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Original Research

Exogenous Guggul Gum Intervention Confers Resistance to Anthracnose Disease and Improves Postharvest Quality of Banana Fruit through Coordinated Regulation of Cell Wall–Degrading Enzymes and Redox Homeostasis

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Abstract

Banana is a tropical fruit with a limited shelf life, and it deteriorates quickly after harvesting. This study aimed to examine the impact of guggul gum coating at different concentrations of 5, 10, and 15% on anthracnose disease, physicochemical changes, and postharvest quality of banana fruit during storage at 25ºC for 28 days. The results revealed that banana fruit coated with 10% or 15% guggul gum substantially inhibited mycelial growth, spore germination, and disease incidence. Banana fruit coated with guggul gum exhibited weight loss, soluble solids concentration, ion leakage, polygalacturonase, pectin methylesterase, and cellulase enzyme activities. Guggul gum-coated banana fruit maintained a higher level of titratable acidity, firmness, phenolic content, ascorbic acid, and total antioxidant activity in comparison with uncoated banana fruit. These findings indicated that guggul gum might

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serve as an innovative approach for delaying anthracnose disease, physicochemical changes, and finally sustaining the postharvest quality of banana fruit during storage.

Keywords: guggul gum, banana fruit, texture, cell wall-degrading enzymes, antioxidant

Introduction

Banana (*Musa* sp.) fruit has a high nutritional value and a delicious taste, as well as antidiabetic, anticancer, antioxidant, and anti-inflammatory effects. However, banana is an extremely perishable fruit and has limited storability. Banana fruit is prone to many postharvest diseases, making it susceptible to rot. Anthracnose, for example, is a serious disease of tropical vegetables and fruits resulting from the fungus *Colletotrichum musae* [1]. Salicylic acid is a widespread plant phenol that causes a delay in fruit ripening when applied. Salicylic acid-treated samples had less softening, a lower peel ratio, reduced pulp softening, decreased sugar content, and a lower respiration rate than the control samples. Heat injury in bananas causes several physiological symptoms. These include peel blackening, peel browning, and increased moisture loss. Heat injury shortens the time required for the fruit to turn yellow. It also results in a soggy texture and the development of soft pulp. Damage to cell membranes delays the conversion of starch into sugars. This disruption leads to the formation of a glassy pulp. Edible coatings such as chitosan and Guggul gum (GG) are widely used. According to research, when chitosan is applied to the Cavendish banana, the result is delayed fruit ripening compared to an uncoated banana [2].

Guggul gum (GG), derived from *Commiphora wightii* (Bhandari) and also known as *Commiphora mukul*, commonly referred to as guggul, is a highly utilized medicinal plant. It encompasses a diverse array of bioactive constituents and represents a complex blend of multiple chemical groups, such as lignins, steroids, diterpenoids, and lipids. The traditional Ayurveda literature showed that GG is used for the treatment of rheumatoid stiffness, obesity, nervous diseases, haemorrhoids, urinary complaints, and skin diseases [3]. Guggul is an versatile medicinal compound, and due to its phenomenal properties, it is essential in the treatment of various disorders. Due to its wide range of uses, its pharmacological effects have been validated in traditional medicine for the treatment of many disorders. Bioactive elements found in it include lignans, tetrols, guggul, flavonoids, terpenoids, steroids, sugars, and amino acids. This plant still has untapped potential and increasing research interest. GG provides new potential for the discovery of novel bioactive components [4]. This study aimed to investigate the influence of GG on anthracnose disease, physicochemical properties, and cell wall-degrading enzymes of banana fruit during storage.

Materials and Methods

Fruit Materials

Banana fruit was collected at the hard green stage using the hand-picking method. After harvesting, all banana bunches were immediately transferred to the horticulture laboratory, Faculty of Agriculture, LUAWMS, where banana samples were uniformly selected with similar size and maturity and well-developed firmness.

Fungus Isolation

In this research, the isolation of *Colletotrichum musae* was carried out using small fragments of infected banana fruit, which were then subjected to surface sterilization. Surface sterilization was used to establish a contamination-free culture in which sodium hypochlorite (0.01%) was used for washing, and sterile paper was used for drying. Sodium hypochlorite is commonly found in household bleach solution. It is the most popular choice for surface sterilization because it is inexpensive and readily available. Isolates were cultured in Petri plates with potato dextrose agar (PDA) at 25ºC under aseptic conditions. On fresh potato dextrose agar (PDA) dishes, the colonies were subcultured to acquire a pure culture for the identification of the isolates. The pathogens were identified through microscopy using their morphological and cultural characteristics. The pure culture was maintained on PDA dishes at 4ºC for further studies.

Preparation of Dipping Solutions

In each trial, banana samples were immersed in GG solutions of varying concentrations. Solutions containing 5%, 10%, and 15% GG were formulated by dissolving 50, 100, and 150 g of gum, respectively, in 1000 mL of distilled water. The mixtures were maintained at 40ºC and subjected to constant stirring for 60 min utilizing a magnetic stirrer on a model MS-300HS hot plate. Later, coating solutions were plasticized with 1% glycerol, and the pH was regulated to 5.6 using 1 mol L^{-1} NaOH. For the experiment, the following treatments were used: distilled water (control), GG 5%, GG 10%, and GG 15%.

In vitro Antifungal Assay

In vitro culture was conducted in a sterile culture medium. The poison food method was employed in conjunction with PDA media to prevent *C. musae* radial mycelial development and spore germination. This technique was used to evaluate the impact of plants and their compounds on fungi using GG. A 5 mm diameter fungal disc was obtained from a 14-day-old pure culture of *C. musae* and was placed in the center of a Petri dish holding PDA supplemented with 5, 10, and 15% GG. Control plates consisted solely of PDA medium without GG supplementation. The Petri dishes were maintained at 25±2ºC for seven days, during which the radial mycelial growth was monitored daily until the control plates were entirely colonized. The growth of fungal colonies was used to measure treatment efficacy.

