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Effect of Gibberellic acid concentrations on physicochemical attributes and shelf life of different mango (*Mangifera indica* L.) varieties

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Abstract

Mango (*Mangifera indica*), often referred to as the "king of fruits," is a staple of tropical fruit production, offering high economic and nutritional value. However, mangoes are highly perishable, facing challenges like significant post-harvest losses due to rapid physiological weight loss, reduced fruit firmness, and shortened shelf life. To address these issues, this study evaluated the effects of gibberellic acid (GA3) on the physical, chemical, and storage characteristics of mangoes, aiming to improve post-harvest quality and extend their marketability. The experiment, conducted at Girija Prasad Koirala College of Agriculture and Research Centre (GPCAR), used a Completely Randomized Design (CRD) with six GA3 treatments (0, 50, 100, 200, 300, and 400 ppm). Uniformly sized, newly harvested ripe mangoes were treated with GA3 solutions for 10 minutes, with parameters such as physiological weight loss, total soluble solids, pulp pH, fruit firmness, and titratable acidity assessed after three days. The results revealed that mangoes treated with 400 ppm GA3 had the lowest physiological weight loss (35.75%), highest fruit firmness (1.14), and longest shelf life, with the Maldah variety performing best. Future studies could focus on optimizing GA3 application for diverse mango varieties and explore its integration with advanced storage technologies to further reduce post-harvest losses and improve global mango supply chains.

Keywords: GA_3, Firmness, Ripening delay, Physiochemical traits, Mango shelf life

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INTRODUCTION

Mango (Mangifera indica L.), belonging to the Anacardiaceae family, is one of the most important tropical and subtropical fruit crops grown worldwide (Fitmawati et al., 2017). It is often referred to as the "king of tropical fruits" due to its exceptional flavor, appealing color, pleasant aroma, and rich nutritional content. The fruit is highly valued for its dietary benefits, containing essential vitamins, minerals, and antioxidants. Mango originated in the Indo-Burma region and Southeast Asia, with 69 recognized species (Shankaraswamy et al., 2015). It is cultivated in over 100 countries, with more than 65 nations producing over 1,000 metric tonnes annually (Mitra, 2016). Asia is the dominant producer, contributing approximately 77% of the total global mango production, followed by the USA (13%) and Africa (10%), while Oceania and Europe contribute less than 1% each (FAO, 2012). Major mango-producing countries include India, China, Brazil, Indonesia, Mexico, Pakistan, Egypt, the Philippines, Thailand, and Vietnam. India stands as the largest mango producer, leading in both cultivation area and total production. In Nepal, mango is a high-value fruit crop cultivated in the Terai, inner Terai, and foothills, extending up to 1100 meters above sea level. It ranks second in terms of total cultivated area and productivity. In the fiscal year 2016/17, Nepal produced 2,98,692 metric tonnes of mangoes across 48,204 hectares (MoAD, 2016/17). The main mango pocket areas in Nepal include Sarlahi (10 mt/ha), Mahottari (11 mt/ha), Dhanusha (11 mt/ha), Kapilvastu (9 mt/ha), Dang (6 mt/ha), Banke (9 mt/ha), and Bardiya (9 mt/ha) (MoAD, 2016/17).

Despite Nepal's potential for high mango production, postharvest losses and poor storage infrastructure lead to significant fruit spoilage annually. One of the major challenges in mango production is postharvest losses due to rapid ripening and short storage life. Mango is a climacteric fruit, meaning it undergoes a sharp rise in ethylene production after harvest, accelerating the ripening process (Singh, 2016). Due to its short shelf life, postharvest losses range from 25–40%, with 25% losses occurring between harvesting and consumption (Evans et al., 2017). The fast deterioration of mangoes reduces their commercial value, making storage and transportation challenging. Although refrigeration slows down the ripening process, mangoes are susceptible to chilling injury, which causes damage to the fruit tissues (Rathore et al., 2007). Mangoes are rich in essential nutrients, providing 64–86 kcal of energy per 100g, along with significant amounts of vitamin C (32–200 mg per 100g of pulp), carotenoids, and minerals like calcium and potassium (Bernardini et al., 2005). Vitamin C plays a crucial role in preventing degenerative diseases such as cancer and cardiovascular disorders. However, due to inadequate postharvest management, a substantial portion of mangoes are lost before reaching consumers. In developing countries, postharvest losses range from 20–50%, while developed nations report losses of up to 5–25% (Kumar et al., 2015).

Effective postharvest treatments, such as controlled atmosphere storage, plant growth regulators, and packaging techniques, are essential to extending shelf life and maintaining mango quality. Plant growth regulators (PGRs) are organic compounds that, even in minute quantities, influence plant growth and development. These include auxins, gibberellins, cytokinins, ethylene, growth retardants, and inhibitors. Gibberellins (GAs), particularly gibberellic acid (GA3), are diterpene acids known for their role in delaying fruit ripening and senescence. GA3 is widely used in agriculture as an endogenous plant growth regulator, although it is rarely produced in significant amounts by plants themselves. The application of GA3 has proven beneficial in preserving mango fruit quality and prolonging its shelf life. GA3 acts as a senescence-delaying agent by slowing the ripening process, reducing ethylene production, and delaying carotenoid synthesis (Lokesh et al., 2013). In papaya, GA3 treatment delays ripening by affecting sucrose metabolism and the breakdown of complex carbohydrates. Similarly, GA3 application in tomatoes has been found to reduce tissue permeability, leading to lower physiological weight loss and decay (Singh et al., 2014). These findings suggest that GA3 can be an effective tool in postharvest mango management. Gibberellic acid application after harvest plays a critical role in maintaining mango quality by reducing metabolic activity and weight loss. GA3 functions as an ethylene antagonist, preserving physiological and enzymatic activity while delaying ripening. It decreases respiration rate, inhibits ethylene synthesis, and slows fruit softening and color development. The reduction in tissue permeability also helps lower physiological losses in weight, contributing to an extended storage life. Several postharvest treatments are employed to improve mango storage, including wax emulsions, fungicides, polythene film, and chemical coatings (Munhuweyi et al., 2020). Among these, GA3 has emerged as a promising alternative due to its ability to modulate ripening and extend fruit shelf life naturally. The use of GA3 in mango storage reduces postharvest losses, maintains nutritional value, and enhances commercial viability.

The goal of this study is to ascertain the ideal concentration of GA3 to improve the shelf life, nutritional value, and postharvest preservation of mangos in storage.

MATERIALS AND METHODS

Experimental site

The study was carried out at G.P. Koirala College of Agriculture and Research Centre (GPCAR) in Gothgaun, Morang, Nepal, from June 16 to June 30, 2023. The experimental site is situated at 26.6806°N latitude and 87.35317°E longitude, as illustrated in the location map (Figure 1). Throughout the study period, environmental conditions were closely observed. The recorded maximum and minimum temperatures were 44.51°C and 24.45°C, respectively, while relative humidity fluctuated between 87.56% and 30.94%. These variations in climatic conditions are visually represented in Figure 2, which depicts the environmental changes recorded in the laboratory during the experiment. Together, Figures 1 and 2 offer a detailed overview of the study location and its climatic conditions, providing essential context for the research.

