00ab	29.67ab	36.33ab	168.73ab	42.27ab	4.13ab	324.67ab	26.67b	50.67ab

Means followed by the same letters are not significantly different at 5% level of probability. AGE was applied at weekly intervals including once (F1), twice (F2) and thrice (F3). O, control treatment

Table 6b. Interaction between varieties and frequencies on tomato yield

Varieties	AGE frequencies	Number of fruits	Fruit weight Per plat (g)	Fruit size (m)
Sayo	O	1.33c	4.23d	71.90ab
	F1	1.00c	5.57d	67.72b
	F2	1.00c	4.53d	74.79ab
	F3	1.00c	3.70d	65.13b
Premium	O	4.00ab	136.87a	92.14a
	F1	1.33c	33.43bc	75.98ab
	F2	1.33c	79.97b	77.99ab
	F3	1.00c	15.47cd	69.53b
Royal bold	O	2.00b	65.90b	56.11b
	F1	1.33c	43.33bc	83.52ab
	F2	1.00c	21.10c	50.39b
	F3	1.33c	36.67bc	63.72b
Akungba local	O	9.00a	123.17ab	66.06b
	F1	1.67b	14.70d	47.72c
	F2	3.33b	29.37c	47.04c
	F3	4.67ab	24.33c	48.17bc

Means followed by the same letters are not significantly different at 5% level of probability

Table 7. Interaction between variety and the frequency of foliar spraying with aqueous garlic bulb extract (AGE) on the antioxidant enzyme of tomato

Varieties.	AGE	SOD	GSH	MDA
Sayo	O	64.71ab	30.32b	0.09d
	F1	59.91b	40.92ab	0.15d
	F2	65.15ab	45.80ab	0.42b
	F3	66.15ab	70.49a	0.5d
Premium	O	56.04b	23.12c	0.34c
	F1	57.49b	12.66d	0.71a
	F2	56.04b	16.75d	0.68ab
	F3	61.82a	20.31c	0.38b
Royal bold	O	58.35b	26.45c	0.56b
	F1	60.81ab	36.84c	0.54b
	F2	60.09ab	17.66d	0.23cd
	F3	62.40ab	8.03d	0.18d
Akungba local	O	59.80b	34.76b	0.24cd
	F1	60.09ab	8.87d	0.54b
	F2	56.77b	15.08cd	0.10d
	F3	58.50ab	40.25ab	0.31c

Means followed by the same letters are not significantly different at 5% level of probability

(Superoxide dismutase, SOD; malondialdehyde, MDA content and glutathione, GSH). AGE was applied at weekly intervals including, once (F1), twice (F2), and three times (F3). O, control treatment

Table 8a. Interaction between variety and the frequency of foliar spraying with aqueous garlic bulb extract (AGE) on phytochemicals enzyme of tomato.

Varieties	AGE	Alkaloid	Flavonoid	Saponin
Sayo	O	6.61ab	1.97b	216.64a
	F1	5.21c	1.39c	215.54a
	F2	5.61c	1.93b	217.56a
	F3	5.61c	2.08b	218.48a
Premium	O	6.81b	1.77b	216.28a
	F1	6.21b	1.79b	216.46a
	F2	7.61a	2.11ab	216.64a
	F3	5.21c	1.48c	217.19a
Royal bold	O	6.81b	2.52ab	219.94a
	F1	5.61c	1.60c	217.74a
	F2	6.01c	2.54a	220.49a
	F3	6.41b	1.23d	220.31a
Akungba local	O	6.61ab	1.82b	217.74a
	F1	5.21c	2.11ab	218.66a
	F2	6.61ab	2.08b	217.93a
	F3	6.81ab	1.71b	218.48a

Means followed by the same letters are not significantly different at 5% level of probability
AGE was applied at weekly intervals, including once (F1), twice (F2), and three times (F3). O, control treatment including once (F1), twice (F2) and thrice (F3). O, control treatment

Table 8b. Interaction effects between varieties and aqueous garlic extracts of tomato on leaf chlorophyll

Varieties	AGE frequency	Leaf chlorophyll
Sayo	O	3.12ab
	F1	3.25a
	F2	3.26a
	F3	3.01b
Premium	O	3.12ab
	F1	3.19ab
	F2	3.27ab
	F3	3.30a
Royal bold	O	2.56c
	F1	2.01d
	F2	3.06ab
	F3	2.86b
Akungba local	O	2.67b
	F1	2.16d
	F2	2.32c
	F3	3.07ab

Means in the Table followed by the same letter in the same column for each parameter are not significantly different from each other

