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Changes of physico-chemical parameters in relation to storage time and temperature of mango fruit cv. Kent harvested in northern Côte d'Ivoire for export purposes

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Abstract

The aim of this study was to evaluate the physicochemical parameters of mangoes for export. The results revealed that mangoes lose firmness after three days of storage and the pulp turns yellow-orange. The sugar content increases progressively along storage time. However, phenylalanine ammonia-lyase (PAL) activity decreases with storage time confirming the decrease of phenol content. As for the activity of polyphenoloxidases (PPO) and peroxidases (POD), it increased during the storage of mangoes suggesting a degradation of phenolic compounds during storage. Furthermore, the study reported a loss of firmness inversely proportional to the time (7, 14, 21-days) and temperature (4, 10, 14 °C) of mango storage. The pulp of mangoes stored at low temperature started to show orange color after 14 days of storage at 10 °C and after 7 days of storage at 14 °C. The sugar content of mangoes stored at 14 °C was higher than that of mangoes stored at 4 and 10 °C. Similarly, phenol content, PAL, PPO and POD activities were lower at 4 and 10 °C and high when mangoes were stored at 14°C. Therefore, storage time and temperature influence harvested mangoes physico-chemical parameters of mangoes. High storage times and temperatures promote rapid ripening of mangoes by increasing sugar content and color, and decreasing pulp firmness. Furthermore, phenol synthesis decrease and oxidation increase was observed. Also, low temperatures delay ripening and preserve the quality of mangoes for up to 21 days. This makes it possible to envisage an export without deterioration of mangoes, which requires a maritime transport of 14 days.

Keywords: Côte d'Ivoire; Cultivar Kent; Mango; Physicochemical parameter; Storage time; Temperature

1. Introduction

Mango is the most consumed tropical fruit in the world after banana. Its juicy orange flesh is a good source of fiber, vitamin C, sugars, organic acids, phenolic antioxidants that give it exceptional nutritional quality (1). Mango is a climacteric fruit, whose ripening process begins on the tree and continues after harvesting therefore has the ability to continue its ripening in storage (2). Harvested too early, the mango fries without really ripening; harvested too late, its

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shelf life will be too short to support long-distance transport (3). With an average production of 150,000 tons annually, mango plays an important role in the economy of Côte d'Ivoire in general and the northern region in particular (4). The country exports about 10% of its production to the European market and is the largest mango exporting country in West Africa (5). Mango is the third largest export fruit from Côte d'Ivoire after pineapple and banana. During the mango season in the northern production area of Côte d'Ivoire, exporters receive the harvested fruit and store it in the warehouse at 27 °C before packaging it in refrigerated containers for transfer to the port of Abidjan and then for shipment to Europe (6). Upon arrival, the mangoes are placed at a temperature of 20-22 °C and then distributed on the areas for sale. All these temperature variations and storage times can lead to physicochemical changes in mango and cause deterioration of the commercial or organoleptic quality, i.e. physicochemical parameters (7). Besides, mango is consumed fresh and can be used by the processing industry at different stages of growth, ripeness and maturation. Products prepared from mangoes are very popular abroad (8). Therefore, harvested mangoes are processed and stored in order to send them to distant markets. During fruit ripening, softening occurs due to enzymatic degradation of cell walls (9). As a result, fruit firmness decreases as the fruit becomes more mature and decreases rapidly as it ripens. To ensure the supply of high quality fruit abroad, it is important that the fruit be well preserved with appropriate ripeness (10). Physical appearance, i.e., firmness and color of the pulp, taste, i.e., level of sweetness and presence of antioxidants, etc., depend on the storage conditions of the fruit. On the other hand, poor fruit storage leads to early ripening with greater susceptibility to diseases (11,8). Moreover, fruit softening causes physical damage during handling (12). Thus, for delivery of good quality fruit abroad, it is important to ensure that textural changes during storage are minimal during transportation (13). Indeed, texture perception is an important factor in assessing fruit quality (14) and is critical in determining the acceptability of fresh fruit . Indeed, it has been reported that mango firmness, pulp coloring and sensory attributes vary with storage time and temperature (15). Therefore, the objective of this study was to investigate the effect of mango storage time and temperature on physicochemical parameters in order to provide a quality product for export.

