Biological and Environmental Sciences Journal for the Tropics
Volume 21, Number 3, December 2024. Pp 117 - 129
https://dx.doi.org/10.4314/bestj.v21i3.11

Research article

Effect of gibberellic acid (GA_3) and polyethylene film linings on the physicochemical properties and shelf- life of banana (Cavendish) stored under cold and ambient conditions

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Submission: 10/07/2024
Accepted: 24/12/2024

Abstract
Fresh bananas have a short shelf-life owing to rough handling, unprotected storage conditions and poor packaging methods leading to postproduction losses of 30-40 %. The study was to determine the effect of different concentrations of GA_3 and polyethylene film linings on the physicochemical properties and shelf life of Cavendish banana stored under different temperatures. Dwarf Cavendish was obtained from a private farm orchard at Ninting, Ashanti Mampong. Three months old matured green banana (starting from flowering) were dipped in 150, 250 and 350 ppm of GA_3 for 2 minutes and control (0 ppm) were immersed in distilled water the same way. A 4 x 4 x 2 factorial was employed, arranged in a completely randomized design. Data were collected at ripening stages as contained in banana ripening chart except fruit weight that was recorded daily. Weight loss, firmness, TSS, TTA and pH were defined at different ripening stages throughout the storage period. The study revealed significant difference in weight loss (30 %) at 350 ppm in perforated low density lining under cold storage as best results. It also showed firmness of 4.57 kg cm^{-2} at 350 ppm and 4.53 kg cm^{-2} in perforated film lining, significantly different from the rest. TSS showed best results of 8.51 % at 350 ppm and 8.55 % in cold storage while TTA reduced to 1.31 % at 350 ppm which also revealed significant difference. Similarly, pulp pH dropped to 5.30 % at 0 ppm whereas shelf life was 13.75 % at 350 ppm, 11.06 % in perforated film lining and 14.13 % translating to 21 days being the best results under cold storage condition. Therefore, postharvest application of gibberellic acid at a concentration of 350 ppm and the use of perforated low density polyethylene lining in cold storage was an efficient method and can be employed by farmers and traders to reduce losses, maintain quality attributes of banana and prolong shelf life.

Keywords; Banana, storage, gibberellic acid, and shelf-life.

Introduction

Fresh produce especially fruits and vegetables are considered an important part of our daily diet because they are a major source of vitamins, minerals, organic acids, dietary fibres and also antioxidants (Bano et al., 2023). The banana, originally domesticated in Southeast Asia, has become one of the most widely cultivated staple crops globally, ranking as the fourth most important food crop after rice, wheat, and maize. It serves as a significant source of energy for consumers worldwide due to its high carbohydrate content and versatile applications in food processing (IISD, 2020; Britannica, 2024).

In Ghana, particularly in the Ashanti Region, bananas are cultivated alongside other tropical fruits, contributing significantly to the local agricultural economy. Ghana is a major supplier of tropical fruits to international markets, with the United Kingdom alone importing over 2,000 tons of Ghanaian fruits annually (FAO, 2023; IISD, 2020).

Bananas are also a key ingredient in a variety of processed foods and are valued for their energy density. To maintain freshness, bananas are typically harvested at high moisture levels, a crucial factor for both local consumption and export markets (Britannica, 2024).

Banana remains one of Ghana's significant agricultural exports, second only to pineapple in terms of foreign exchange earnings. Recent data from the Ghana Export Promotion Authority (GEPA) and the Food and Agriculture Organization (FAO) indicate that Ghana has seen a steady increase in its banana exports to international markets, particularly to Europe (Ayambila, et al., 2023). The banana fruit is also produced locally by many smallholder farmers in the Kwahu area in the Eastern Region and the Ashanti Akim and Mampong areas in the Ashanti Region for the local markets in Kumasi, Accra and Tema.

Food guide indicated that, a good meal should consider at least 2 - 4 servings of fruit daily (Springmann et al., 2020). The intake of horticultural produce is on the increase with a lot of consumer awareness about the health benefits of fresh and processed horticultural crops. Fruits and vegetables are extremely delicate foods and good handling after harvest is required to prevent them from going bad and to retain freshness and quality (Josh *et al.*, 2013)

Postharvest loss of fresh produce is a major challenge in the postharvest sector resulting in short shelf life under tropical climate less than 7 days (Akpabio *et al*. (2012). Fresh bananas have a short shelf-life owing to rough handling, unprotected storage conditions and poor packaging methods leading to postproduction losses of 30-40 % which contributes hugely to food insecurity, hunger, malnutrition and poverty (Josh *et al.,* 2013).

Despite the fact that Ghana is experiencing huge losses in the post-harvest chain of banana produce, less attention or no emphasis is given to postharvest management of perishables such as banana. The research aimed to determine the effect of different concentrations of GA_3 and polyethylene film linings on the physicochemical properties and shelf life of Cavendish banana variety stored under ambient and cold environments

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Materials and Methods

Study area

Cavendish banana bunches were obtained from a private farmer's orchard fields at Ninting, Ashanti Mampong, a banana farming community and a suburb of Kumasi. The three months old fruits (starting from flowering) were harvested at optimum stage of maturity and bunch gently cut off from the stems to ensure that the fruits were not damaged. They were transported immediately after harvesting to the experimental site at Kwame Nkrumah University of Science and Technology.