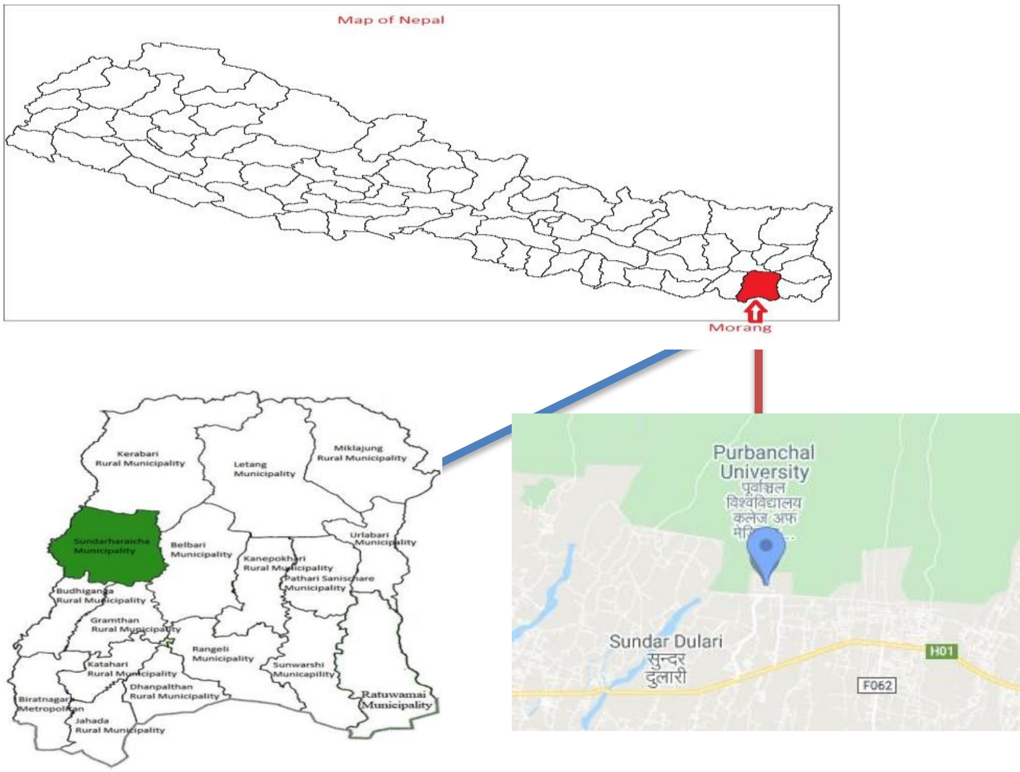

Figure 1. Map of study area

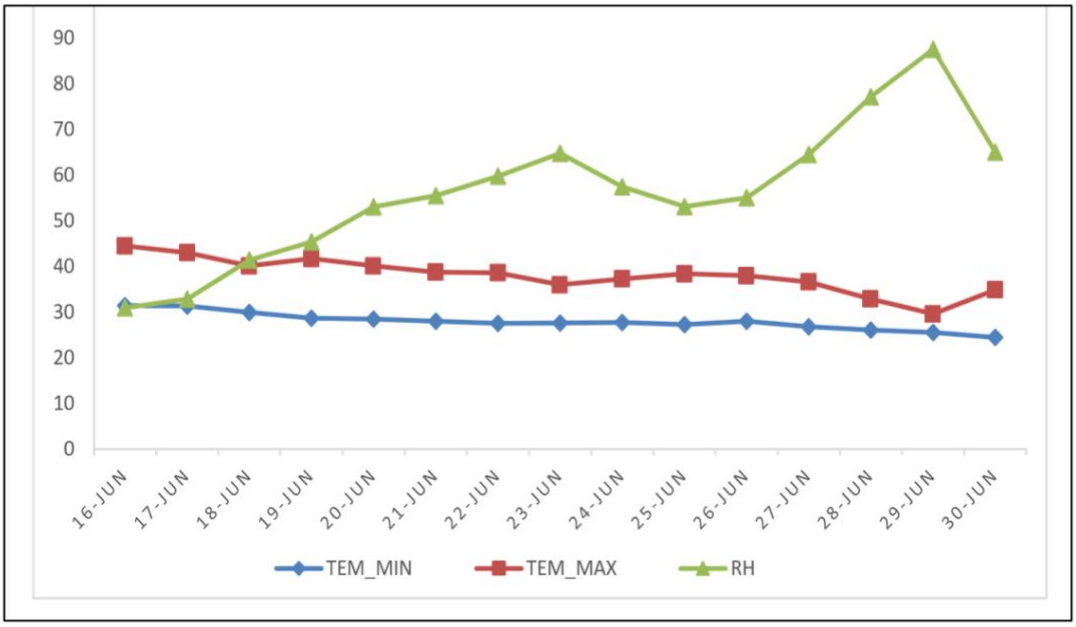

Figure 2. Geographical representation of meteorological data in laboratory.

Experimental design and treatment details

The experiment was conducted using a completely randomized design (CRD) to evaluate the effects of gibberellic acid (GA_3) on three mango varieties: Maldah, Bombay, and Dasheri. A two-factor factorial design was employed, incorporating six GA_3 treatment levels and three replications per treatment combination. Gibberellic acid solutions were prepared at concentrations of 50 ppm, 100 ppm, 200 ppm, 300 ppm, and 400 ppm by dissolving 250 mg, 500 mg, 1000 mg, 1500 mg, and 2000 mg of GA_3 in five liters of distilled water, respectively, while distilled water served as the control treatment. Mango fruits of uniform size and free from defects were first washed thoroughly with tap water, air-dried, and grouped by size before treatment. The fruits were then immersed in the respective GA_3 solutions for 10 minutes to ensure absorption, followed by air-drying on a clean laboratory surface. The mangoes treated were stored under ambient room conditions for further evaluation. The experiment involved three mango varieties and six GA_3 concentrations, arranged in a completely randomized design with three replications, leading to a total of 54 experimental units. Treatments were randomized within each replication to meet the assumptions of CRD, and observations were systematically recorded to analyze the post-treatment effects of GA_3 on mango shelf life and quality. Figure 3 illustrates the details of the mango varieties and treatment combinations used in the study.

Table 1. Experimental design with list of varieties and different concentrations of GA_3.

		Factor B						
Factor A	Replication	1	2	3	4	5	6	Total A
1	1	T111	T121	T131	T141	T151	T161	T1
	2	T112	T122	T132	T142	T152	T162	
	3	T113	T123	T133	T143	T153	T163	
	Total AB	T11	T12	T13	T14	T15	T16	
2	1	T211	T221	T231	T241	T251	T261	T2
	2	T212	T222	T232	T242	T252	T262	
	3	T213	T223	T233	T243	T253	T263	
	Total AB	T21	T22	T23	T24	T25	T26	
Total B		T1	T2	T3	T4	T5	T6	T
Factor A		Factor B						
S.N.	Varieties	S.N.	Concentration of gibberellic acid					
		T1	Control/Distilled water					
1	Maldah	T2	50 ppm of GA_3					
2	Bombay	T3	100 ppm of GA_3					
3	Dasheri	T4	200 ppm of GA_3					
		T5	300 ppm of GA_3					
		T6	400 ppm of GA_3					

Observations

A total of 54 experimental units were established, considering three replications, six GA_3 treatments, and three mango varieties. Each experimental unit consisted of five mango fruits. Among them, three mangoes were designated as destructive samples for assessing physicochemical parameters, including total soluble solids (TSS), titratable acidity (TA), pH, firmness, and palatability. The remaining two mangoes were maintained as non-destructive samples to evaluate shelf life and physiological loss of weight (PLW) at different observation intervals (6, 9, and 12 days after treatment).

Shelf life and Physiological loss

The shelf life of mango fruits was determined by monitoring the number of days required for them to reach an optimal ripening stage while maintaining their marketable and consumable quality. The calculation was performed based on the duration between the first day of storage after treatment and the last day when the fruits were considered edible (Hasan et al., 2020). The first day of storage after treatment was recorded as Day 0, and the fruits were observed daily for changes in physical appearance, texture, aroma, and overall quality. The percentage of deterioration was recorded for each treatment and replication. The shelf life was considered to have ended when more than 50% of the stored mangoes became unfit for consumption. The number of days from Day 0 to this stage was recorded as the shelf-life duration for that specific treatment. Similarly, at the same time, the physiological loss was calculated using the following formula from (Yadav et al., 2022), PLW, Physiological loss in weight, utilizing non-destructive sampling at three-day intervals.

$$\text{PLW}\ (\%) = \frac{\text{Initial weight of fruits (IW)} - \text{Final weight of fruits (FW)}}{\text{Initial weight of fruits (IW)}} \times 100$$

Potential of Hydrogen (pH)

The pH of mango fruit juice was determined using a digital pH meter, an electronic device that measures hydrogen ion concentration to indicate acidity or alkalinity. Before measurement, the pH meter was calibrated with standard buffer solutions (pH 4.0 and 7.0) to ensure accuracy. It operates based on an electrochemical principle, where a glass electrode detects hydrogen ion activity in the solution and generates a voltage proportional to the H^+ ion concentration. A reference electrode provides a stable comparison potential, ensuring precise readings. After calibration, the electrode was immersed in mango pulp juice, and the pH value was displayed on the digital screen.