This study will eventually allow the control of firmness, pulp color, sweetness and variations in phenolic antioxidants of mangoes during post-harvest. This, with the aim of minimizing losses on arrival on export markets due to rapid ripening of mangoes. This will lead to an extension of the commercial life and guarantee the market share of Côte d'Ivoire for mangoes in export.

2. Material and methods

2.1. Plant material

An important export cultivar of Ivorian mango, namely ''Kent'' was used for the experiments. Mangoes were harvested from an orchard in Lavononka (9°22'56"N; 5°33'39"W), Korhogo department in northern Côte d'Ivoire. They were homogeneous, ovoid-shaped, relatively large, weighing between 500 and 900 g and physiologically mature.

2.2. Methods

2.2.1. Mango sample

The mangoes selected for the study were harvested at the same time and brought to the warehouse on the same day. They were sorted and treated according to the criteria used by the exporters before export were treated as before export. Briefly, mangoes were washed in a bowl containing hot water, disinfected with chlorinated water and then rinsed with water (16). The mangoes are finally wiped with clean sponges and conditioned in a packhouse carton.

Afterwards, 15 lots of 36 mangoes were constituted, including a control which was stored at 27°C. The other 14 lots were separated into two groups. The first group consisting of 5 lots was stored at 27°C for 5 days. The second group consisting of 9 lots was transferred to a refrigerator set at 4, 10 and 14°C, respectively. Mangoes were stored in each condition for 7, 14, and 21 days. The experiments were triplicate.

2.2.2. Determination of mango firmness

A firmness tests were performed using arbitrary scores assigned to the different firmness stages after being assessed by touch at three sections, top, middle and bottom after each storage. So, five stages were chosen to characterize the firmness of the studied mangoes. Score 1 = very firm mango; score 2 = firm mango; score 3 = slightly soft mango; score 4 = soft mango; score 5 = very soft mango.

2.2.3. Determination of mango pulp color

Pulp colour of mango was determined on the middle of the fruits cheek using the visual techniques. In general, mean color hue was quantified by visual techniques. Thus, six stages were chosen to characterize the degree of coloration of the mango pulp after each experiment. The scored vissually are: score 1 = pale yellow; score 2 = light yellow; score 3 = bright yellow; score 4 = a slightly soft mango; score 4 = orange-yellow coloration; score 5 = coloration; score 6 = dark orange coloration.

2.2.4. Determination of total soluble sugar content

The soluble sugars content was determined according to the method of **17**. An amount of approximately 5 g of mango pulp was mixed with 10 mL of 95% ethanol (v/v). The mixture wa filtered under vacuum and the extraction residue was washed twice with 5 ml of 80% ethanol and the final volume was made up to 15 ml with 50% ethanol. A centrifugation at 5,000g was performed and the supernatant was recovered. Afterward, 0.2 mL of the supernatant was treated with 0.2 mL of 5% phenol and 1 mL of concentrated sulfuric acid. After 5 min of incubation in a boiling bath, the mixture was then incubated in the dark for 30 min and 2 mL of water was added. The absorbance was measured at 480 nm using a visible spectrophotometer. The contents of soluble sugar were determined using glucose standard and expressed as milligrams per gram FW.