Experimental Design

The experiment was laid out in a 4 x 4 x 2 factorial arrangement in a Completely Randomised Design (CRD) with three replicates and was carried out at the laboratory of Horticulture Department, Faculty of Agriculture, Kwame Nkrumah University of Science and Technology.

Preparation and treatment of sample materials

Sample preparation

Banana were harvested when the fruits of the first hand on the bunch indicated signs of ripening or yellowing and the fingers changed to circular in shape but those that showed sign of yellowing were not used in the experiment. Harvesting was carried out early and manually in the morning between the hours of 6:00-7:00 am with great care to avoid mechanical damaged. Harvested banana were de-handed and arranged in a paper box lined with a soft material to provide cushioning and transported to the laboratory by a vehicle.

Transportation was done in the early hours of the morning to reduce heat damage. Individual fingers were separated and similar size rounded fruits were selected. Fruits were selected as samples with no serious defects such as cuts, bruises, deep wounds or insect damage. The samples were then graded by size and colour, and fruits with defects were discarded. The unblemished uniform fruits were cleaned using a wet soft material in order to clean them of dirt/soil particles on the fruits.

Treatment of samples

0.15 g, 0.25 g, and 0.35 g, each of powdered GA_3 was dissolved in three drops of ethanol using dropper pipette before adding clean tap water to prepare the solution in plastic buckets. Each was added to 1000 ml, 1500 ml, 2500 ml and 3500 ml of water respectively and stirred to ensure that it was thoroughly mixed as recommended by AOAC (2005).

The different concentrations of GA_3 solution (0 ppm, 150 ppm, 250 ppm, and 350 ppm) were applied to the individual fingers of banana as T_o, T1, T2 and T3 respectively by dipping a whole fruit for 2 minutes and then air-drying. The control (T_o-0 ppm) was dipped in distilled water and air dried. In each variety GA_3 treated fruits were put into four packaging methods; perforated low density polyethylene film lining, non-perforated low density polyethylene film lining and vacuum polyethylene bag and also left in the open as control as (PERF, UNP, CAC and NP) respectively and stored under cold and ambient storage conditions in three replications and monitored.

Parameters

Colour

Green banana fruits were considered fully ripened when their peel colour completely changed from green to yellow colour. Peel colour of banana fruit was determined using a banana colour chart and was observed daily. Changes in colour of peel and pulp were also determined and recorded during the storage period. Seven stages of colour changes were characterized in banana colour chart; green, green-trace of yellow, green, green - trace of yellow, more green than yellow, more yellow than green, green tip, all yellow and yellow-flecked with brown colour.

Weight loss

The initial weights of the banana fingers were also taken using a digital balance. The physiological loss in weight (PLW) was measured as the loss of weight in grams in relation to initial weight and expressed as percentage. During storage, the fruits were weighed every day and their weight recorded. The difference between initial and final weight was considered as total weight loss (%) during the storage interval. Both temperature and relative humidity of the both storage environments (cold and ambient environments) were also recorded throughout the period with a portable data logger model EL-USB 110674 manufactured in the USA.

Firmness

A mechanical property such as firmness of the whole fruit was determined using a hand held penetrometer (model 65104, China) and values were expressed in kg cm^{-2}. The samples were placed on a lateral surface of a fixed table and the puncture test was carried out by puncturing the fruit at the middle, stem end and the end of the fruit and the readings recorded. Firmness values were measured as the maximum force required causing tissue failure, assessing the penetrometric hardness of the entire fruit.

Total soluble solids (TSS)

The total soluble solids (TSS) were determined using a Refractometer (model HI 96801, China). The fruit was peeled and sliced into an electric blender, the resultant pulp was weighed and.distilled water was added to top up to 100 g before it was blended. Distilled water was used to clean the Refractrometer before standardising to zero. Three drops of the sample pulp juices was dropped on a table top Refractrometer and the readings recorded three times, and then mean values calculated. The process was repeated three times.

Titratable acidity (TTA) and pH

Assessment of pH and titratable acidity (TTA) of banana was used mainly to estimate consumption quality and hidden qualities. They are considered as indicators of fruit maturity or ripeness. The pH values from the filtrate of the pulp samples were determined using a pH metre model A131509092 USA at a temperature of 25°C. The process was repeated three times. Total titratable acidity of the filtrate from the fruit samples was determined by titrating the sample with sodium hydroxide to the phenolphthalein according to (Hailu, *et al*, (2012).

Shelf life

The shelf life of the banana fruits was calculated by counting the days required for them to attain the last stage of ripening, but up to the stage when they still remained acceptable for marketing. The fruit shelf life was determined at the completely yellow ripened stage using banana colour chart as a guide. Changing of the peel colour to yellow is an indication of banana ripening. In the colour chart, it is represented by stage 6 (all yellow) however; stage seven marked the end of the shelf life of the banana fruits.

Statistical Analysis

All data were collected according to the ripening stages of banana for the determination of physical and chemical qualities of the fruits except fruit weight, temperature and relative humidity that were recorded on daily basis.