Total Soluble Solids (TSS)

A digital refractometer was used to measure the total soluble solids (TSS) content of mango fruit pulp. A few drops of fresh mango juice were extracted using a clean pipette and placed on the refractometer's prism surface. The reading was recorded at room temperature, ensuring accuracy. After each measurement, the specimen chamber was thoroughly cleaned with distilled water and wiped using a fresh muslin cloth to prevent contamination. The digital refractometer works on the principle of light refraction, where the degree to which light bends as it passes through the sample correlates with the concentration of dissolved solids, primarily sugars. The instrument measures the refractive index and converts it into Brix (% TSS), which is displayed on the screen. Calibration was performed using distilled water (0% TSS) before measurements to ensure precision (Hasan et al., 2020; Yadav et al., 2022).

Titratable Acidity (TA)

By titrating diluted fruit juice (5 ml) against base 0.1 N NaOH solutions using 100 ml of distilled water and 5 drops of phenolphthalein indicator, titrable acidity was ascertained. The following formula (Yadav et al., 2022) was used to calculate the mango juice's TA.

$$\text{TA}\ (\%) = \frac{[\text{ml of NaOH used}] \times [0.1\text{N NaOH}] \times [\text{Milliequivalent factor}]}{\text{Grams of sample used}} \times 100$$

Where,

TA, Titratable Acidity

N NaOH, Normality of NaOH

Milliequivalent factor of predominant acid (malic acid) = 0.0679

Firmness

Fruit firmness is a key quality trait influencing mango shelf life and marketability. In this study, firmness was measured using a handheld penetrometer (Model GY-3, No. 400102024) at 2-day intervals after treatment. The peak puncture force (g) was recorded from three points (top, bottom, and side) on each fruit, with the average considered as the actual firmness. This method helps assess the effect of gibberellic acid (GA_3) on fruit texture, providing insights into its role in delaying softening and extending shelf life.

Palatability

Palatability was evaluated based on color, odor, texture, touch, and taste using a sensory panel of five individuals. Each panelist scored the fruits on a scale from 0 to 5, with 0 indicating very poor and 5 representing excellent palatability. Assessments were conducted at 6, 9, and 12 days after treatment (DAT), and the average score from all panelists was used to determine the overall palatability rating, helping assess the impact of gibberellic acid (GA_3) on fruit quality and acceptability over time.

Statistical analysis

R studio (4.2.2 edition) was used to analyse the acquired data after it was imported into MS Excel. The Duncan Multiple Range Test (DMRT) was used as a statistical technique to compare the means of data for each parameter. Furthermore, the daewr, gvlma, and Agricolae packages in R studio programme (4.2.2 version) were utilised to analyse the interaction impact between the varieties and treatments. Tables and graphs were created using Microsoft Excel.

RESULTS

Effect of GA_3 on physiological weight loss

Variations in gibberellic acid (GA3) concentrations influenced the patterns of physiological weight loss in mangoes. On the twelfth day post-treatment, significant differences were observed in weight loss across different GA3 dosages. Among all treatments, the control group exhibited the highest physiological weight loss for each mango variety. By the end of the study, mangoes treated with 400 ppm GA3 showed the lowest weight loss (35.75%), whereas control fruits experienced the highest loss (61.19%). Tables 2, 3, and 4 present the detailed results. A consistent increase in weight loss was observed across all treatments as storage duration progressed. Fruits treated with 400 ppm GA3 retained the most weight, followed by those treated with 300 ppm, 200 ppm, 100 ppm, and 50 ppm, while control fruits lost the most weight throughout the 12-day storage period. Among the mango varieties, Dasheri exhibited the highest weight loss (66.06%), followed by Bombay Green (48.08%) and Maldah (38.32%).

Table 2. Effect of different concentrations of gibberellic acids on physiological loss of mango varieties

Varieties	Physiological loss (%)			
	3 DAT (%)	6 DAT (%)	9 DAT (%)	12 DAT (%)
Dasheri	6.22^{a}	15.94^{a}	31.61^{a}	66.06^{a}
Bombay	4.55^{b}	11.60^{b}	22.96^{b}	48.08^{b}
Maldah	3.60^{c}	9.25^{c}	18.35^{c}	38.32^{c}
SEM (±)	0.036	0.093	0.185	0.392
$LSD_{0.05}$	0.104	0.268	0.531	1.125
F test	***	***	***	***
Treatments				
$GA3_{0}$	5.37^{a}	14.25^{a}	28.64^{a}	61.19^{a}
$GA3_{50}$	5.01^{b}	13.41^{b}	26.74^{b}	59.43^{b}
$GA3_{100}$	4.86^{c}	12.29^{c}	23.58^{c}	53.71^{c}
$GA3_{200}$	4.68^{d}	11.68^{d}	23.42^{c}	52.29^{c}
$GA3_{300}$	4.45^{e}	11.13^{e}	22.29^{d}	42.55^{d}
$GA3_{400}$	4.36^{e}	10.81^{e}	21.17^{e}	35.75^{e}
Grand mean	4.795	12.265	24.310	50.825
CV (%)	3.176	3.209	3.212	3.292
SEM (±)	0.051	0.132	0.262	0.555
$LSD_{0.05}$	0.147	0.378	0.751	1.591
F test	***	***	***	***

***Significant at 0.1% level of significance, LSD: Least significant difference, SEM: Standard error of the mean, CV: Coefficient of variation

Table 3: Interaction of different concentrations of gibberellic acids on the physiological loss of mango varieties

Interactions		Physiological loss (%)			
Varieties	Treatments	3 DAT	6 DAT	9 DAT	12 DAT
Dasheri	$GA3_{0}$	6.46^{a}	19.52^{a}	39.25^{a}	83.84^{a}
	$GA3_{50}$	6.04^{b}	16.12^{b}	32.13^{b}	71.41^{b}
	$GA3_{100}$	6.66^{a}	14.82^{c}	28.44^{c}	64.78^{c}
	$GA3_{200}$	6.58^{a}	16.41^{b}	32.92^{b}	73.48^{b}
	$GA3_{300}$	5.70^{c}	14.25^{cd}	28.52^{c}	57.07^{e}
	$GA3_{400}$	5.85^{bc}	14.50^{c}	28.40^{c}	45.76^{g}
Bombay	$GA3_{0}$	5.28^{d}	11.57^{fg}	23.27^{e}	49.71^{f}
	$GA3_{50}$	5.63^{c}	13.16^{e}	26.24^{d}	58.33^{de}
	$GA3_{100}$	3.95^{g}	13.80^{de}	26.48^{d}	60.32^{d}
	$GA3_{200}$	4.22^{ef}	10.52^{h}	21.10^{f}	47.10^{fg}
	$GA3_{300}$	4.29^{e}	10.73^{h}	21.49^{f}	38.54^{h}
	$GA3_{400}$	3.95^{g}	9.79^{i}	19.17^{g}	34.48^{ij}
Maldah	$GA3_{0}$	4.39^{e}	11.64^{f}	23.41^{e}	50.01^{f}
	$GA3_{50}$	3.36^{h}	10.95^{gh}	21.84^{f}	48.54^{fg}
	$GA3_{100}$	3.97^{fg}	8.24^{j}	15.82^{h}	36.03^{hi}
	$GA3_{200}$	3.25^{h}	8.11^{j}	16.26^{h}	36.30^{hi}
	$GA3_{300}$	3.36^{h}	8.41^{j}	16.84^{h}	32.04^{j}
	$GA3_{400}$	3.28^{h}	8.14^{j}	15.94^{h}	27.02^{k}
SEM (±)		0.089	0.229	0.454	0.961
$LSD_{0.05}$		0.254	0.655	1.301	2.755
F test		***	***	***	***