2.2.5. Determination of total phenols content

To extract the total phenolic compounds, an amount of 0.5 g of mango pulp was mixed with 5 mL of 95% ethanol (v/v). The mixture was centrifuged for 10 min at 15,000×g and the supernatant was recovered. An aliquot (0.5 mL) of supernatant was added with 5 mL of distilled water and 0.5 mL of Folin-Ciocalteu reagent. The mixture was left to stand for 5 min, and then 1.5 mL of 17% sodium carbonate was added. After agitation, the reaction mixture is divided into two lots. To one of both lots, 0.1 g of polyvinylpyrrolidone (PVP) was added and the mixture was centrifuged as before. Both lots are kept in the dark for 10 min and the optical density was measured at 725 nm using the visible spectrophotometer according the method of **18**. The difference between of phenols without PVP and with PVP represents the phenolic content, which was reported milligrams per gram FW using gallic acid as the standard.

2.3. Extraction of enzymes

The enzymes were extracted by grinding 0.5 g of mango pulp in extraction buffer at 4° C supplemented with 0.5% of polyethylene glycol 6000 (PEG 6000), 0.25% of sodium thiosulfate, 15% of glycerol, 15 mM of mercaptoethanol and 2% of EDTA (ethylene diamine tetraacetic acid). Mixing was centrifuged at 5,000 rpm for 20 minutes at 4° C by previously adding 0.5 mL of Dowex-2. The supernatant called crude enzyme extract was collected and stored at -25° C in a freezer for the analyzes.

2.3.1. Phenylalanine ammonia-lyase assay

Phenylalanine ammonia-lyase (PAL) activity in the buffer supernatant was determined by the production of cinnamic acid, as measured by the absorbance change at 290 nm (19). The assay mixture contained 1 mL of 0.1 M phenylalanine, 1.9 mL of 0.2 M sodium borate buffer (pH 8.8) and 0.1 mL of enzyme extract, in a total volume of 3.0 mL. The reaction was carried out at 40 °C for 30 min and terminated by the addition of 0.05 mL of HCl 3N. PAL activity was calculated based on the molar extinction coefficient of 19,600 $mM^{-1}cm^{-1}$ for cinnamic acid and expressed in millimole per minute per milligramme of fresh material (mM/min/g FM). For the control, phenylalanine was replaced with the sodium borate buffer.

2.3.2. Tyrosine ammonia-lyase assay

Tyrosine ammonia-lyase (TAL) activity was performed using the method of 20. The essay mixture consisting of 1 mL of 0.1 M tyrosine, 1.9 mL of 0.2 M sodium borate buffer (pH 8.8) and 0.1 mL of enzyme extract, in a total volume of 3.0 mL. After 30 min at 37°C, the reaction was stopped by the addition of 0.05 mL of HCI 3N. TAL was assayed spectrophotometrically at 310 nm following the formation of p-coumaric acid. The molar extinction coefficient of p-coumaric acid in assay buffer plus HCI was determined to be 17,600 $mM^{-1}cm^{-1}$. TAL activity was expressed as millimoles of p-coumaric formed per minute per milligramme of fresh material (mM/min/g FM). For the control, tyrosine was replaced with the sodium borate buffer.

2.3.3. Polyphenoloxidase assay

Polyphenoloxidase (PPO) activity was assayed following the method of 21 with minor modifications. Phosphate citrate buffer solution pH 6.5 (0.1 M, 1.9 mL), 1 mL of 0.1 M catechol as a substrate and 0.1 mL of the enzyme extract were pipetted into a test tube and mixed thoroughly. The reaction mixture was incubated for 10 min at room temperature. The oxidation of catechol was monitored with a spectrophotometer at 500 nm. PPO activity was calculated based on the molar extinction coefficient of 3400 $mM^{-1}cm^{-1}$ for catechol and expressed in millimole per minute per milligramme of fresh material (mM/min/g FM). For the control, catechol was replaced with the phosphate citrate buffer.