Table 8c. Interaction between variety and aqueous garlic extract on of frequency of foliar spraying with aqueous garlic bulb extract (AGE) on proximate composition of tomato

Varieties	AGE	Moisture	Ash	Protein	Crude fiber	Fat	CHO
Sayo	O	70.48a	2.28c	8.45ab	5.41c	0.95b	12.43bc
	F1	60.79d	2.22c	3.34d	5.87c	0.63d	27.15a
	F2	64.03b	2.50b	5.48c	8.36b	0.76c	18.87b
	F3	68.41ab	0.736d	7.76b	5.33b	0.90b	16.85bc
Premium	O	62.98c	2.61b	9.51b	9.17b	1.01ab	14.73b
	F1	67.22b	0.91d	5.67b	11.16ab	0.78b	13.47b
	F2	61.12c	0.96d	5.54b	9.44b	0.77b	22.17ab
	F3	63.42c	2.73ab	4.70c	11.82a	0.72c	16.62b
Royal bold	O	69.76ab	1.48cd	9.30b	6.39b	1.12ab	11.94c
	F1	63.13c	2.57b	7.38b	9.17a	0.88b	16.87bc
	F2	67.96b	2.15b	6.92c	5.60b	0.85c	16.52bc
	F3	67.60ab	0.89d	7.25bc	10.60ab	0.87bc	12.80bc
Akungba local	O	63.38ab	3.52a	9.76b	10.45ab	1.12ab	11.77c
	F1	66.43ab	2.69b	12.73a	7.31bc	1.21a	9.64d
	F2	61.44c	1.68cd	9.53b	8.38bc	1.01c	17.95b
	F3	62.00c	1.75cd	4.63c	12.00a	0.71d	18.91a

Means followed by the same letters are not significantly different at 5% level of probability
(Carbohydrate, CHO). AGE was applied at weekly intervals, including once (F1), twice (F2), and three times (F3). O, control treatment

4. DISCUSSION

While the practice of foliar spraying with AGE has been established, the effects of its frequency and timing have not been systematically studied. This research investigates how different frequencies of AGE foliar application affect tomato growth and stress-related physiological

characteristics, such as antioxidant enzyme activities and MDA content.

Our findings indicate that applying AGE three times significantly enhanced tomato growth, including increased plant height, stem girth, number of branches, and both green and senescent leaves at flowering and fruiting stages. In contrast, applying AGE twice resulted in reduced plant height and yield. These results are consistent with those of Hanafy et al. (2012), who found that garlic extract applications improved plant growth in Schefflera arboricola. Similar studies by (Hayat et al., 2018) also reported garlic extract treatment increase plant growth in pepper plants. Foliar AGE applications stimulate plant growth by promoting the production of photosynthetic pigments and soluble sugars (Mohamed and Akladious, 2014). Garlic contains various beneficial compounds, including sulfur compounds, enzymes, vitamins, minerals, carbohydrates, saponins, alkaloids, flavonoids, and free sugars (Otunola *et al*. 2010; Bhandari *et al*. 2014; El-Hamied and El-Amary 2015), which contribute to its effectiveness as a balanced nutritional source for tomato plants. The improved efficacy of AGE with increased spraying frequency highlights its positive impact on tomato plant growth.

Our study also demonstrated significant variations in antioxidant enzyme activities and MDA content in tomato plants. AGE application enhanced antioxidant enzyme activities, with three applications (F3) boosting these activities and possibly reducing MDA content. Higher foliar spray rates led to increased superoxide dismutase (SOD) activity compared to the control. Regarding the effects of tomato variety, the Premium variety exhibited superior growth characteristics, including greater plant height, leaf area, number of green leaves, number of branches, and number of senescent leaves at both flowering and fruiting stages which could be as a result of the gene makeup. In terms of yield, significant differences were observed among tomato varieties. The Premium variety produced the highest fruit weight and fruit size, underscoring its superior yield potential.

5. CONCLUSION

This study demonstrates that AGE significantly influences antioxidant mechanisms, growth, and yield in tomato plants. Triple foliar applications of AGE effectively modulate antioxidant enzymes and phytochemical levels, leading to enhanced plant growth. The Premium variety notably outperformed others in biomass accumulation, indicating its potential for higher productivity and adaptability. Additionally, AGE preparation is simple, with minimal hazardous side effects, offering an eco-friendly and sustainable approach to horticultural production.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

COMPETING INTERESTS

Author has declared that they have no known competing financial interests or non-financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Peer-review history:
The peer review history for this paper can be accessed here:
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