GA3: Gibberellic acids, ***Significant at 0.1% level of significance, LSD: Least significant difference, SEM: Standard error of the mean

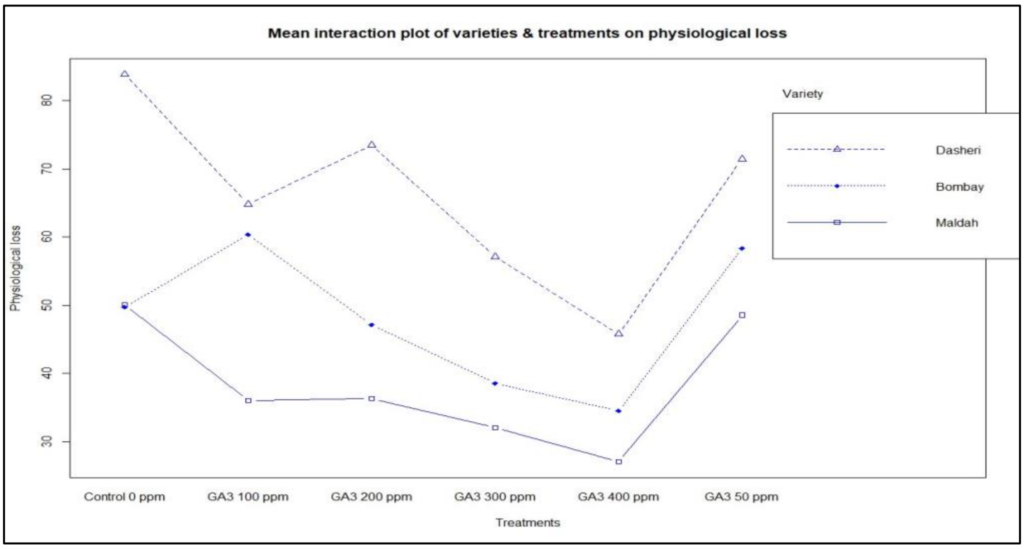

Figure 4. Showing the pattern of physiological loss of different varieties of mango in different concentrations of GA_3.

Effects of GA_3 on Total Soluble Solids and Titratable acidity

A statistically significant variation in total soluble solids (TSS) of mango was observed on the twelfth day after treatment application. Fruits treated with 400 ppm GA3 exhibited the lowest TSS (16.21 °Brix), while the control fruits recorded the highest (20.20 °Brix). Although most treatments showed a continuous increase in TSS throughout the study, fruits treated with 50 ppm GA3 (T2) and the control (T1) followed a distinct pattern, increasing until the ninth day before declining by the twelfth day. The variation in TSS across treatments, as shown in Table 4, Table 5, and Figure 5, reflects the postharvest effects of gibberellic acid application. In control and 50 ppm GA3-treated fruits, TSS initially increased until the ninth day, followed by a decline. Conversely, mangoes treated with 100 ppm, 200 ppm, 300 ppm, and 400 ppm GA3 exhibited a steady increase in TSS throughout the 12-day storage period. A highly significant difference in titratable acidity (TA) was also recorded on the twelfth day. TA consistently declined across all treatments over time, with the lowest TA observed in the control (0.111) and the highest in fruits treated with 400 ppm GA3 (0.162), indicating a gradual increase in TA with higher GA3 concentrations. Details on titratable acidity, variety-treatment interactions, and corresponding graphical representations are provided in Table 4, Table 5, and Figure 6.

Table 4. Effect of different concentrations of gibberellic acids on total soluble solids and titratable acidity of mango varieties

Varieties	TSS (°Brix)			TA (%)		
	6 DAT	9 DAT	12 DAT	6 DAT	9 DAT	12 DAT
Dasheri	15.06[c]	17.84[b]	17.98[c]	0.17[c]	0.15[b]	0.13[b]
Bombay	17.17[a]	18.50[a]	19.05[a]	0.18[b]	0.15[b]	0.13[b]
Maldah	16.04[b]	17.55[c]	18.40[b]	0.19[a]	0.17[a]	0.16[a]
SEM (±)	0.0631	0.0601	0.0572	0.000843	0.000957	0.00318
$LSD_{0.05}$	0.1810	0.1725	0.1641	0.002417	0.002746	0.00911
F test	***	***	***	***	***	***
Treatments						
$GA3_0$	18.80[a]	20.50[a]	20.20[a]	0.14[f]	0.119[e]	0.111[c]
$GA3_{50}$	17.76[b]	19.27[b]	19.15[b]	0.16[e]	0.151[d]	0.141[b]
$GA3_{100}$	17.32[c]	19.01[c]	19.14[b]	0.16[d]	0.159[c]	0.144[b]
$GA3_{200}$	15.08[d]	17.46[d]	19.08[b]	0.18[c]	0.172[b]	0.148[ab]
$GA3_{300}$	14.78[e]	16.04[e]	17.08[c]	0.19[b]	0.174[b]	0.159[a]
$GA3_{400}$	12.81[f]	15.50[f]	16.21[d]	0.23[a]	0.179[a]	0.162[a]
Grand mean	16.095	17.968	18.480	0.182	0.159	0.144
CV (%)	1.655	1.440	1.178	1.965	2.446	9.294
SEM (±)	0.0892	0.0851	0.0809	0.001192	0.001354	0.00449
$LSD_{0.05}$	0.2560	0.2440	0.2320	0.003418	0.003884	0.01288
F test	***	***	***	***	***	***

***Significant at 0.1% level of significance, LSD: Least significant difference, SEM: Standard error of the mean, CV: Coefficient of variation

Table 5. Interaction of different concentrations of gibberellic acids on total soluble solids and titratable acidity of mango varieties

Interactions		TSS (°Brix)			TA (%)		
Varieties	Treatments	6 DAT	9 DAT	12 DAT	6 DAT	9 DAT	12 DAT
Dasheri	$GA3_0$	18.53^{b}	22.46^{a}	20.43^{b}	0.13^{k}	0.106^{j}	0.115^{hij}
	$GA3_{50}$	17.36^{c}	18.93^{d}	19.46^{c}	0.17^{g}	0.154^{f}	0.145^{defg}
	$GA3_{100}$	17.53^{c}	16.36^{g}	19.60^{c}	0.16^{h}	0.156^{ef}	0.126^{ghij}
	$GA3_{200}$	10.26^{i}	17.36^{f}	19.40^{c}	0.17^{g}	0.154^{f}	0.146^{defg}
	$GA3_{300}$	14.46^{f}	16.50^{g}	13.43^{i}	0.19^{e}	0.173^{c}	0.142^{efg}
	$GA3_{400}$	12.23^{h}	15.43^{h}	15.56^{h}	0.19^{e}	0.161^{de}	0.155^{cdef}
Bombay	$GA3_0$	18.50^{b}	21.56^{b}	19.76^{c}	0.14^{j}	0.118^{i}	0.104^{j}
	$GA3_{50}$	16.70^{d}	19.66^{c}	18.53^{d}	0.15^{i}	0.145^{g}	0.109^{ij}
	$GA3_{100}$	19.20^{a}	22.50^{a}	20.40^{b}	0.15^{i}	0.146^{g}	0.131^{fghi}
	$GA3_{200}$	19.61^{a}	17.43^{f}	17.43^{e}	0.18^{f}	0.164^{d}	0.136^{fgh}
	$GA3_{300}$	15.38^{e}	15.20^{h}	21.36^{a}	0.21^{c}	0.196^{b}	0.133^{fghi}
	$GA3_{400}$	13.63^{g}	14.66^{i}	16.80^{f}	0.23^{b}	0.143^{g}	0.185^{ab}
Maldah	$GA3_0$	19.36^{a}	17.49^{f}	20.40^{b}	0.15^{i}	0.131^{h}	0.114^{hij}
	$GA3_{50}$	19.23^{a}	19.23^{d}	19.46^{c}	0.16^{h}	0.154^{f}	0.169^{bcd}
	$GA3_{100}$	15.23^{e}	18.16^{e}	17.44^{e}	0.18^{f}	0.175^{c}	0.176^{bc}
	$GA3_{200}$	15.38^{e}	17.60^{f}	20.43^{b}	0.20^{d}	0.197^{b}	0.164^{bcde}
	$GA3_{300}$	14.50^{f}	16.43^{g}	16.45^{fg}	0.19^{e}	0.154^{f}	0.203^{a}
	$GA3_{400}$	12.56^{h}	16.40^{g}	16.26^{g}	0.26^{a}	0.233^{a}	0.146^{defg}
SEM (±)		0.1546	0.1473	0.1401	0.002064	0.002345	0.00778
$LSD_{0.05}$		0.4434	0.4226	0.4018	0.005919	0.006726	0.02231
F test		***	***	***	***	***	***