2.3.4. Peroxidase assay

Peroxidase (POD) activity was measured according to the method described by (22) with minor modifications. The reaction mixture contained 1.5 mL of 0.1 M sodium phosphate buffer, 1 mL of 25 mM guaiacol and 0.1 mL of extract enzyme. The reaction was initiated upon addition of 0.4 mL of hydrogen peroxide (10^{-2} M). The mixture was incubated for 5 min in the dark to prevent partial destruction (by light) of the red-brown oxidation product formed from guaiacol in the presence of hydrogen peroxide. POD activity was spectrophotometrically measured at 470 nm following the formation of tetragaiacol. POD activity was calculated based on the molar extinction coefficient of 26.6 mM^{-1} cm^{-1} for guaiacol and expressed in millimole per minute per milligramme of fresh material (mM/min/g FM). For the control, catechol was replaced with the sodium phosphate buffer.

2.4. Statistical analysis

All experiments were conducted in triplicate and all results were expressed as the average ±standard deviation of the measurements. Statistical analyses were performed using Statistica 7.1 software. An analysis of variance (ANOVA) was performed on all treatments applied. When this analysis showed a difference between the means, Tukey's HSD test was carried out to determine the significant differences between the treatments at the 5 % level.

3. Results

3.1. Change in physicochemical parameters of mango during storage time at 27 °C

3.1.1. Firmness and pulp color of mangoes

The mangoes was initially very firm during the first two days of storage at 27 °C. From the 3rd day onwards, the mangoes begin to soften. Indeed, they went from slightly soft to soft on the 4th day and then to very soft after 5-days of storage (Table 1).

Regarding the coloration of mango pulp, results show that it is light yellow during the first two days of storage at 27 °C. Then, the coloring of the mango pulp becomes bright yellow after 3 and 4 days of storage. Thereafter, the mango pulp turns orange yellow on the 5th day of storage at 27°C (Table 1).

Table 1 Firmness and pulp color of mangoes in relation to storage time at 27 °C

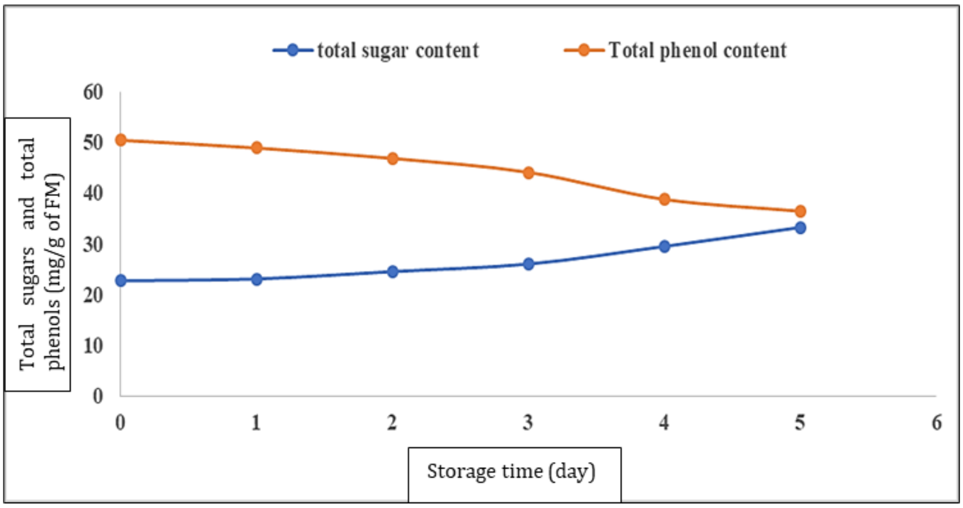
Lot of mangoes	Storage time (day)	Firmness	Pulp color
M0	0	1	2
M1	1	1	2
M2	2	1	2
M3	3	2	3
M4	4	2	3
M5	5	3	4

Arbitrary firmness scale: 1 = very firm; 2 = firm; 3 = slightly soft; 4 = soft; 5 = very soft; Arbitrary colors scale: 1 = pale yellow color; 2 = light yellow color; 3 = bright yellow color; 4 = orange-yellow color; 5 = orange color; 6 = dark orange color.