The cavity slide technique, which has a shallow depression, was used to hold objects and samples such as liquids and tissue cultures. An aliquot (40 µL) of 5, 10, and 15% GG was placed on the cavity slide using a pipette. Freshly prepared *C. musae* spore suspension (10^5 spores mL^{-1}), determined using a hemocytometer, was applied to the cavity slide, covered with a coverslip, and stored for 24 h at 25ºC in the dark. Purified water was supplied as a control in the cavity slides. Using a light microscope at a magnification of 40×, the spores were examined for continued germination. The percentage inhibition was determined by counting, in 12 duplicate plates, the number of germinated spores in 10 isolated areas of 100 spores each. The germ tube length exceeded that of the spore itself [5].

In vivo Evaluation

The fruits were assigned to various treatments by immersing them in the respective GG formulations. For the control group, only glycerol ($C_3H_8O_3$) was incorporated into distilled water, owing to its safe, non-toxic antimicrobial and antiviral effects. In every treatment, banana samples were immersed in the designated solutions for a minimum of 5 min, followed by air-drying for 1 h. The fruits were divided into 2 groups. In the first group, each fruit was wounded at the equatorial region using sterilized needles. Each wound site was inoculated with 20 µL of *C. musae* spore suspension (10^5 spores mL^{-1}) and allowed to dry at ambient temperature. The fungal spores were obtained by flooding the culture surface with sterile distilled water containing 0.05% (v/v) Tween-20. The resulting suspension was filtered through muslin cloth to eliminate mycelial fragments. For the second group, fruits were stored under identical conditions without inoculation to evaluate physicochemical parameters. The bananas were placed within plastic packaging (40×30×12 cm). The packaging was done to maintain relative humidity (RH) by covering all samples with polyethylene plastic films of 0.02 mm thickness. On the plastic films, five 7 mm diameter holes were punched to alter the internal atmosphere, and the fruits were stored at 20ºC for 28 days. Data for each treatment were collected from day 0 to day 28 at intervals of seven days.

Disease Incidence

Disease incidence was computed as the percentage of fruit surfaces showing disease symptoms. Banana anthracnose disease incidence data were expressed as the percentage of fruits indicating disease symptoms out of the total number of fruits in each treatment.

Weight Loss and Fruit Firmness

The measurement of banana weight loss was conducted using a digital balance (PB4001-S, Mettler Toledo, Switzerland). The samples were weighed by comparing the initial weight after GG application with the final weight recorded from day 0 to day 28 at 7-day intervals during storage at 20ºC. Fruit firmness was assessed using a digital fruit penetrometer (GY-4) with a probe diameter of 8 mm. The penetration depth was 10 mm inside the fruit. Readings were recorded on two opposite sides in the equatorial region of the fruit, and the results were expressed as force in Newtons (N).

Soluble Solids Concentration and Titratable Acidity

The concentration of soluble solids was measured using a hand refractometer (Alla 950,032B-ATC, France). The SSC was expressed as a percentage (°Brix). Titratable acidity was assessed by the titration of banana juice against a 0.1 M NaOH solution to pH 8.1. The acidity was expressed as a citric acid equivalent.

Ion Leakage

Ion leakage was assessed as outlined by [6] for the measurement of cell membrane permeability with slight modification. A cork with a diameter of 5 mm was used to bore four cylinders of banana fruit for each repetition. Two 4 mm thick slices were cut from each cylinder and rinsed with deionized water three times (2-3 min). Twelve pieces were placed in a glass vial holding 25 mL of deionized water and shaken for 30 min at 25ºC. A conductivity meter (BANTE, DDS 12DW, USA) was used to measure electrolyte leakage. The glass bottle was warmed in boiling water at 98ºC for 15 min. Once the sample was cooled, the conductivity was measured again. The results were expressed as a percentage.

Extraction for PME, PG, and Cellulase Enzymes

Two g of banana tissue were homogenized in 15 mL of 20 mM sodium phosphate buffer (pH 7.0) containing 0.05% Triton X-100, 20 mM EDTA, and 20 mM cysteine-HCl at 4ºC. The samples were subjected to centrifugation at 15,000×g for 30 min at 4ºC after homogenization. The enzyme tests were conducted using the extracted supernatant.

Assay of PG, PME, and Cellulase Enzymes

The approach outlined by [7] was employed to assess PG activity. The assay mixture was formulated, comprising 0.3 mL of 1% polygalacturonic acid, 0.2 mL of 200 mM sodium acetate buffer (pH 4.5), 0.1 mL of 200 mM NaCl, and 0.1 mL of enzyme extract. The mixture was incubated for one hour at 37ºC. Using 3,5-dinitrosalicylic acid reagent at 540 nm, the measurement of the released reducing groups was performed. Galacturonic acid served as the reference standard, and a single enzyme activity unit was defined as the quantity of enzyme needed to release 1 nmol of galacturonic acid per gram of original fresh tissue per minute. A mixture of 20 mL of 1% citrus pectin was combined with 5 mL of PME extract and titrated with 1 mmol L^{-1} NaOH to sustain a pH of 7.4 during incubation at 30ºC. The reaction was monitored over 30 min. A single enzymatic activity unit was defined as the consumption of 1 mmol of NaOH per gram of fresh weight (FW) of the original flesh per minute. The approach outlined by [7] was employed to evaluate the activity of the cellulase enzyme. The mixture for the reaction consisted of 0.2 mL of enzyme extract, 100 mM sodium acetate buffer (pH 5.0), and 0.5 mL of 1% carboxymethyl cellulose. The amount of liberated reducing groups was determined after the mixture had been incubated at 37ºC for 12 h. A single enzymatic activity unit was defined as the quantity of enzyme needed to produce 1 µmol of reducing groups per minute per gram of fresh weight (FW).