GA3: Gibberellic acids, ***Significant at 0.1% level of significance, LSD: Least significant difference, SEM: Standard error of the mean

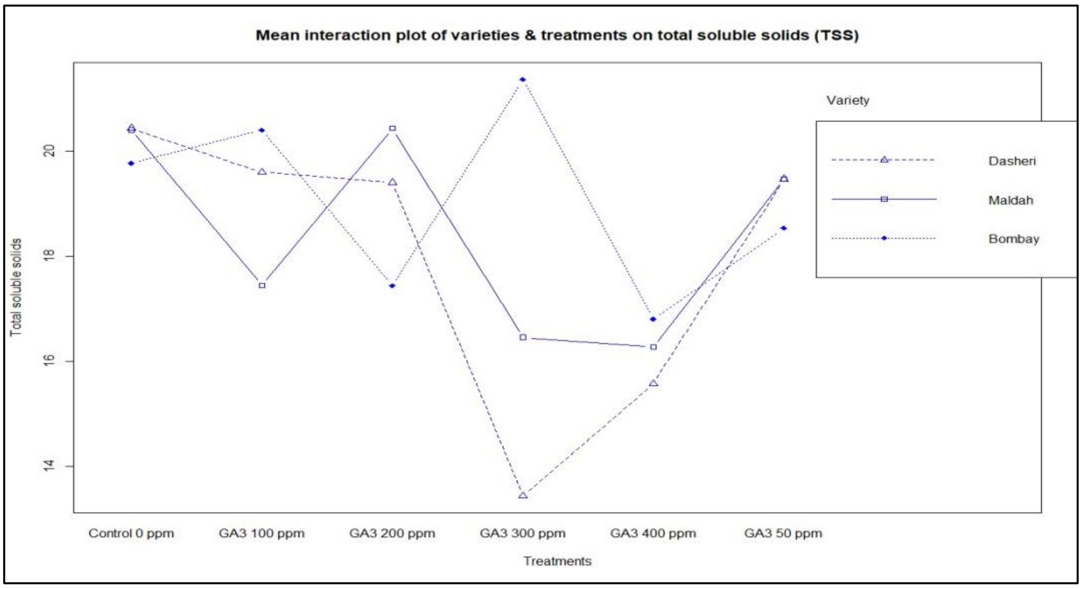

Figure 5. Showing the changes in total soluble solids (TSS) of different varieties of mango in different concentrations of GA_3.

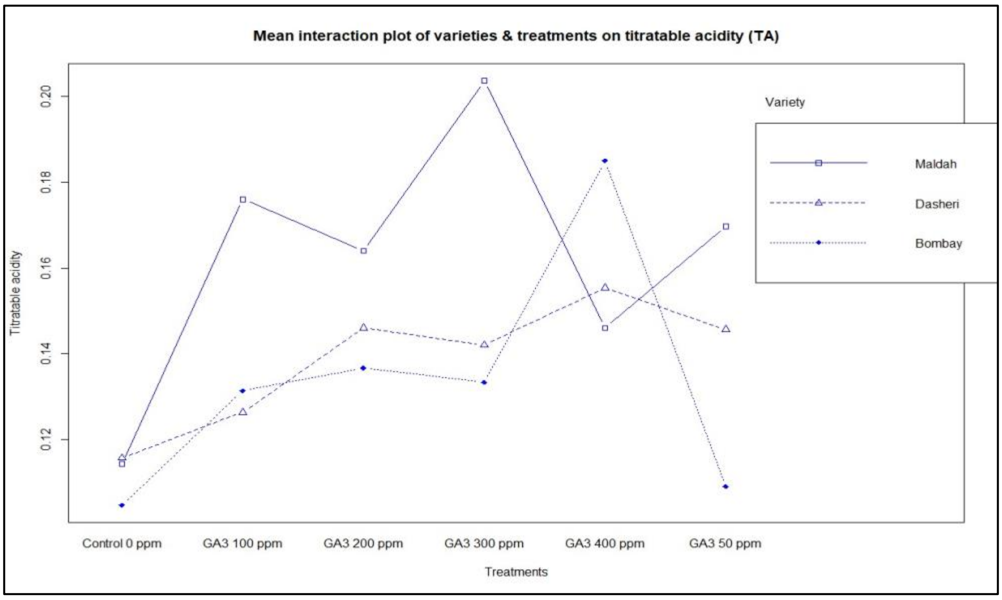

Figure 6. Showing the changes in titratable acidity (TA) of different varieties of mango in different concentrations of GA_3.

Effects of GA_3 on Fruit firmness and Pulp p^H

On the twelfth day after treatment application, a statistically significant variation in fruit firmness was observed across different mango varieties and gibberellic acid (GA3) treatments. The highest fruit firmness (1.14 kg/cm²) was recorded in fruits treated with 400 ppm GA3, while the lowest firmness (0.84 kg/cm²) was observed in the control (0 ppm GA3). Notably, fruit firmness in T4 and T5 was statistically similar on the final day of the study. A lower firmness value indicated a more drastic reduction in fruit firmness, which was most evident in the control (T1). The study results, including interactions between mango varieties and GA3 treatments and the trend of firmness changes over the 12-day storage period, are presented in Tables 6, 7, and Figure 7. Similarly, a highly significant variation in pulp pH was observed throughout the study. The control (T1) exhibited the highest pulp pH, followed in decreasing order by fruits treated with 50 ppm, 100 ppm, 200 ppm, 300 ppm, and 400 ppm GA3. By the end of the trial, mangoes treated with 400 ppm GA3 recorded the lowest pulp pH (5.22), whereas the control group had the highest (6.07). The results, including variety-treatment interactions and the trend of pulp pH changes across different GA3 concentrations, are illustrated in Tables 6, 7, and Figure 8.

Table 6. Effect of different concentrations of gibberellic acids on fruit firmness and pulp pH of mango varieties

Varieties	Fruit firmness (Kg/cm^2)			Pulp pH		
	6 DAT	9 DAT	12 DAT	6 DAT	9 DAT	12 DAT
Dasheri	1.82^c	1.33^c	0.89^b	4.51^a	5.07^a	5.82^a
Bombay	1.90^b	1.45^b	1.12^a	4.27^b	4.87^b	5.59^b
Maldah	2.49^a	1.72^a	1.14^a	4.03^c	4.77^c	5.30^c
SEM (±)	0.019	0.022	0.023	0.031	0.032	0.025
$LSD_{0.05}$	0.055	0.064	0.065	0.089	0.093	0.071
F test	***	***	***	***	***	***
Treatments						
$GA3_0$	1.64^d	1.26^d	0.84^c	4.60^a	5.13^a	6.07^a
$GA3_{50}$	1.97^c	1.43^c	0.98^b	4.55^a	5.06^a	5.71^b
$GA3_{100}$	2.09^b	1.51^{bc}	1.11^a	4.35^b	5.05^a	5.55^c
$GA3_{200}$	2.11^b	1.52^{bc}	1.12^a	4.12^c	5.03^a	5.52^c
$GA3_{300}$	2.28^a	1.57^b	1.12^a	4.11^c	4.63^b	5.35^d
$GA3_{400}$	2.35^a	1.72^a	1.14^a	3.90^d	4.54^b	5.22^e
Grand mean	2.076	1.503	1.056	4.275	4.909	5.573
CV (%)	3.988	6.374	8.843	3.120	2.465	1.861
SEM (±)	0.027	0.032	0.032	0.044	0.046	0.035
$LSD_{0.05}$	0.078	0.091	0.092	0.126	0.131	0.100
F test	***	***	***	***	***	***