Data on the chemical properties as well as firmness of banana were taken from sample banana fruits meant for destructive analysis during the storage period. The experiment was arranged on a completely randomized design and data were analysed using analysis of variances (ANOVA) at P=0.01 with the aid of Statistics software and mean separated using Tukey's Honest Significant Difference (HSD).

Results

Weight loss

Banana packaged in vacuum bags lost the most weight (Figure 1). Similarly, bananas that were subjected to cold storage retained significantly weight while banana in ambient condition lost more weight. There were significant differences (p = 0.01) among the various packaging methods for fruit weight as banana in perforated low density polyethylene lining retained more weight. There were also significant differences (p = 0.01) in weight loss as well as GA_3 x packaging x storage interaction (Table 1).

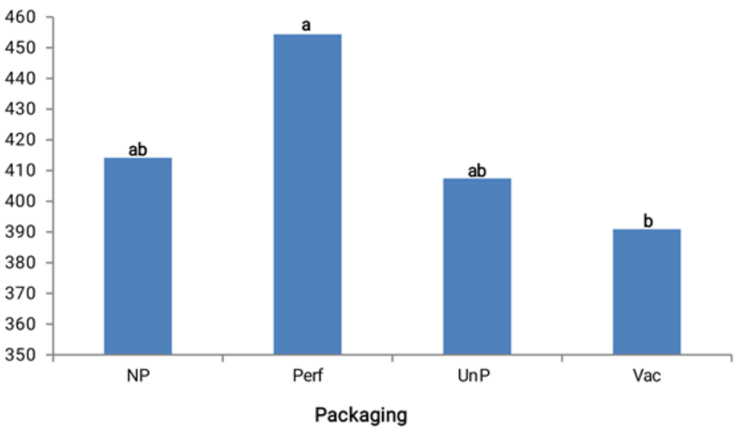

Figure 1: Effect of packaging on the weight loss of banana
NP = No pack; Perf = Perforated film lining; Unp = Unperforated; Vac = Vacuum

Table 1: Effect of GA_3 and packaging on the weight loss of Cavendish banana stored under different environments (%).

Pre -treatment		Storage	Condition	
GA_3	Package	Cold	Ambient	Mean
0 ppm	No package	334.67bc	417.45ab	
	Perforated	425.86ab	418.33ab	
	Unperforated	473.81ab	417.71ab	
	Vacuum	381.66bc	417.37ab	20.99bc
150 ppm	No package	449.39ab	425.66ab	
	Perforated	419.59ab	408.72ab	
	Unperforated	456.46ab	423.06ab	
	Vacuum	399.01ab	411.22ab	18.95ab
250 ppm	No package	453.69ab	364.13abc	
	Perforated	450.01ab	351.79bc	
	Unperforated	365.54bc	368.75bc	
	Vacuum	372.07bc	346.33bc	15.99ab
350 ppm	No package	392.41bc	422.23ab	
	Perforated	574.66a	414.79ab	
	Unperforated	424.27ab	415.09ab	
	Vacuum	406.07ab	393.59bc	7.89a
Mean		5.79a	20.74b	
CV		27.99		

HSD 1% GA_3 = 73.07; Packaging = 73.07; Storage = 42.59; GA_3x Packaging x Storage = 273.82
HSD = Honest significant difference, ppm = part per million; CV = Co-efficient of variation;
Means with different letters within a column are significantly different at 1 % using HSD.

Fruit firmness

There were significant differences among the various packaging methods for firmness of banana fruits (Figure 2). Fruit firmness varied from 3.98 kg cm^{-2} to 4.34 kg cm^{-2}. There were also significant differences in firmness among

GA_3 treated banana fruit firmness. Banana fruit firmness varied from 4.01kg cm^{-2} to 4.57 kg cm^{-2}. In the same way, banana stored in cold condition were significantly firmer than banana stored in ambient environment. There were no significant differences for GA_3 x packaging x storage interaction for firmness of banana fruits (Table 2).

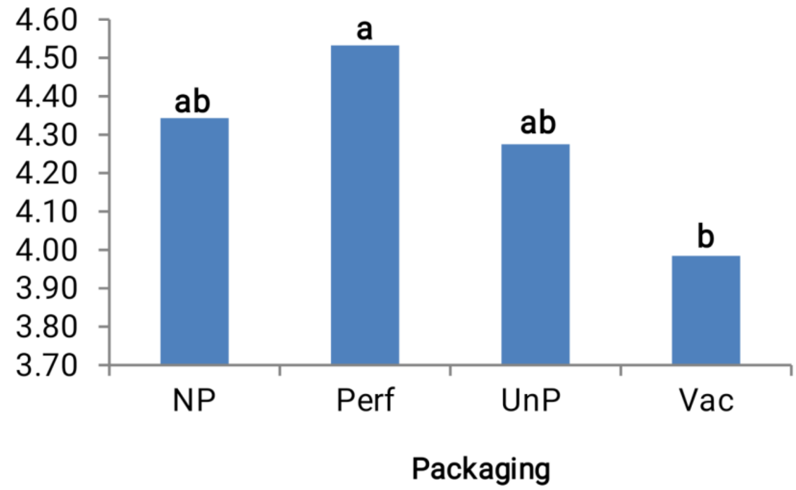

Figure 2: Effect of packaging on the firmness of banana
NP = No pack; Perf = Perforated film lining; Unp = Unperforated; Vac = Vacuum

Table 2: Effect of GA_3 and packaging on the firmness of Cavendish banana stored under different environments (kg cm^{-2}).