Ascorbic Acid and Total Phenolics

Ascorbic acid was analyzed using the 2,6-dichlorophenolindophenol dye method. A total of 40 mL of 3% metaphosphoric acid was mixed with a 10 g sample of banana fruit. A 5.0 mL sample was titrated against 2,6-dichlorophenolindophenol until a pink color formed, and the final reading was recorded as ascorbic acid. The outcomes were expressed as mg per 100 g fresh weight. The approach outlined by [6] was utilized to evaluate the total phenolic compounds.

Total Antioxidant Activity

The procedure was carried out using a 2,2-diphenyl-1-picrylhydrazyl (DPPH) solution. A 0.1 mM DPPH solution (3 mL) was combined with 10 µL of the sample extract [8]. The resulting mixture was stirred and incubated in the dark for half an hour. The decrease in absorbance at 517 nm was evaluated. The capability to scavenge the DPPH radical was determined using the following expression:

DPPH scavenging activity (%) = (control absorbance – sample absorbance) / control absorbance × 100.

Statistical Analysis

The experiment was conducted using four replications in a completely randomized design (CRD). Analysis of variance (ANOVA) was performed on the data using SAS software. Differences among means were assessed using the Least Significant Difference (LSD) test, with $P<0.05$.

Results and Discussion

Mycelium Growth

The application of GG treatments alone considerably inhibited mycelial growth (Fig. 1a)). The GG 10% and 15% significantly inhibited mycelial growth. Previously, GG coatings were noted for their gel-forming abilities, high stability, hydrophilicity, and nontoxicity, and they also reduced the mycelial growth and spore germination of *Colletotrichum coccodes* [6]. GG is particularly effective against bacteria, fungi, and viruses. Edible coatings are composed of a diverse mix of chemicals, making it difficult to pin down their antifungal mechanism of action [9]. The occurrence of bioactive substances that reduce *C. musae* mycelial growth and spore germination could clarify the fungistatic effects of the GG coating, as indicated by this research.

Spore Germination Inhibition

The maximum spore germination inhibition was noted in the 15% GG treatment, followed by 10% GG, while the lowest spore germination was noted in the control, followed by GG 5%. According to the results, the 15% GG extract inhibited spore germination among the treated fruits, as shown in Fig. 1b). Various edible coatings have demonstrated antifungal properties against a range of fungi [10].

Disease Incidence

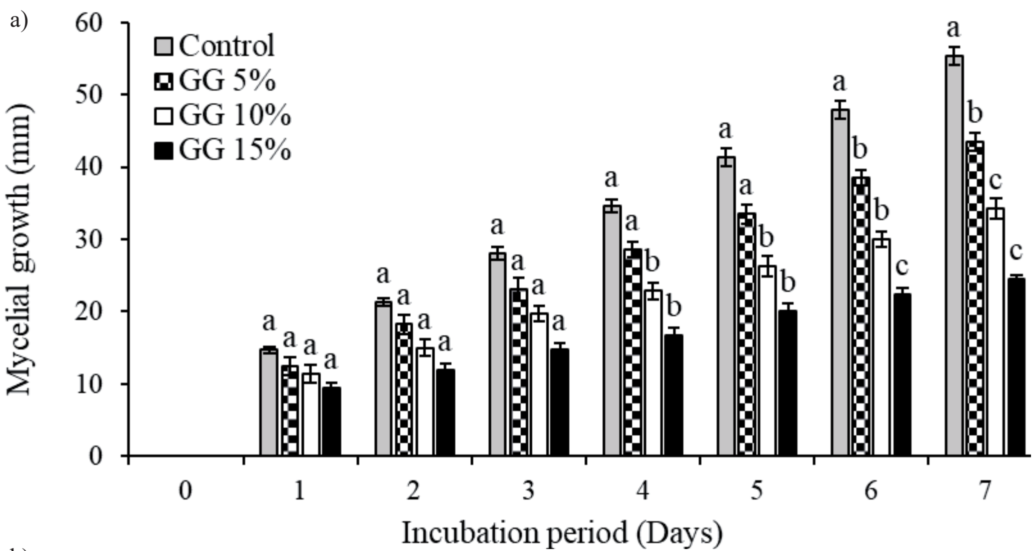
In this study, after 28 days of storage, the incidence of banana decay was observed, and with an extended storage period, a higher trend of postharvest loss was observed. The deterioration incidence in banana fruit treated with GG 5%, GG 10%, and GG 15% after storage was not statistically significant, but it was lower than that of the control. From the results, it can be concluded that the disease incidence in bananas treated with GG 15% was the lowest, indicating it was the best treatment (Fig. 2a)). The control samples had the highest disease percentage, followed by GG 5%, GG 10%, and GG 15%. It has been reported that edible coatings delay the ripening process and reduce disease incidence [11]. In the current study, the guggul gum coating formulation was used as a film on the surface of the banana, which acted as a barrier, and it might be effective in protecting banana fruit from other pathogen infections, thereby decreasing disease incidence during storage.