***Significant at 0.1% level of significance, LSD: Least significant difference, SEM: Standard error of the mean, CV: Coefficient of variation

Table 7. Interaction of different concentrations of gibberellic acids on fruit firmness and pulp pH of mango varieties

Interactions		Fruit firmness (Kg/cm^2)			Pulp Ph		
Varieties	Treatments	6 DAT	9 DAT	12 DAT	6 DAT	9 DAT	12 DAT
Dasheri	$GA3_0$	1.21^h	1.38^{efg}	0.82^{de}	4.62^{abc}	5.80^a	5.47^{de}
	$GA3_{50}$	1.81^{ef}	1.30^{fg}	0.85^{de}	4.63^{abc}	5.14^{cd}	6.27^b
	$GA3_{100}$	1.74^{fg}	1.31^{fg}	0.76^e	4.41^{cde}	5.03^{de}	6.31^b
	$GA3_{200}$	2.14^c	1.31^{fg}	1.08^{bc}	4.49^{cd}	4.94^{def}	5.93^c
	$GA3_{300}$	1.88^{ef}	1.25^{fg}	0.88^{de}	4.75^{ab}	4.86^{efgh}	5.51^{de}
	$GA3_{400}$	2.15^c	1.43^{ef}	0.96^{cd}	4.17^{ef}	4.67^{ghi}	5.42^e
Bombay	$GA3_0$	1.89^{ef}	1.02^h	0.75^e	4.57^{abcd}	4.56^i	6.75^a
	$GA3_{50}$	2.15^c	1.50^{de}	0.88^{de}	4.81^a	4.97^{de}	5.24^{fg}
	$GA3_{100}$	1.90^{ef}	1.23^g	1.38^a	4.50^{bcd}	5.48^b	5.45^{de}
	$GA3_{200}$	2.07^{cd}	1.53^{de}	1.13^b	3.62^g	5.27^c	5.57^{de}
	$GA3_{300}$	1.80^{ef}	1.81^b	1.25^{ab}	4.36^{def}	4.72^{fghi}	5.38^{ef}
	$GA3_{400}$	1.63^g	1.61^{cd}	1.34^a	3.76^g	4.25^j	5.16^g
Maldah	$GA3_0$	1.83^{ef}	1.38^{efg}	0.95^{cd}	4.61^{abc}	5.03^{de}	5.98^c
	$GA3_{50}$	1.95^{de}	1.50^{de}	1.21^{ab}	4.22^{ef}	5.06^{de}	5.63^d
	$GA3_{100}$	2.63^b	1.98^a	1.21^{ab}	4.13^f	4.65^{hi}	4.89^h
	$GA3_{200}$	2.12^c	1.72^{bc}	1.13^b	4.24^{ef}	4.89^{efg}	5.06^{gh}
	$GA3_{300}$	3.17^a	1.64^{cd}	1.23^{ab}	3.24^h	4.31^j	5.16^g
	$GA3_{400}$	3.27^a	2.11^a	1.13^b	3.77^g	4.69^{ghi}	5.08^g
SEM (±)		0.047	0.055	0.055	0.076	0.079	0.061
$LSD_{0.05}$		0.135	0.157	0.159	0.217	0.227	0.174
F test		***	***	***	***	***	***

GA3: Gibberellic acids, ***Significant at 0.1% level of significance, LSD: Least significant difference, SEM: Standard error of the mean

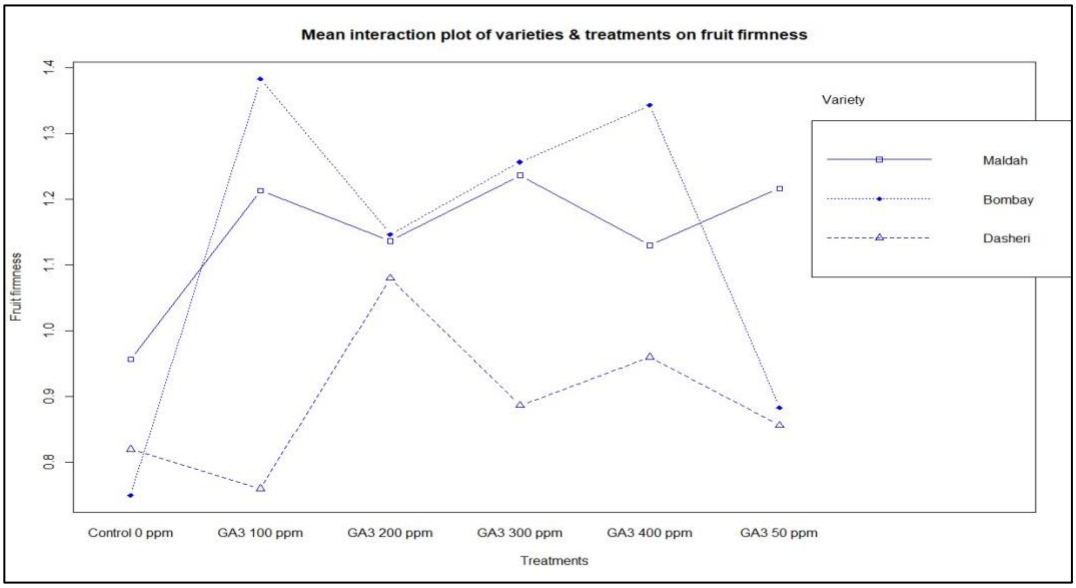

Figure 7. Showing the changes in fruit firmness of different varieties of mango in different concentrations of GA_3.

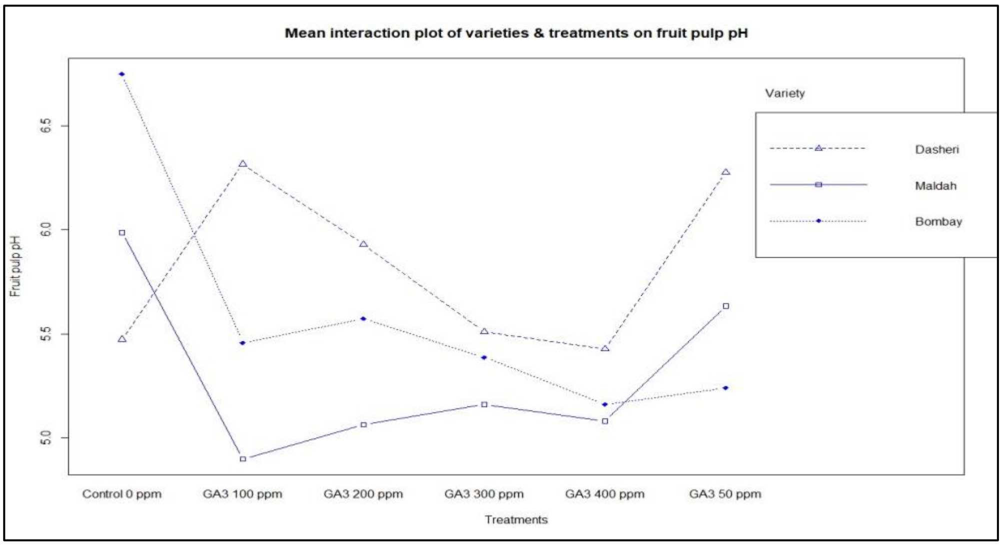

Figure 8. Showing the changes in pulp pH of different varieties of mango in different concentrations of GA_3.