Pre-treatment		Storage Condition		
GA_3	Package	Cold	Ambient	Mean
0 ppm	No Pack	4.24a	4.23a	
	Perforated	4.96a	4.42a	
	Unperforated	4.03a	4.79a	
	Vacuum	4.43a	4.00a	4.01b
150 ppm	No Pack	4.37a	4.46a	
	Perforated	4.26a	4.52a	
	Unperforated	4.95a	4.63a	
	Vacuum	4.02a	4.25a	4.12ab
250 ppm	No Pack	4.73a	4.36a	
	Perforated	3.96a	3.93a	
	Unperforated	4.22a	4.06a	
	Vacuum	3.91a	3.79a	4.43ab
350 ppm	No Pack	3.93a	4.43a	
	Perforated	5.52a	4.10a	
	Unperforated	4.06a	4.07a	
	Vacuum	3.72a	3.76a	4.57a
Mean		4.53a	3.24b	
CV		9.06		

HSD 1% GA_3 = 0.46; Packaging = 0.46; Storage = 0.26; GA_3 x Packaging x Storage = 1.85
HSD = Honest significant difference, ppm = part per million; CV = Co-efficient of variation
Means with different letters within a column are significantly different at 1 % using HSD.

TSS of banana
There were no significant differences among the various packaging methods for TSS of banana fruits (Figure 3). Banana fruit TSS ranged from There were also significant differences between storage conditions with cold storage performing better. Cold storage had a higher TSS level (8.55 %), significantly greater than ambient storage 7.90 % to 8.60 %. There were significant differences among treatments for banana TSS as high concentration of GA_3 application revealed high TSS (8.51 %). condition. However, there were no significant differences for GA_3 x packaging x storage interaction for TSS of banana fruits.

Pre -treatment		Storage	Condition	
GA_3	Package	Cold	Ambient	Mean
0 ppm	No package	334.67bc	417.45ab	
	Perforated	425.86ab	418.33ab	
	Unperforated	473.81ab	417.71ab	
	Vacuum	381.66bc	417.37ab	20.99bc
150 ppm	No package	449.39ab	425.66ab	
	Perforated	419.59ab	408.72ab	
	Unperforated	456.46ab	423.06ab	
	Vacuum	399.01ab	411.22ab	18.95ab
250 ppm	No package	453.69ab	364.13abc	
	Perforated	450.01ab	351.79bc	
	Unperforated	365.54bc	368.75bc	
	Vacuum	372.07bc	346.33bc	15.99ab
350 ppm	No package	392.41bc	422.23ab	
	Perforated	574.66a	414.79ab	
	Unperforated	424.27ab	415.09ab	
	Vacuum	406.07ab	393.59bc	7.89a
Mean		5.79a	20.74b	
CV		27.99		

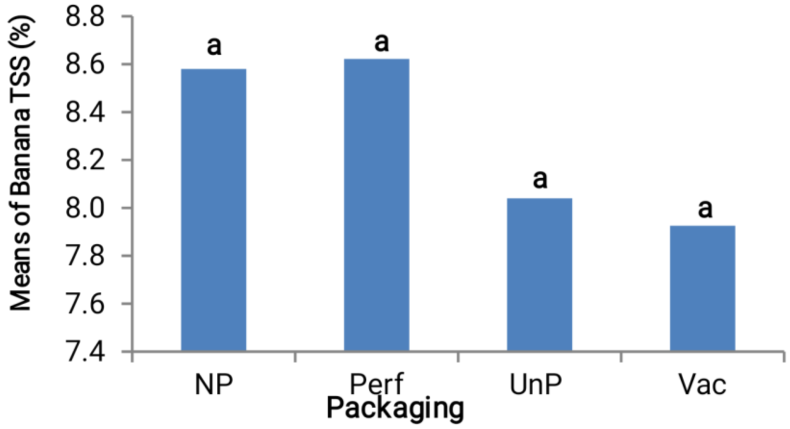

Figure 3: Effect of packaging on the TSS of banana

NP- No pack; Perf- Perforated film lining; Unp- Unperforated; Vac = Vacuum

Table 3: Effect of GA_3 and packaging on the TSS of Cavendish banana stored under different environments (%).

Pre-treatment		Storage	Condition	
GA_3	Package	Cold	Ambient	Mean
0 ppm	No Pack	9.16a	8.79a	
	Perforated	7.80a	7.89a	
	Unperforated	8.53a	8.48a	
	Vacuum	7.94a	7.55a	8.27abc
150 ppm	No Pack	8.57a	8.29a	
	Perforated	8.75a	8.29a	
	Unperforated	9.70a	8.85a	
	Vacuum	9.09a	8.35a	8.73ab
250 ppm	No Pack	9.21a	8.75a	
	Perforated	8.13a	7.44a	
	Unperforated	8.67a	8.00a	
	Vacuum	7.83a	7.18a	8.15ab
350 ppm	No Pack	8.26a	7.59a	
	Perforated	8.26a	7.80a	
	Unperforated	8.64a	8.12a	
	Vacuum	8.24a	7.23a	8.51a
Mean		8.55a	8.04b	
CV		8.19		

HSD 1% GA_3 = 0.81; Packaging = 0.81; Storage = 0.46; GA_3 x Packaging x Storage = 3.24
HSD = Honest significant difference, ppm = part per million; CV = Co-efficient of variation.
Means with same letters within a column are not significantly different at 1 % using HSD.