Weight Loss and Fruit Firmness

In this study, it was determined that moderate weight loss was observed throughout fruit storage. A comparison between the untreated (control) and GG 5%, GG 10%, and GG 15% treated bananas exhibited significantly higher weight loss in untreated bananas throughout storage at 25ºC for 28 days (Fig. 2b)). The decrease in weight loss was noted when banana fruits were coated with GG, which modified the atmosphere, restricted O_2 and CO_2 exchange, and reduced water loss [12]. In the present study, bananas were coated with GG 5%, GG 10%, and GG 15%, leading to a gradual reduction in weight loss throughout storage. The transpiration process is also a cause of weight loss in fruit and vegetables, as the variation in water vapor pressure between the surrounding atmosphere and the fruit tissue has an effect. In this study, the GG coating applied on the surface of the banana served as a barrier. Thus, reduced water transfer led to the protection of bananas from dehydration.

Fruit firmness in the control samples quickly decreased with an increasing period of storage. Bananas treated with GG 5%, GG 10%, and GG 15% preserved fruit firmness (Fig. 2c)). In contrast to the control samples that were not treated in the experiment, the firmness of the treated samples improved. It has been observed that edible coatings delay modification in fruit texture, which helps to decrease the ripening process in fresh products [13]. Another study found that combining gum Arabic and chitosan treatments significantly maintained avocado fruit firmness [14]. Banana fruit treated with GG 15%, GG 10%, and GG 5% had greater firmness

a)



b)

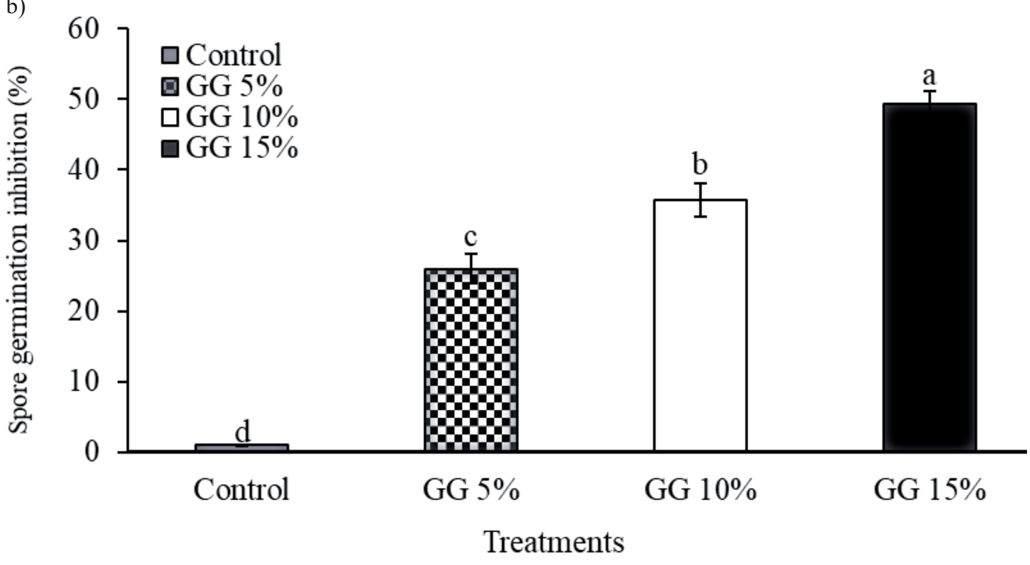


Fig. 1. Effect of guggul gum on a) the growth of *C. musae* for 7 days of incubation at 25ºC and b) spore germination inhibition of *C. musae* for 24 h. Vertical bars represent the standard error of the mean for 4 replicates. Means with different letters for each day and among treatments are significantly different at $P<0.05$.

than the control in this study. It can be concluded that this was due to the thick coating of GG on the fruit surface, which created a modified atmosphere, resulting in a reduction in textural loss of bananas. This may be due to changes in pectin substances and the activity of cell wall-degrading enzymes in bananas, as pectins in the plant, which are soluble fibers, can be degraded more slowly by applying a thick layer of GG.

Soluble Solids Concentration and Titratable Acidity

In the present study, an increasing tendency of SSC in banana fruits was found as the storage period was extended. From the results, SSC was highest in the control treatment, followed by GG 5%, GG 10%, and GG 15% treated fruits during 28 days of storage