3.1.2. Sugar and phenol content in mango

Total sugar and phenol content of mangoes stored at 27 °C varies in the opposite way over time (Figure 2). In fact, total phenols, with starting content of 50.45 mg/g FM gradually decreases over the days of storage to be 33.50 m/g FM after 5-days of storage. On the other hand, the sugar content which was 22.72 mg/g FM at the beginning of storage was increased significantly to reach 33.25 mg/g FM after 5-days of storage.

The analysis of the figure also revealed that the evolution of the content of the both compounds in the mangoes can be divided into three stages: storage time of 1-3 days where the content has changed slowly, 3-4 days where the content changes abruptly and the 5th day where the phenol and sugar contents join to be statistically identical.

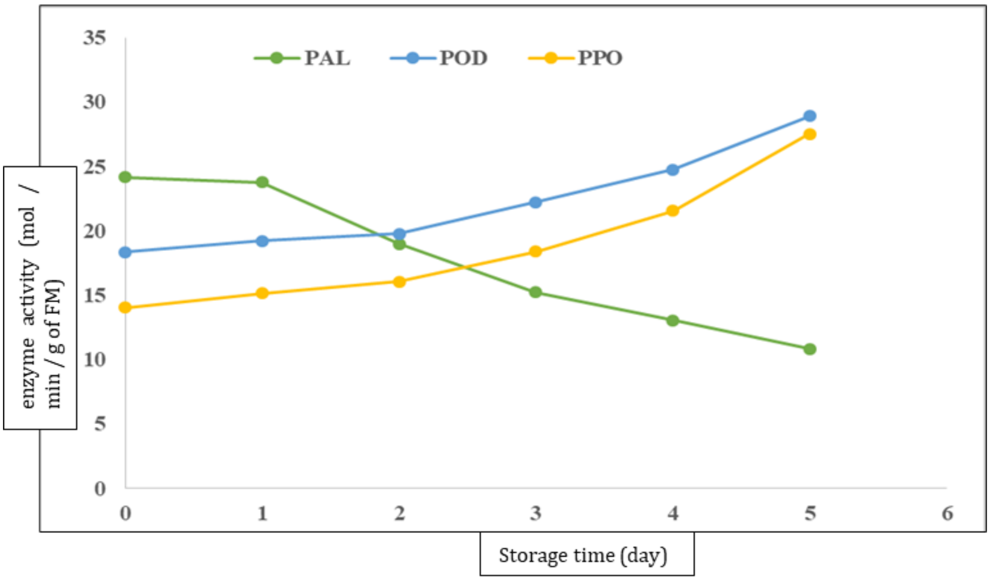


Values followed by the same letter are not significantly different (Tukey's HSD test at 5%); FM, fresh material

Figure 1 Total sugar and phenol content change in relation to storage time at 27 °C

3.1.3. Enzyme activity of mango during storage time at 27 °C

The analysis of Figure 3 shows the evolution of phenylalanine ammonia-lyase (PAL), peroxidase (POD) and polyphenoloxidase (PPO) activities as a function of storage time at 27°C. PAL activity initially significantly greater followed by POD and PPO fell progressively after one day of storage to be the lowest at 5-days (10.54 mM/g/FM). For POD and PPO, their activity were similar evolved during the storage period. However, the POD activity is higher than that of PPO, except on 5th day where no significant difference was observed between them (28.93 and 27.51 mM/g/FM, respectively).



Values followed by the same letter are not significantly different (Tukey's HSD test at 5%); FM, fresh material

Figure 2 Enzymes activities change in mango during storage time at 27 °C

3.2. Effect of storage time on the physicochemical parameters of cold-treated mango

3.2.1. Firmness

Table 2 shows that after 7 days of storage, the firmness of the mangoes changes little at 4°C. In addition, mangoes stored at 10 °C change from firm to slightly soft, except for mangoes exposed first at 27 °C for 5 days (M5) before being stored at low temperature. The same applies to mangoes stored at 14 °C. For mangoes stored for 14 and 21 days, the temperature of 4 °C, firmness varies slightly from firm to slightly soft then soft for mangoes previously for 0 to 2 on the one hand and 3 to 4 days on the other hand. At mangoes pre-preserved for 5 days at 27 °C, they become very soft.