TTA of banana

There were no significant differences among the various packaging methods for TTA of banana fruits (Figure 4). Banana fruit TTA ranged from 1.25 % to 1.30 %. There were significant differences among treatments for banana TTA with 150 ppm and 350 ppm (1.32 %) and (1.31 %) respectively. However, there were no significant differences between storage conditions.

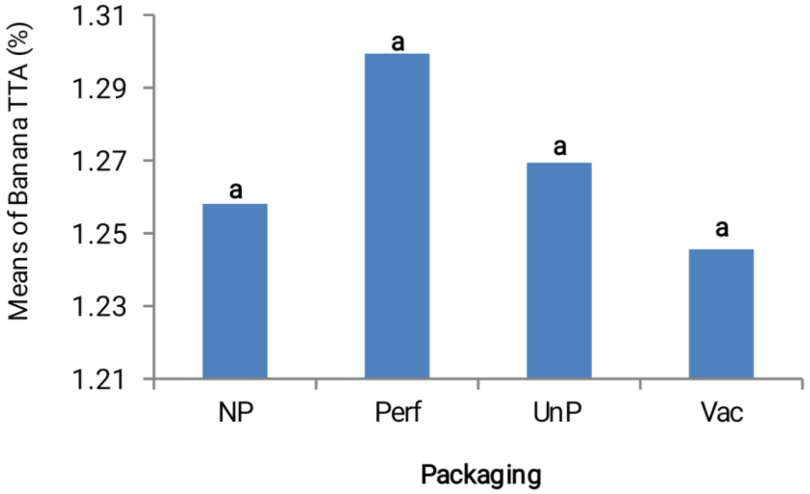

Figure 4: Effect of packaging on the TTA of banana

NP = No pack; Perf = Perforated film lining; Unp = Unperforated; Vac = Vacuum

Table 4: Effect of GA_3 and packaging on the TTA of Cavendish banana stored under different environments (%).

Pre-treatment		Storage	Conditions	
GA_3	Package	Cold	Ambient	Mean
0 ppm	No Pack	1.22a	1.27a	
	Perforated	1.20a	1.21a	
	Unperforated	1.19a	1.20a	
	Vacuum	1.04a	1.05a	1.17b
150 ppm	No Pack	1.29a	1.23a	
	Perforated	1.45a	1.45a	
	Unperforated	1.26a	1.23a	
	Vacuum	1.32a	1.34a	1.32a
250 ppm	No Pack	1.20a	1.19a	
	Perforated	1.32a	1.29a	
	Unperforated	1.28a	1.28a	
	Vacuum	1.31a	1.34a	1.27ab
350 ppm	No Pack	1.34a	1.35a	
	Perforated	1.22a	1.28a	
	Unperforated	1.33a	1.40a	
	Vacuum	1.31a	1.28a	1.31a
Mean		1.26a	1.27a	
CV		8.22		

HSD 1% GA_3 = 0.12; Packaging = 0.12; Storage = 0.07; GA_3 x Packaging x Storage = 0.5
HSD = Honest significant difference, ppm = part per million; CV = Co-efficient of variation.
Means with different letters within a column are significantly different at 1 % HSD.

Pulp pH

Packaging methods for pH of banana fruits indicated no significant differences at P=0.01 (Figure 5). Banana pH ranged from 4.90 % to 5.11 %. There were significant differences among treatments for banana pH with GA_3 0 ppm fruits recorded higher value (5.30 %). No significant interaction GA_3 x packaging x storage interaction was observed.

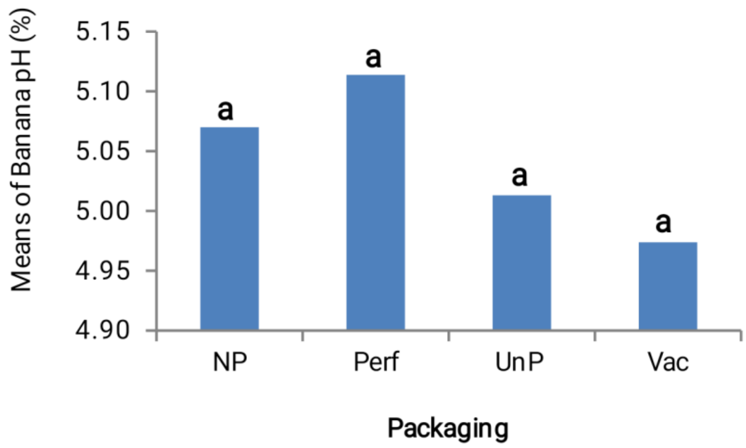

Figure 5: Effect of packaging on the pH of banana (%)

NP = No pack; Perf = Perforated film lining; Unp = Unperforated; Vac = Vacuum

Table 5: Effect of GA_3 and packaging on the pulp pH of Cavendish banana stored under different environments (%).