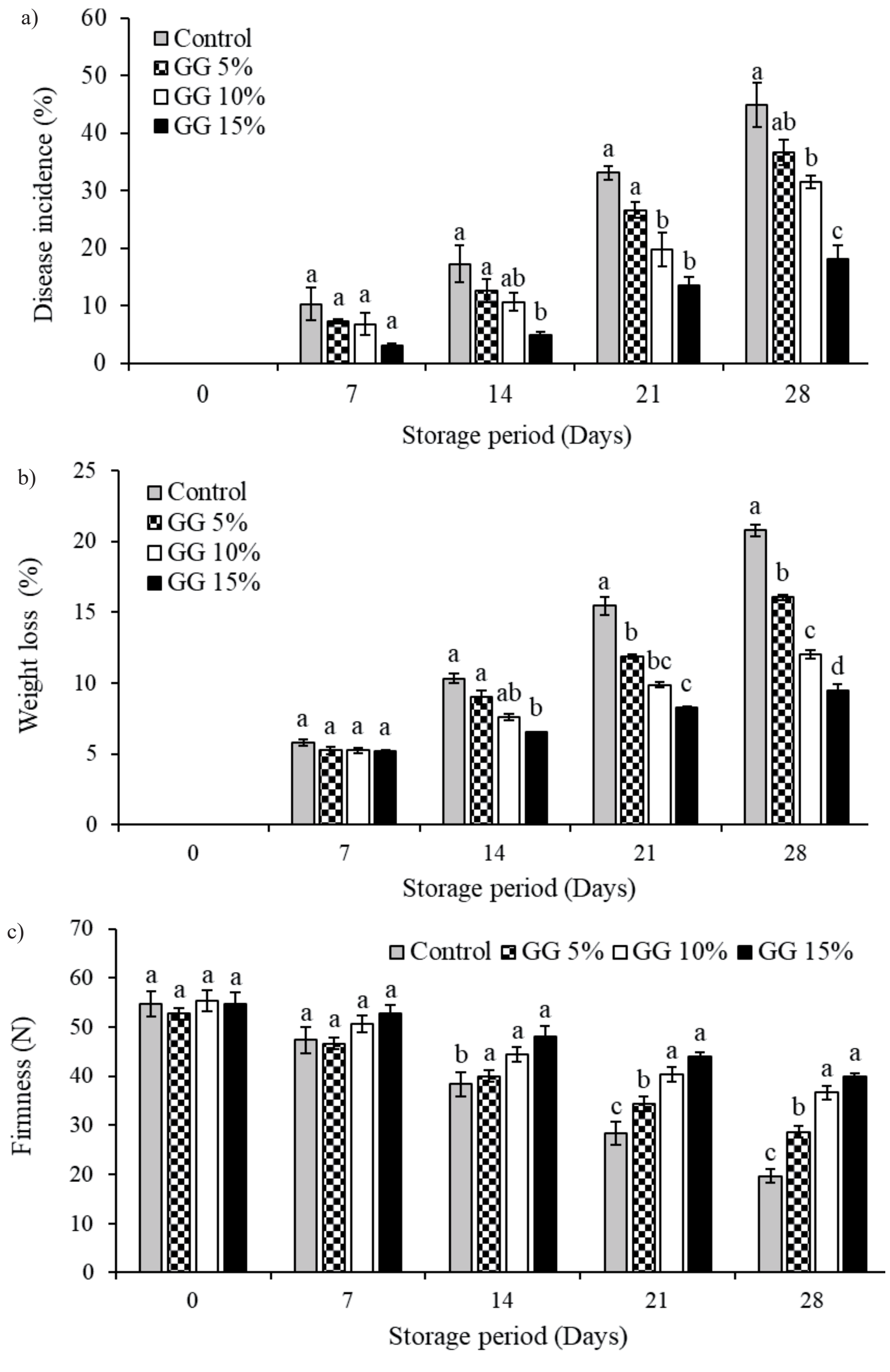


Fig. 2. a) Disease incidence, b) weight loss, and c) firmness of banana fruit treated with guggul gum during storage at 20ºC for 28 days. Vertical bars represent the standard error of the mean for 4 replicates. Means with different letters for each day are significantly different at $P<0.05$.

(Fig. 3a)). Banana fruit treated with GG 15% maintained the lowest SSC compared to the other treatments. According to previous reports, during the ripening process, complex carbohydrates begin breaking down into simple sugars, which tend to increase soluble solids concentration in fruits. Gum Arabic with chitosan as a natural preservative was used to delay modification in avocado fruit by obtaining a significant change in SSC [14]. The utilization of coatings improved the storage quality of banana fruits and safeguarded them against quick spoilage throughout storage.

The findings revealed a trend of reduction in TA with an increasing storage period. The greatest TA was noted in banana fruits treated with GG 15%. From the results, it can be concluded that bananas treated with GG 15% were highly successful in increasing shelf stability during storage in comparison to the other treatments (Fig. 3b)). TA plays a major role in reflecting compositional changes that occur in fruits for attaining longer storage life [15]. The gum Arabic coating maintained high titratable acidity [16]. El-Anany et al. [17] suggests that TA has a relationship with the fruit respiration rate, which may be due to changes occurring in predominant fruit organic acids like citric acid, tartaric acid, and malic acid. Thus, GG inhibited the breakdown of organic acids and prevented the decline in titratable acidity.

Ion Leakage

The maximum ion leakage was noted in the control, which was statistically different from all the treatments applied. However, the least ion leakage was noted in banana fruit treated with GG 15%, followed by GG 10%, and GG 5% (Fig. 3c)). The findings revealed that ion leakage elevated significantly with the increase in storage days. The compounds present in guggul gum may have significant potential for controlling ion exchange. These active compounds are believed to be engaged in the protection process of many plants against harmful fungal pathogens [6].

PG, PME, and Cellulase Enzyme Activities

PG activity increased over time, especially in uncoated fruit, but was significantly reduced in fruit coated with GG (Fig. 4a)). The greatest PG activity was noted in uncoated fruit, while the lowest was in fruit coated with 15% GG. Similarly, PME activity was elevated in all samples throughout storage, but was lower in fruit treated with GG, with the lowest activity observed in fruit coated with 15% GG, followed by GG 10%, and GG 5%, respectively, in relation to the control fruit (Fig. 4b)). Cellulase activity in both untreated and treated fruit showed a steady increase until day 21, followed by a decline on day 28 of storage (Fig. 4c)). Notably, banana fruit treated with GG 15% and GG 10% showed significantly lower cellulase activity compared to the control fruit, which had higher enzyme activity.

PG and PME enzymes play specific roles in breaking down pectin in fruit cell walls, with PME disrupting ester bonds and PG breaking glycosidic bonds. Previous studies have shown that these enzymes increase during ripening in tomato fruits [18]. Nevertheless, this research found that GG treatment of banana fruit diminished the activity of both PME and PG enzymes. This is consistent with previous findings in pear and Jamun, where edible coatings decreased pectolytic enzyme activity. The GG coating effectively inhibited PG and PME enzyme activity, thereby maintaining firmness in coated fruit, whereas early softening and senescence in control fruit were likely due to higher enzyme activity. Fruit softening is typically ascribed to the synergistic effect of cell wall-degrading enzymes like cellulase, pectic enzymes, and glycosidases. Cellulase breaks down polysaccharides like cellulose and xyloglucan, a key constituent of the cell wall structure [19].