Table 2 Firmness change of mango during storage time under low temperatures

Firmness of mangoes					
Lots of mangoes	**Temperature (°C)**	**Storage time (days)**			
		0 (control)	**7**	**14**	**21**
M0	4	1	1	2	3
	10	1	2	3	3
	14	1	2	3	3
M1	4	1	1	2	3
	10	1	2	3	3
	14	1	3	3	4
M2	4	1	2	2	3
	10	1	3	3	4
	14	1	3	4	4
M3	4	2	2	3	3
	10	2	3	3	4
	14	2	3	4	4
M4	4	2	2	3	3
	10	2	3	3	4
	14	2	3	4	4
M5	4	3	3	3	4
	10	3	4	4	5
	14	3	4	5	5

Arbity firmness scale: 1 = very firm; 2 = firm; 3 = slightly soft; 4 = soft; 5 = very soft.

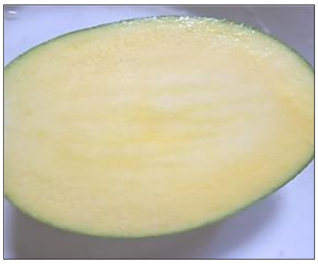
3.2.2. Mango pulp color

The color of mango pulps after storage at 4, 7 and 14°C for 7, 14 and 21 days was reported in Table 3. Indeed, the mango pulps changes after 7 days of storage at low temperatures, except for mangoes that have not been stored (M0) and stored at 4 °C. At this temperature, the coloration of the pulp of the M0 mangoes changes little up to 21 days of storage. For storage at 10°C, the pulp of all mangoes becomes orange yellow from the 14th day and remains until the 21st day. For mangoes pre-exposed for 1 to 2 days at 27°C (M1-M2), the color of the pulp changes from bright yellow to orange yellow from 4 to 14°C, regardless of the storage time. For mangoes pre-stored at 27 °C for 3-5 days (M3-M5), the pulp turns yellow-orange after 14 and 21 days of storage (Figure 3). It should be noted that at 10 °C, the coloration of mango pulp is less intense than at 14 °C. In addition, the pulp of the mangoes pre-exposed at 27° C. becomes dark orange for storage at 14 °C for 21 days.

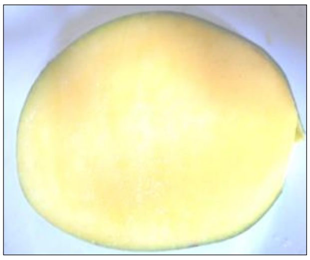
Table 3 Pulp color of mango during storage time under low temperatures

Pulp colour of mangoes					
Lots of mangoes	**Temperature (°C)**	**Storage time (days)**			
		0 (control)	**7**	**14**	**21**
M0	4	2	2	2	3
	10	2	3	4	4
	14	2	3	4	4
M1	4	2	3	3	3
	10	2	3	4	4
	14	2	3	4	4
M2	4	2	3	3	3
	10	2	3	4	4
	14	2	3	4	4
M3	4	3	3	3	4
	10	3	3	4	5
	14	3	4	4	5
M4	4	3	3	4	4
	10	3	4	4	5
	14	3	4	5	5
M5	4	4	4	4	5
	10	4	5	5	6
	14	4	5	5	6

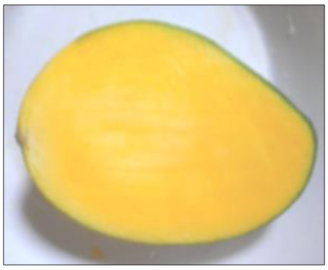
Arbitrary colors scale: 1 = pale yellow color; 2 = light yellow color; 3 = bright yellow color;4 = orange-yellow color; 5 = orange color; 6 = dark orange color.