Pre-treatment		Storage Condition		
GA_3	Package	Cold	Ambient	Mean
0 ppm	No Pack	5.28abc	5.31ab	
	Perforated	5.45a	5.30ab	
	Unperforated	5.33ab	5.33ab	
	Vacuum	5.22abc	5.23abc	5.30a
150 ppm	No Pack	5.16abc	5.16abc	
	Perforated	5.06abc	5.05abc	
	Unperforated	4.95abc	4.95abc	
	Vacuum	4.84abc	4.83abc	5.02b
250 ppm	No Pack	5.05abc	5.06abc	
	Perforated	4.86abc	4.85abc	
	Unperforated	4.83abc	4.81bc	
	Vacuum	4.66c	4.66c	4.99bc
350 ppm	No Pack	4.77bc	4.75bc	
	Perforated	5.22abc	5.37ab	
	Unperforated	4.77bc	4.84abc	
	Vacuum	5.22abc	5.23abc	4.85c
Mean		5.04a	5.04a	
CV		2.6		

HSD 1% GA_3 = 0.16; Packaging = 0.16; Storage = 0.09, GA_3 x Packaging x Storage= 0.63
HSD = Honest significant difference, ppm = part per million; CV = Co-efficient of variation.
Means with different letters within a column are significantly different at 1 % using HSD.

Banana shelf life

Shelf life of banana fruits varied significantly (P=0.01) from 5 days to 21 days among the various packaging methods (Figure 5). There were also significant differences among treatments for the shelf life with concentration at 350 ppm showed longer shelf life (21 days). There was significant interaction of GA_3 x packaging x storage for shelf life of banana. Banana stored in cold environment also showed higher shelf life lasting up to 21 days in storage as compared to 11 days in ambient storage.

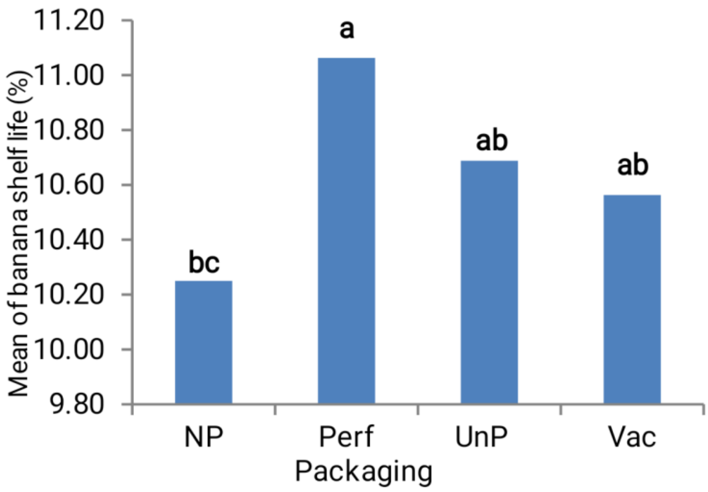

Figure .6: Effect of packaging on the shelf life of banana (days)

Table 6: Effect of GA_3 and packaging on the shelf life of Cavendish banana stored Under different environments (days).

Pre-treatment		Storage	Condition	
GA_3	Package	Cold	Ambient	Mean
0 ppm	No package	10.00cdef	5.50f	
	Perforated	7.50def	7.00ef	
	Unperforated	7.50def	5.50f	
	Vacuum	8.00def	5.50f	5c
150 ppm	No package	14.50abcd	5.50f	
	Perforated	13.50abcde	7.50def	
	Unperforated	12.50bcdef	6.00f	
	Vacuum	14.50abcd	6.50ef	15b
250 ppm	No package	17.50ab	7.00ef	
	Perforated	14.50abcd	14.50abcd	
	Unperforated	14.50abcd	14.50abcd	
	Vacuum	17.00abc	7.50def	19b
350 ppm	No package	19.00ab	8.50def	
	Perforated	20.00a	9.00def	
	Unperforated	18.50ab	9.50def	
	Vacuum	17.00abc	8.50def	21a
Mean		21a	9b	
CV		14.72		

HSD 1% GA_3 =1.87; Packaging = 1.87; Storage = 1.07; GA_3 x Packaging x Storage = 7.48
HSD = Honest significant difference, ppm = part per million;
Means with different letters within a column are significantly different at 1 % using HSD.

Discussion

The ripening of bananas involves biochemical and physiological changes that impact their appearance, texture, and quality. A key indicator of ripeness is the transition of the peel colour from green to yellow, caused by chlorophyll degradation (Gonzalez *et al*., 2022). This colour change influences consumer and retailer decisions, as it is associated with the fruit's sweetness and texture. Understanding the factors driving chlorophyll degradation, along with environmental conditions, ripening treatments, and packaging methods, is crucial for improving postharvest handling and shelf life. Recent studies have emphasized the role of treatments like GA3 and packaging methods such as perforated polyethylene films in controlling ripening and maintaining fruit quality (Sinanoglou *et al*., 2023; Alonso-Salinas *et al.*, 2024).).