Ascorbic Acid and Total Phenolic Contents

GG 15% reduced the loss of ascorbic acid in contrast to the control treatment after 28 days of storage. However, GG 5% and GG 10% also maintained ascorbic acid, which indicates effective fruit characteristics during long-term storage. Following 28 days of storage, the control treatment showed the greatest reduction in ascorbic acid levels (Fig. 5a)). Different previous studies have reported results similar to ours, where the level of ascorbic acid loss decreased by using gum Arabic on slices of ponkan fruit throughout storage [20]. Ascorbic acid is the dominant ROS detoxifying substance that can remove harmful compounds by decreasing hydrogen peroxide to water and scavenging superoxide anions and hydroxyl radicals [21]. As an antioxidant, ascorbic acid is essential for the human body, whether derived from natural sources or synthetically produced, as it aids in safeguarding cells from damage. Untreated fruits showed a greater decline in ascorbic acid, likely due to unrestricted oxygen exposure. Overall, the application of GG effectively preserved banana quality by maintaining higher ascorbic acid levels over the storage period relative to the control samples.

In this research, phenolic content moderately decreased during the storage period of both treated and untreated fruits. This decreasing tendency was more obvious in the control treatment. However, GG 10% and GG 15% treated fruits exhibited greater phenolic content compared to the control treatment (Fig. 5b)). From the findings, it can be concluded that treated banana fruits acquired a stronger protective mechanism, whereas the control fruits failed to achieve this level of protection. These findings correlate with previous studies where gum Arabic coating applied to persimmon fruits reduced the loss of phenolic content [22]. The use of gum Arabic coating on blueberries also reduced phenolic content and maintained fruit quality as well [23]. In terms of reduced phenolic content in fruits over time, phenolic content is related to fruit growth and ripening. Phenolic content increased with increased fruit growth rate, whereas it decreased with a rise in storage time. The phenolic content level of mango fruit reduced progressively as the storage duration increased [24]. There are two defence systems used by plants: enzymatic and non-enzymatic antioxidants. In the present study, the antioxidant activity of banana fruit seemed to be preserved by its phenolic content. Treatment with 15% GG preserved the phenolic compounds in the fruit and provided protection against quick deterioration. The elevated phenolic levels may have contributed to the reduction of oxidative damage in banana fruit.

Total Antioxidant Activity

The antioxidant activity of banana fruit coated with GG 15%, followed by GG 10%, showed a comparable trend to the control fruit during storage, with an initial