Effects of GA_3 on Palatability and Shelf life

Mango palatability varied significantly across different varieties and gibberellic acid (GA3) treatments by the twelfth day after application. The highest palatability score of 4.16 was recorded in T1 (control), T2 (50 ppm GA3), and T4 (200 ppm GA3), whereas T3 (100 ppm GA3) had the lowest score at 3.66. Meanwhile, T5 (300 ppm GA3) and T6 (400 ppm GA3) had scores of 4.00 on the final day. Throughout the study, palatability generally increased across all treatments except for the control, where the trend remained inconsistent. The results, including interactions between varieties and treatments and changes in palatability over 12 days, are presented in Tables 8, 9, and Figure 9. Shelf life also exhibited notable variations based on the gibberellic acid concentration. Defined as the period in which the fruit retains optimal eating and marketing quality without surpassing 50% deterioration, the shelf life ranged from 12.55 to 15.55 days. Fruits treated with 400 ppm GA3 recorded the longest shelf life at 15.55 days, followed by those treated with 300 ppm (14.66 days), 200 ppm (14.11 days), 100 ppm (13.55 days), and 50 ppm (13.11 days). In contrast, untreated mangoes (control) had the shortest shelf life at 12.55 days. These findings indicate that higher GA3 concentrations play a crucial role in prolonging fruit freshness during storage, as detailed in Tables 8, 9, and Figure 10.

Table 8. Effect of different concentrations of gibberellic acids on palatability score and shelf life of mango varieties

Varieties	Palatability score			Shelf life
	6 DAT	9 DAT	12 DAT	
Dasheri	3.25[b]	3.58[c]	3.75[c]	13.72[b]
Bombay	3.50[a]	4.08[a]	4.08[b]	13.94[ab]
Maldah	3.50[a]	3.83[b]	4.25[a]	14.11[a]
SEM (±)	0.1734	0.2659	0.1778	0.1242
$LSD_{0.05}$	0.0207	0.0214	0.0212	0.3563
F test	***	***	***	*
Treatments				
$GA3_0$	3.16[d]	4.33[a]	4.16[a]	12.55[e]
$GA3_{50}$	3.66[a]	4.00[b]	4.16[a]	13.11[d]
$GA3_{100}$	3.50[b]	3.33[e]	3.66[c]	13.55[d]
$GA3_{200}$	3.66[a]	3.83[c]	4.16[a]	14.11[c]
$GA3_{300}$	3.16[d]	3.50[d]	4.00[b]	14.66[b]
$GA3_{400}$	3.33[c]	4.00[b]	4.00[b]	15.55[a]
Grand mean	3.416	3.833	4.027	13.925
CV (%)	0.925	0.824	0.078	3.663
SEM (±)	0.1415	0.2171	0.1452	0.1757
$LSD_{0.05}$	0.0301	0.0304	0.0324	0.5039
F test	***	***	***	***

*Significant at 5% level of significance, ***Significant at 0.1% level of significance, LSD: Least significant difference, SEM: Standard error of the mean, CV: Coefficient of variation

T

able 9. Interaction of different concentrations of gibberellic acids on palatability score and shelf life of mango varieties

Interactions		Palatability score			Shelf life
Varieties	Treatments	6 DAT	9 DAT	12 DAT	
Dasheri	$GA3_0$	3.5^b	4.0^b	4.0^b	12.33^h
	$GA3_{50}$	3.0^c	3.5^c	4.0^b	13.00^{gh}
	$GA3_{100}$	3.5^b	3.5^c	3.5^c	13.33^{fg}
	$GA3_{200}$	3.5^b	3.5^c	4.0^b	14.00^{def}
	$GA3_{300}$	3.0^c	3.5^c	3.5^c	14.33^{cde}
	$GA3_{400}$	3.0^c	3.5^c	3.5^c	15.33^{ab}
Bombay	$GA3_0$	3.0^c	4.5^a	4.0^b	12.33^h
	$GA3_{50}$	4.0^a	4.0^b	4.5^a	13.33^{fg}
	$GA3_{100}$	3.5^b	4.0^b	4.0^b	13.66^{efg}
	$GA3_{200}$	3.5^b	4.0^b	4.0^b	14.00^{def}
	$GA3_{300}$	3.5^b	4.0^b	4.0^b	15.00^{abc}
	$GA3_{400}$	3.5^b	4.0^b	4.0^b	15.66^a
Maldah	$GA3_0$	3.0^c	4.5^a	4.5^a	13.00^{gh}
	$GA3_{50}$	4.0^a	4.5^a	4.0^b	13.33^{fg}
	$GA3_{100}$	3.5^b	2.5^e	3.5^c	13.66^{efg}
	$GA3_{200}$	4.0^a	4.0^b	4.5^a	14.33^{cde}
	$GA3_{300}$	3.0^c	3.0^d	4.5^a	14.66^{bcd}
	$GA3_{400}$	3.5^b	4.5^a	4.5^a	15.67^a
SEM (±)		0.1001	0.1535	0.1027	0.3043
$LSD_{0.05}$		0.0524	0.0520	0.0517	0.8728
F test		***	***	***	NS

GA3: Gibberellic acids, ***Significant at 0.1% level of significance, NS = Non-significant, LSD: Least significant difference, SEM: Standard error of the mean

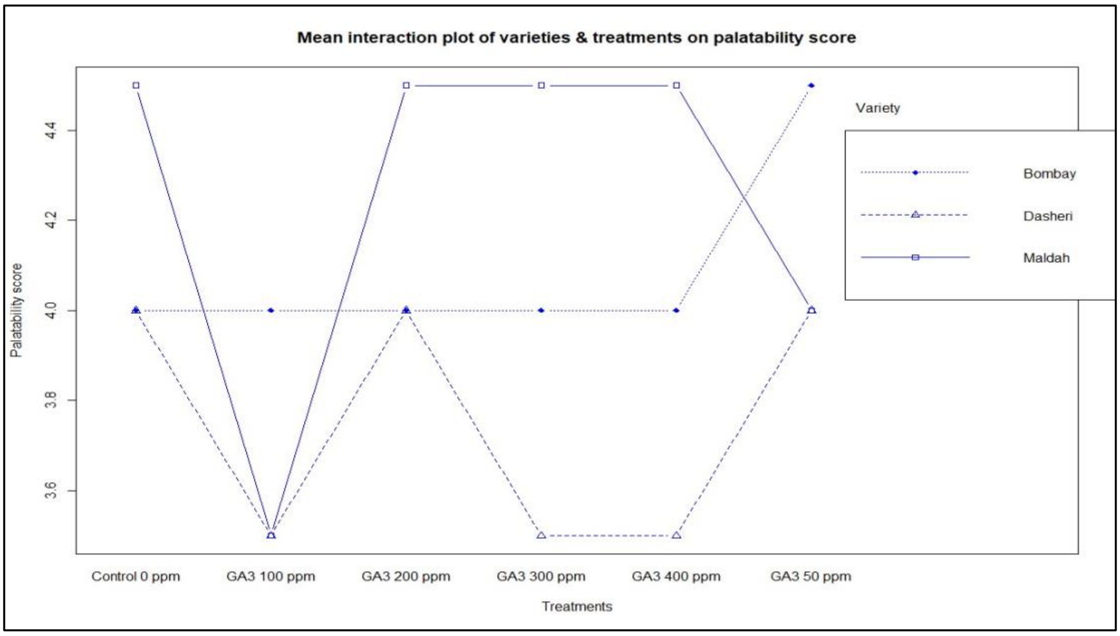

Figure 9. Showing the changes in palatability of different varieties of mangoes in different concentrations of GA_3.