The chlorophyll degradation that changes the peel colour from green to yellow is the most obvious change that occurs during the ripening of bananas. This results from the loss of chlorophyll, which serves as a rough guide to the stage of ripeness. The peel colour is used as an indicator of shelf life for retail distribution, while texture is a key factor in eating quality. External skin colour changes during ripening, reflecting changes in pulp colour. Yellowing begins at or shortly after the climacteric peak, and fruits that are not packaged become fully yellow in less than seven days at ambient storage, similar to the observations by Sinanoglou *et al* (2023). The disappearance of the green colour is due to the degradation of the chlorophyll structure. The main agents responsible for this degradation are pH changes (primarily due to the leakage of organic acids from the vacuole), oxidation systems, and chlorophyllase activity. Recent studies indicate that the loss of green colour depends on these factors acting in sequence to destroy the chlorophyll structure (Alonso-Salinas *et al.*, 2024). Changes in fruit colour during ripening are linked by consumers to the conversion of starch into sugar, leading to sweetening and the development of desirable characteristics, making peel colour an essential factor for purchasing decisions (Sinanoglou *et al*., 2023).

Bananas treated with 350 ppm of GA3 showed the best ripening, likely due to the prolonged ripening period, resulting in complete yellowing. Additionally, perforated low-density polyethylene (LDPE) linings performed best in terms of ripening since the perforations allowed for gas exchange, modifying the environment around the fruit. Cold storage conditions were more favorable for achieving the desired color of bananas (Gonzalez et al., 2022).

Weight loss is an inevitable part of the ripening process. GA3 retarded ripening, but its effects varied depending on concentration. At 350 ppm, GA3 had the most significant effect on fruit weight, due to the delayed ripening process. Since weight loss is linked to fruit ripening, faster ripening leads to faster weight loss. Bananas treated with 0 ppm GA3 lost weight rapidly (20.99%) due to rapid ripening. On the other hand, a GA3 concentration of 350 ppm led to the least weight loss (7.89%) due to delayed ripening (Hasan, *et al.,* 2024).

Packaging methods also influenced the ripening and weight loss of bananas. The use of perforated LDPE film reduced ripening rates and resulted in lower weight loss (16%), as the perforations facilitated gas exchange, diffusing accumulated ethylene. Conversely, bananas stored in vacuum bags experienced rapid ripening due to heat and ethylene accumulation. Temperature and relative humidity are key factors in determining weight loss during storage and ripening. Packaging bananas in intact or perforated polyethylene packages creates high humidity inside the package, which helps reduce weight loss (Carnaval *et al*., 2024).

The average temperature and relative humidity at ambient storage were 30°C and 60%, respectively, while in cold storage, the temperature was 18°C with 80% humidity. Cold storage significantly reduced weight loss (Al-Dairi *et al*., 2023).

Hence banana in the cold storage performed best (5.79 %), resulting in significantly heavier fruits than bananas stored in ambient condition because the cold storage slowed down the rate of water loss as temperature was relatively low.

As shelf life period progressed, firmness decreased from 4.53 kg cm^{-2} to 3.98 kg cm^{-2} across all treatments as texture of banana fruits is being softened by ripening. Application of GA_3 (350 ppm) contributed to the retention of fruit firmness for GA_3 (350 ppm) showed the best performance resulted in highest firmness 4.57 kg cm^{-2} which could be attributed to the fact that GA_3 delayed ripening in fruits which also affected softening during the ripening process resulting in firmer fruits (Sinanoglou *et al*., 2023). Similarly, banana in perforated low density polyethylene film lining had relatively firmer fruits at the end of the shelf life hence showed the best results 4.53 kg cm^{-2}. This was due to the perforations which altered the immediate surroundings of the fruits by allowing easy exchange of gases. The perforations enabled carbon dioxide and ethylene to escape and that reduced the rate of respiration and metabolism within the fruit thereby reducing softening of fruits. Cold storage also showed positive effect (better storage environment) with firmness of 4.53 kg cm^{-2} as it decreased the pulp permeability and so reduced the rate of water loss resulting in delayed fruit ripening and reduced softening as compared to fruits that were in ambient conditions and this was also observed by (Carnaval *et al*., 2024).

Regarding pulp pH, bananas treated with 0 ppm GA3 had the highest pH (5.30), likely due to changes in malic acid content. The Ph increase in bananas treated with GA3, and is further supported by recent findings from (Smith *et al*., 2023), which demonstrated similar trends in pulp pH variations under GA3 treatments The conversion of starch into sugars is the most important change in ripening bananas and these soluble substances form the soluble content of banana. Even though GA_3 application on bananas affected the TSS level, GA_3 350 ppm concentration revealed most significant and best results in TSS up to 8.51 %, probably due to longer storability which led to more sugar build up in the fruits. Fruits that were subjected to 0 ppm concentration of GA_3 however showed low TSS levels due to the short storability (Al-Dairi *et al*., 2023).