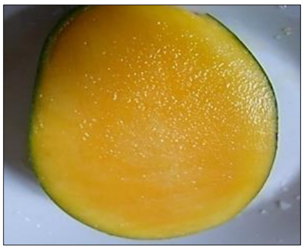
Pale yellow color (27 °C; 0-day)



Light yellow (4 °C; 7-days)



Bright yellow color (10 °C; 14-days)



Orange yellow color (14 °C; 14-days)

Figure 3 Some aspects of mango pulp during storage time under low temperature

3.2.3. Total sugar content

The analysis of Table 3 was showed that the total sugar content of mangoes increases during storage under all conditions. However, this increase was low in mangoes stored at 4 °C, but changes with storage time. For mangoes M0, which had at the beginning of the conservation a total sugar content of 22.72 mg/g FM, contain 26.86 and 31.46 mg/g FM of total sugars after respectively 14 and 21 days of storage at 4 °C. Similarly, the total sugar content increases significantly at 10, 14°C, and increases with storage time. In general, the total sugar content of mangoes is proportional to the temperature and storage time. Thus, the lower the temperature, the lower the total sugar content. This is the same for the storage time.

On the other hand, when mangoes are pre-stored before cold treatment, the total sugar content increases with the pre-storage time. Thus, mangoes preserved at 4 °C are the least sweet, followed by 10 °C and 14°C. In addition, mangoes preserved for 21 days are sweeter than those preserved for 14 days followed by 7 days. Moreover, mangoes pre-stored at 27 °C for 5 days (M5) and then stored at 14 °C have a total sugar content that varies from 33.05 to 65.48 mg/g FM. In all cases, the table shows that mangoes that have been stored for a longer period of time (27°C) have a high total sugar content.

Table 4 Total sugar content in mango during storage time under low temperatures

Total sugar content (mg/g of FM)					
Lot of mangoes	**Temperature (°C)**	**Storage time (days)**			
		0 (control)	**7**	**14**	**21**
M0	4	22.72 ±1.79aA	23.70±0.48aA	26.87± 0.57bA	31.47±0.10cA
	10	21.80 ±1.12aA	26.36±0.41bB	31.09±2.09cB	38.09±1.16dB
	14	22.66 ±1.47aA	28.63±0.44bC	36.81±0.88cC	47.01±0.38dC
M1	4	23.07 ±0.82aA	25.41±0.44bA	29.76± 0.26cA	34.45±0.50dA
	10	22.91 ±0.41aA	28.52±0.45bB	31.50±1.63cA	37.72±0.48dB
	14	23.19 ±0.99aA	29.71±1.39bB	38.57±0.23cB	48.18±1.10dC
M2	4	24.52 ±0.171aA	27.08±0.06bA	30.86±0.77cA	34.48±0.03dA
	10	24.33 ±0.95aA	31.74±0.38bB	35.54±0.61cB	40.18±0.83dB
	14	24.77 ±0.43aA	34.66±0.90bC	39.35±0.50cC	49.56±0.44dC
M3	4	26.01 ±0.13aA	29.13±0.19bA	33.55±0.67cA	37.72±0.39dA
	10	26.20 ±0.25aA	32.41±0.13bB	37.46±0.46cB	46.08±0.60dB
	14	26.15 ±0.77aA	36.72±0.15bC	41.34±0.08cC	50.55±1.40dC
M4	4	29.49 ±1.08aA	34.16±0.13bA	37.73±0.36cA	40.84±0.63dA
	10	29.01 ±1.70aA	35.48±0.73bB	40. 70±0.60cB	49.74±0.35dB
	14	28.89 ±1.801aA	39.19±0.02bC	45.72±0.258cC	57.46±0.22dC
M5	4	34.25 ±0.22aA	37.28±0.24bA	40.59±0.23cA	44.61±0.45dA
	10	32.97 ±0.79aA	39.69±0.17bB	45.45±1.55cB	53.17±0.14dB
	14	33.05 ±0.95aA	43.39±0.34bC	54.37±0.27cC	65.48±0.31dC