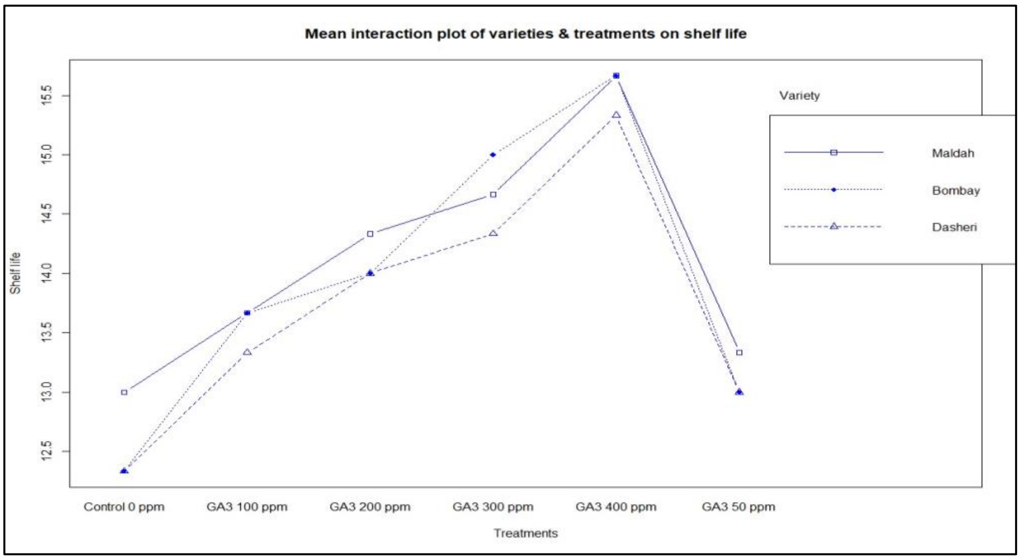

Figure 10. Showing the shelf life of different varieties of mangoes in different concentrations of GA_3

DISCUSSIONS

The findings of this study confirm the efficacy of gibberellic acid (GA3) in extending the shelf life and maintaining the physicochemical qualities of mangoes, aligning with previous research. Yadav et al. (2022) demonstrated that mangoes treated with 400 ppm GA3 exhibited significantly reduced physiological weight loss, which can be attributed to the suppression of respiration and transpiration rates. This effect is crucial in delaying senescence, as excessive water loss leads to shrinkage, textural degradation, and increased susceptibility to microbial spoilage. Similarly, Wahden et al. (2011) emphasized that gibberellic acid functions as a potent ethylene antagonist, delaying ripening and senescence in climacteric fruits. By inhibiting ethylene biosynthesis, GA3 slows down the enzymatic breakdown of cell wall components, including pectin and hemicellulose, thus maintaining fruit integrity for an extended period. Furthermore, the delayed ripening effect of GA3 can be explained by its role in regulating hormonal balance within the fruit. Ethylene triggers the conversion of starch to sugars, leading to rapid softening and degradation of fruit tissue. The anti-senescing properties of GA3 were corroborated by Hu et al. (2018), who demonstrated that GA3 reduces tissue permeability and CO2 production, thereby minimizing water loss during storage. Reduced permeability ensures lower ion leakage, preserving cell structure and delaying the onset of physiological disorders associated with prolonged storage. In the present study, mangoes treated with 400 ppm GA3 exhibited the lowest physiological loss compared to untreated controls. This observation aligns with findings by Chhetri and Ghimire (2023), who reported that GA3 significantly reduced weight loss by slowing down metabolic activities and the enzymatic conversion of starch to sugars. A possible explanation is that GA3 alters the activity of hydrolytic enzymes such as amylases and invertases, thereby regulating the rate at which carbohydrates are stored during respiration. Additionally, the study found that GA3-treated fruits maintained lower pulp pH levels over the storage period. According to Jain and Mukherjee (2000), this effect is due to the delayed oxidation of organic acids, preventing a rapid increase in pH during ripening. Penyimpenan (2013) also noted similar outcomes, highlighting GA3's ability to stabilize pulp acidity by inhibiting metabolic pathways responsible for acid degradation. This is particularly significant since Tosun (2008) established an inverse correlation between pulp pH and titratable acidity, where higher acidity enhances storage quality. The present results suggest that GA3 treatments effectively preserved titratable acidity by minimizing respiration-driven consumption of organic acids, a phenomenon similarly observed by Pal (1998) in other tropical fruits. The reduction in titratable acidity observed in this study aligns with findings by Fatima et al. (2022), who reported that GA3 slows the metabolic conversion of acids into sugars, prolonging the desirable characteristics of fruits during storage. Mango firmness was significantly higher in GA3-treated fruits, consistent with reports by Porat et al. (2001) and Reddy et al. (2014). This outcome is likely due to the inhibition of ethylene synthesis and the subsequent reduction in enzymatic activity responsible for the degradation of cell wall components such as cellulose, hemicellulose, and pectin. Wang et al. (2018) elaborated on this by showing that GA3 modulates ripening-related gene expression, leading to delayed softening. Another possible reason for maintained firmness is the strengthened interactions between cell wall polymers, which prevent rapid textural degradation. Vishwakarma et al. (2022) further provided evidence that GA3-treated mangoes exhibit superior resistance to physiological degradation, likely due to its ability to enhance cell wall reinforcement through calcium retention and lignification processes. Similarly, Panigrahi et al. (2021) explored the application of GA3 coatings and demonstrated their effectiveness in enhancing postharvest quality by reducing surface moisture loss and microbial colonization. These findings are particularly relevant in the present study, where the inhibition of microbial decay in GA3-treated fruits suggests a role in reinforcing fruit cuticle integrity. Additionally, Siddiqui et al. (2013) reported that GA3, when applied as a pre-harvest spray, not only delayed ripening but also preserved the biochemical composition of fruits by maintaining antioxidant enzyme activity. This aligns with the present findings, where the application of 400 ppm GA3 significantly delayed the accumulation of total soluble solids (TSS) by modulating the enzymatic conversion of starch into sugars. The observed decline in TSS at later storage stages can be attributed to respiratory utilization, as noted by Singh et al. (2019), who explained that during prolonged storage, the respiratory process consumes soluble sugars, leading to a subsequent decline in sweetness. The decline in TSS may also be linked to the delayed hydrolysis of polysaccharides due to GA3's impact on amylolytic enzymes. Finally, the study observed a consistent pattern of reduced metabolic activity in GA3-treated mangoes, which is crucial for extending storage life. This aligns with insights by Reddy and Haripriya (2002), who emphasized that GA3 blocks enzymatic pathways responsible for rapid ripening, thereby mitigating weight loss and quality degradation. Moreover, GA3's role in maintaining chlorophyll stability and delaying anthocyanin synthesis provides an additional explanation for delayed visual ripening and prolonged marketability. These findings collectively underscore the multi-faceted role of GA3 in postharvest management by modulating ethylene synthesis, enzyme activity, organic acid metabolism, and structural integrity of cell walls. The results suggest that GA3 treatments could be an effective postharvest strategy to enhance the storability and quality retention of mangoes, making them more appealing for commercial supply chains.

CONCLUSION

The findings of this study suggest that applying different concentrations of GA3 effectively extends the shelf life of mangoes by delaying ripening, with fruits remaining fresh for an additional 4 to 7 days. Mangoes treated with 400 ppm GA3 exhibited the longest shelf life, lasting nearly 16 days, while untreated mangoes deteriorated within 12 days. Physiochemical traits such as physiological weight loss, total soluble solids (TSS), and pulp pH increased rapidly in untreated mangoes, whereas titratable acidity declined sharply. In contrast, GA3-treated mangoes retained better firmness, lower TSS accumulation, and stable titratable acidity, suggesting reduced metabolic activity and ethylene suppression. The study highlights 400 ppm GA3 as the most effective concentration for maintaining postharvest quality and commercial value. However, certain limitations exist, as the findings are based on a specific cultivar, postharvest handling conditions, and environmental factors that may influence outcomes. Future research should explore varietal responses, economic feasibility, and the integration of GA3 with other postharvest treatments to optimize its practical application. Overall, GA3 treatment, particularly at 400 ppm, proves to be a promising approach for reducing postharvest losses and enhancing the storage potential of mangoes.

Compliance with Ethical Standards

Peer-review

Externally peer-reviewed

Declaration of Interests

The authors declare that they have no conflict of interest.

Author Contribution

Daurik Lal Pandit & Dipesh Kumar Mehata: Conceptualization, data curation, investigation, methodology, visualization, original draft writing, review and editing of writing, and validation. **Shafat Rukhsar, Pawan Kumar Yadav, Vivek Lahutiya:** Data curation, methodology, writing original draft. **Sunny Kumar Shah & Umesh Timilsina:** Supervision & Validation

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