Similarly, banana in polyethylene film linings showed differences in TSS, banana in perforated low density polyethylene film lining showed the best results of 8.60 %. This was due to the perforations which improved the immediate surroundings of the fruits by allowing easy exchange of gases (Hasan, *et al.,* 2024). Also, bananas that were exposed to the different storage conditions exhibited differences in TSS levels, banana that were subjected to cold storage showed better performance as they recorded significantly higher TSS of 8.55 % than ambient condition of 8.04 % due to the prolong stay of the fruits in the storage environment as longer shelf life could result in more sugar accumulation even though there were no significant effects. During the ripening process, starch content of bananas is hydrolysed into soluble sugars such as glucose, sucrose and fructose which also increase the total soluble solids content of fruits. This suggests that the TSS levels could increase further given a much longer storage period in low temperature (Smith et al., 2023).

The study examined the effects of GA3 on titratable acidity (TTA) and pulp pH in bananas during storage. TTA varied between 1.17% and 1.31% among fruits treated with GA3. The highest TTA was observed in bananas treated with 350 ppm and 150 ppm GA3 (1.31% and 1.32%, respectively), likely due to reduced pulp pH. TTA increased during ripening and decreased during senescence as organic acids were utilized in metabolic processes, with no significant impact from packaging or storage conditions on TTA (Hasan, *et al.,* 2024).

Regarding pulp pH, bananas treated with 0 ppm GA3 had the highest pH (5.30), likely due to changes in malic acid content. This is consistent with findings from Hailu et al. (2012), which reported pH increase in bananas treated with GA3. The pH of bananas treated with 350 ppm GA3 was lower due to GA3's reverse effects. Packaging methods did not significantly affect the pH, although bananas stored in perforated polyethylene film in cold conditions showed slightly better performance when untreated with GA3. The combined effect of 0 ppm GA3 and perforated film showed the best pH performance (5.45%), though this was not statistically significant (Al-Dairi *et al.,* 2023).

The use of gibberellic acid (GA3) has been shown to extend the shelf life of bananas by delaying the ripening process. A study found that a concentration of 350 ppm of GA3 resulted in the longest shelf life at 13.75%, attributed to GA3's ability to reduce tissue permeability and, when combined with low temperatures and high humidity, slow down the fruit's physiological processes such as respiration, thus reducing water loss and delaying ripening (Smith et al., 2023). Packaging methods also affected shelf life; with perforated film lining yielding the best results at 11.06% because it prevented ethylene gas buildup, unlike vacuum-sealed or non-perforated packaging, which accelerated ripening due to trapped ethylene (Chen & Liu 2022). Cold storage was found to be highly effective, extending the banana shelf life to 21 days (14.13%) compared to just 11 days (7.16%) in ambient storage. This is because cold storage reduces respiration, decreases sensitivity to ethylene, and minimizes water loss, preserving the fruit's quality (Al-Dairi *et al.,* 2023).

Reduced green-life period of stored bananas as a result of low relative humidity has been described by some other researchers. Generally, water deficit triggers ethylene production which causes earlier climacteric respiring rise (Du *et al.,* 2014). In addition, it is also reported that the conversion of chlorophyll occurred prior to degradation and enzyme responsible for the conversion has been identified as non-yellow colouring (NYC) or chlorophyll reductasee (Yang *et al*., 2009a).

The loss of green colour in bananas is primarily due to chlorophyll degradation, influenced by pH changes, oxidation, and chlorophyllase activity. This process typically begins with an increase in chlorophyllase activity at the climacteric peak and declines afterward. Banana ripening at higher temperatures can lead to incomplete colour loss, even if the fruit's flesh is ripened. Enzymatic breakdown of cell wall materials is also associated with banana ripening during storage. Green-ripening, which results in a greenish-yellow peel, is unique to certain fruits, including those in the Musaceae family. Controlled atmospheric storage conditions, such as temperatures between 13°C and 15°C, can reduce respiration, increase firmness, lower weight loss, and delay yellowing, compared to storage in regular air. In the study mentioned, bananas stored at 18°C to 22°C with 68-80% relative humidity performed better in terms of storability, lasting up to 21 days and maintaining quality and firmness. However, some samples still experienced green ripening compared to those stored in ambient conditions, which had more green-ripened fruits.

Conclusion

Gibberellic Acid (GA3) at a concentration of 350 ppm, combined with perforated low-density polyethylene film lining, has been shown to improve the physicochemical properties and prolong the shelf-life of bananas up to 21 days under cold storage conditions. This method proved to be the most effective in enhancing fruit firmness, maintaining fruit weight, and extending shelf-life by preserving the quality of the fruit during storage (Mathiazhagan *et al*., 2023). The use of perforated low-density polyethylene film lining, in particular, enhanced the physicochemical properties of the banana and extended its shelf life by creating an optimal microenvironment around the fruit that allowed for proper gas exchange, which is critical during storage (Zhan *et al.,* 2022). Furthermore, it was found that GA3 at 350 ppm, when used in conjunction with perforated film under cold storage conditions, was the most effective combination for reducing postharvest losses, maintaining quality, and achieving longer shelf life (Maurya *et al*., 2020). Therefore, the application of GA3 at a concentration of 350 ppm, coupled with perforated low-density polyethylene film lining under cold storage conditions, is recommended as an efficient strategy for enhancing banana quality, reducing losses, and ensuring a prolonged shelf life.

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