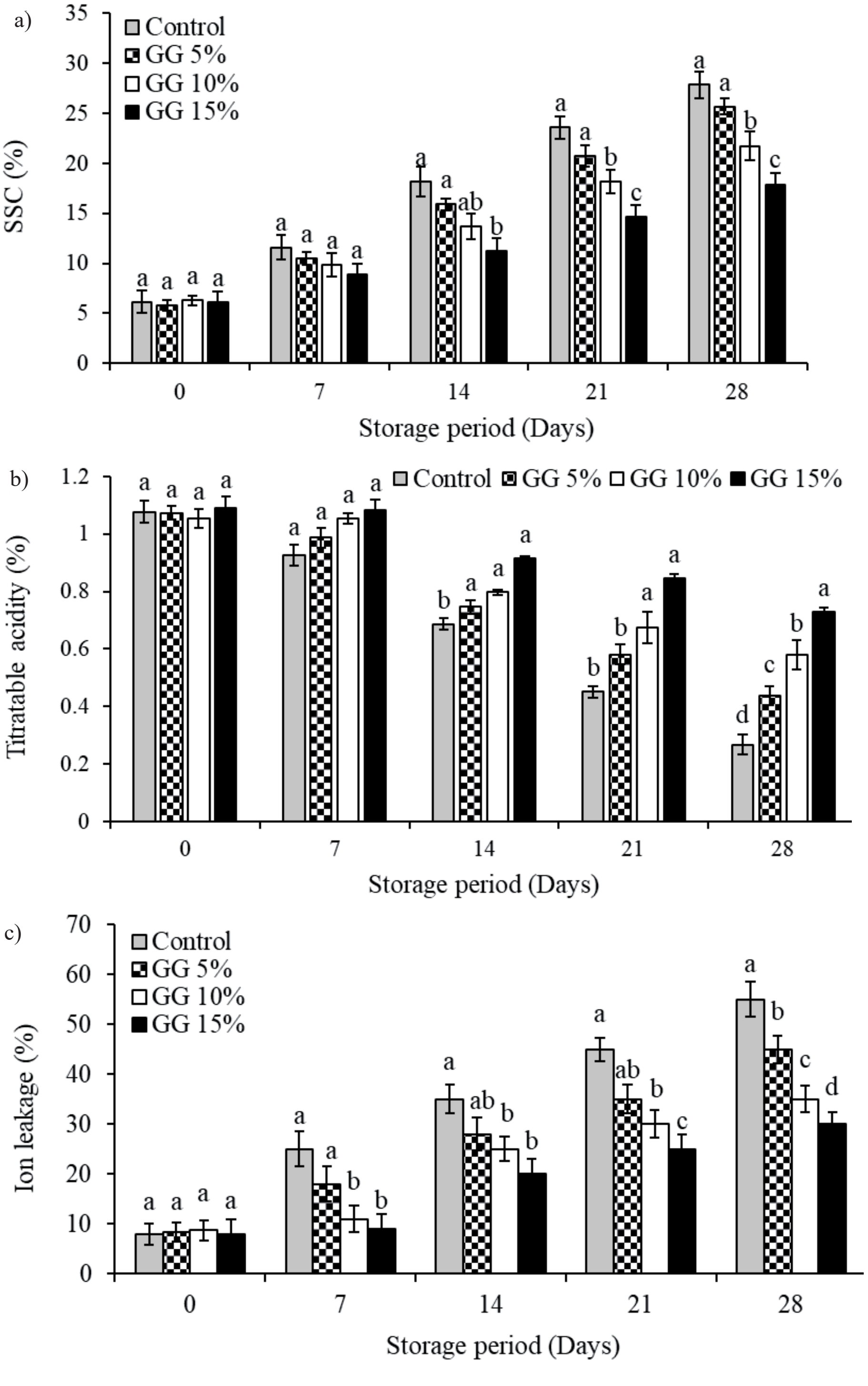


Fig. 3. a) SSC, b) titratable acidity, and c) ion leakage of banana fruit treated with guggul gum during storage at 20ºC for 28 days. Vertical bars represent the standard error of the mean for 4 replicates. Means with different letters for each day are significantly different at $P<0.05$.

rise lasting up to 21 days, followed by a steep decrease (Fig. 5c)). In contrast, banana fruit coated with GG 15% and GG 10% exhibited significantly higher antioxidant activity than the uncoated fruit at the end of storage, suggesting that these coatings effectively preserved the fruit's antioxidant properties. Our results are in agreement with [20], who found that ponkan fruits coated with Arabic gum maintained antioxidant activity compared to the uncoated fruits. The enhanced antioxidant activity in treated fruit might be ascribed to the presence of natural antioxidants, which donate hydrogen to neutralize free radicals [25, 26]. The high

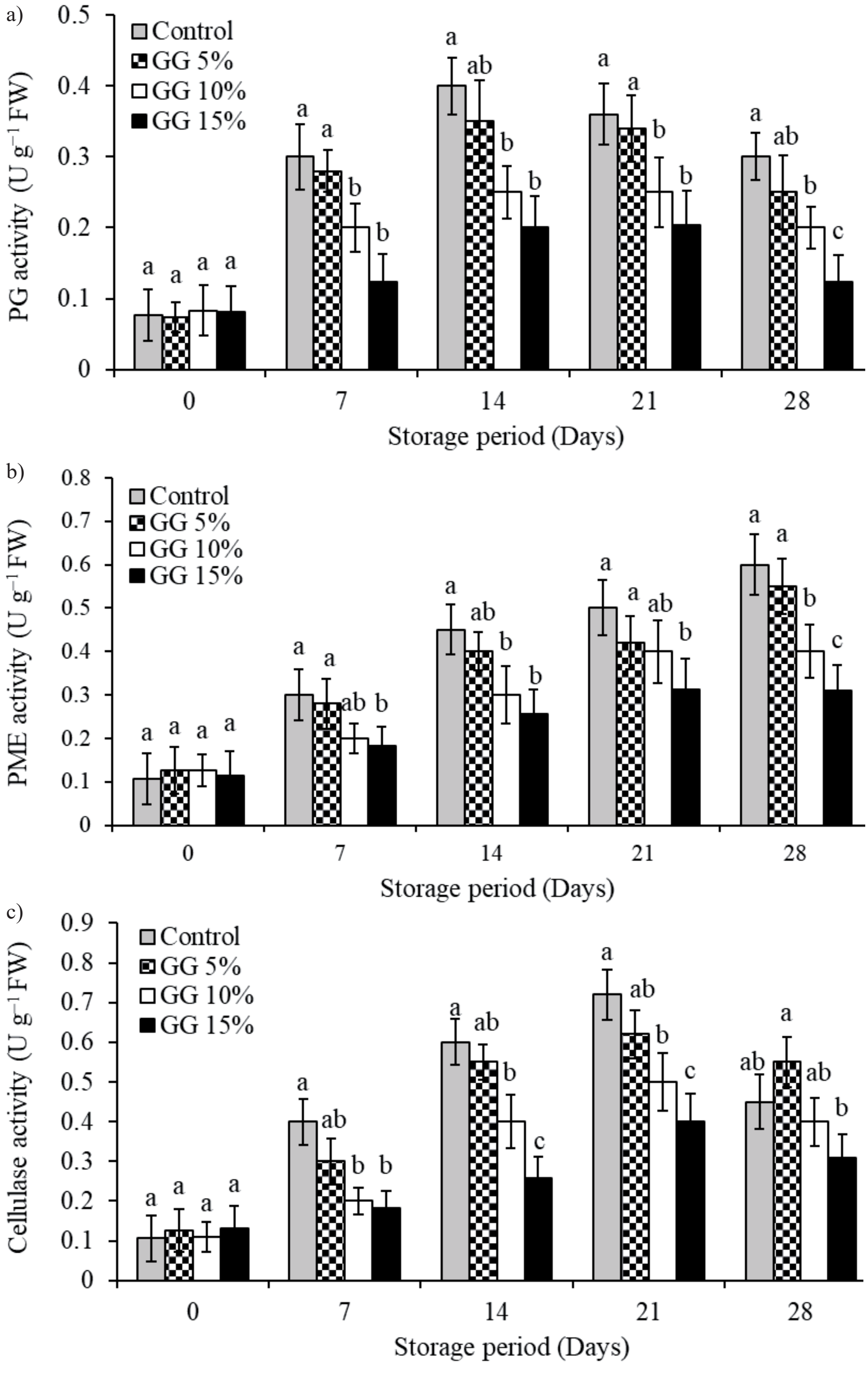


Fig. 4. a) PG, b) PME, and c) cellulase enzyme activities of banana fruit treated with guggul gum during storage at 20°C for 28 days. Vertical bars represent the standard error of the mean for 4 replicates. Means with different letters for each day are significantly different at *P*<0.05.

antioxidant capacity in fruit is largely due to the overall phenolic content [27, 28]. The rise in antioxidant activity observed in banana fruit could be due to the existence of bioactive substances like phenols, flavonoids, and vitamins. The GG treatment likely enhanced the DPPH radical scavenging activity, leading to higher antioxidant capacity in treated fruit compared to the control fruit. This increased retention of antioxidant capacity may be ascribed to the elevated levels of phenolic compounds and ascorbic acid in treated banana fruit.

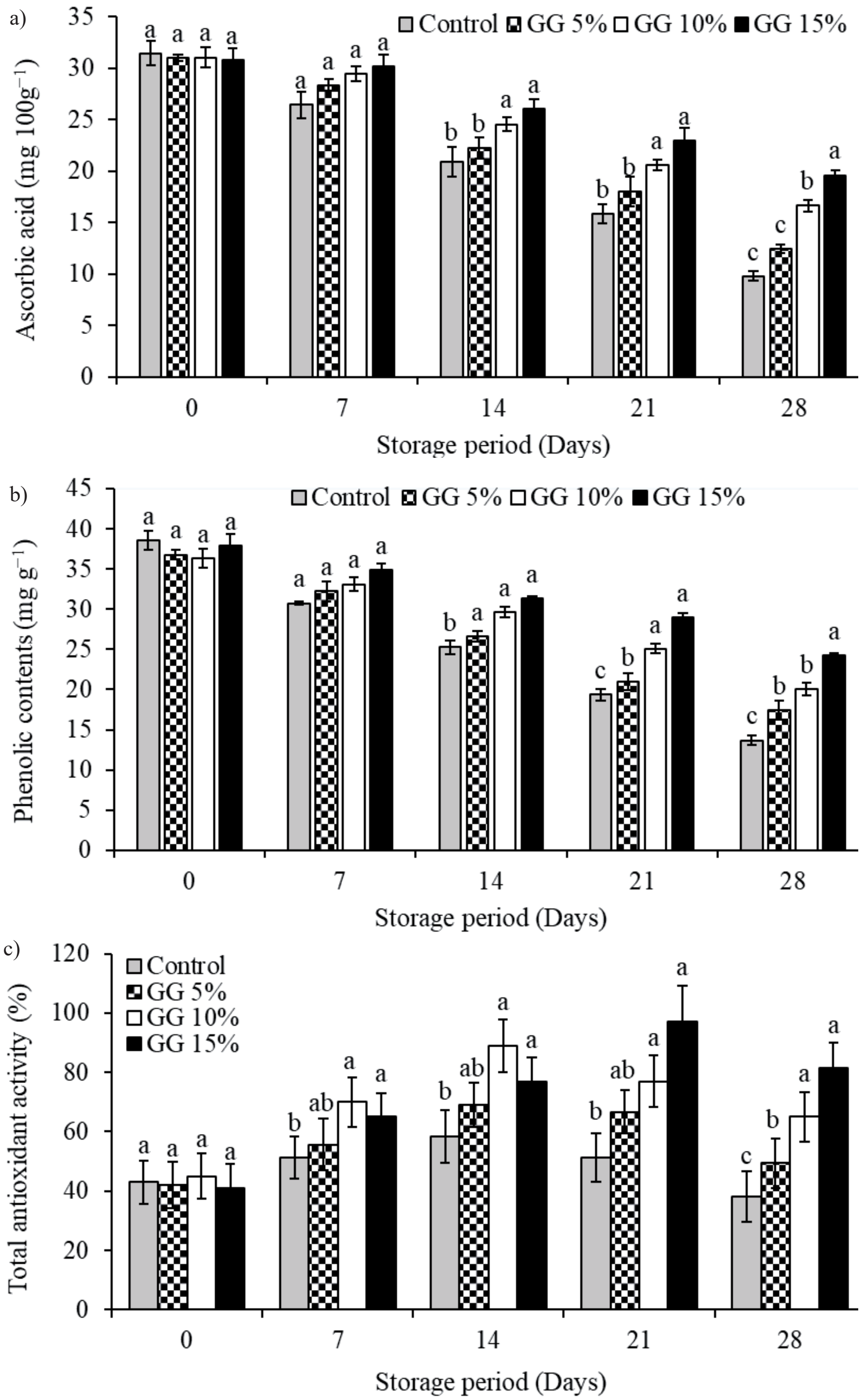


Fig. 5. a) Ascorbic acid, b) phenolic contents, and c) total antioxidant activity of banana fruit treated with guggul gum during storage at 20ºC for 28 days. Vertical bars represent the standard error of the mean for 4 replicates. Means with different letters for each day are significantly different at *P*<0.05.

Conclusions

This study shows that edible coatings like GG serve a crucial function in boosting defense responses and resisting fungal pathogens. Banana fruit treated with GG enhanced its resistance to anthracnose disease, maintained quality, and prolonged shelf life by diminishing physicochemical alterations and cell wall-degrading enzyme activities. Additionally, GG preserved ascorbic acid, phenolic content, and total antioxidant capability. Therefore, using GG as a postharvest treatment may be a novel approach to controlling fungal infections and improving the total quality of banana fruit.

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Conflict of Interest

The authors declare no conflict of interest.

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