Values followed by the same lowercase letter in the same row and by the same uppercase letter in the same column in each batch of mangoes are not significantly different (Tukey's HSD test at 5%)

3.2.4. Total phenol content

Table 5 reported that the total phenol content in mangoes decreases with storage time. It is observed that this decrease is less important in mangoes stored at 4 °C than at 10 °C and 14 °C. In addition, the total phenol content of mangoes was statistically identical from 0 to 7 days. Mango M0 that had at the start of storage a total phenol content of 50.45 mg/g

FM, now contained 47.73 and 42.46 mg/g FM of total phenols after 14 and 21 days of storage at 4 °C respectively. Similarly, the total phenol content decreases significantly at 14 and 21 days. However, there was little change with storage temperature. Furthermore, a significant decrease of total phenols was observed when mangoes are pre-stored at 27 °C. This decrease is proportional to the storage time. Thus, mangoes pre-preserved for 5 days (M5) and then stored at 14 °C have a total phenol content that evolves from 36.99 to 27.96 mg/g FM. In all cases, the longer the mangoes are stored (27 °C), the lower their total phenol content and this almost independently of the storage temperature.

Table 5 Total phenols content in mango during storage time under low temperatures

Total phenol content (mg/g FM)					
Lot of mangoes	**Temperature (°C)**	**Storage time (days)**			
		0 (control)	**7**	**14**	**21**
M0	4	50.45 ±1.40aA	49.29±0.72abA	47.73±0.358bA	42.46±1.16cA
	10	51.05 ±1.66aA	47.54±0.531bA	44.58±0.189cB	40.97±1.17dA
	14	50.15 ±1.38aA	42.55±0.877bB	38.47±0.650cC	34.30±0.14dB
M1	4	48.92 ± 0.63aA	47.22±0.27abA	45.35±2.02bA	42.17±0.90cA
	10	49.12 ± 0.30aA	46.14±1.57bA	42.43±0.16cA	38.34±0.38dB
	14	48.18 ± 0.93aA	42.55±0.88bB	38.46±0.65cB	34.29±0.14dC
M2	4	46.87 ± 0.17aA	46.47±0.46aA	44.49±0.48abA	41.17±1.58bA
	10	46.71 ± 0.21aA	42.99±0.25bB	41.68±0.60bA	38.21±1.18cAB
	14	47.07 ± 0.93aA	43.23±0.55bB	40.44±2.43bcA	38.77±0.16cB
M3	4	44.82 ± 0.45aA	42.42±0.24abA	41.73±1.60bA	38.29±0.35cA
	10	44.22 ± 0.48aA	40.04±0.50bB	37.24±1.75cB	35.48±0.48cB
	14	44.27 ± 0.15aA	38.79±0.60bC	36.39±0.45cB	33.55±1.59dB
M4	4	38.78 ± 0.50aA	36.24±2.01abA	34.263±0.45bA	31.197±0.04cA
	10	38.38 ± 0.84aA	35.33±0.62bA	31.193±1.94cAB	30.160±1.14cA
	14	39.00 ± 0.46aA	33.29±0.46bA	31.78±0.64cB	28.19±0.24dB
M5	4	36.45± 0.64aA	36.53±0.22aA	33.85±0.62bA	31.79±0.40cA
	10	36.85± 0.39aA	32.87±1.12bAB	30.77±0.71cB	29.06±0.36cB
	14	36.99± 0.74aA	34.57±1.21bB	31.79±0.04cB	27.96±0.49dC

Values followed by the same lowercase letter in the same row and by the same uppercase letter in the same column in each batch of mangoes are not significantly different (Tukey's HSD test at 5%)

3.2.5. Phenylalanine ammonia-lyase activity

The activity of phenylalanine ammonia lyase (PAL) in mangoes is presented in Table 6. Its variation was similar to that of the total phenol content of mangoes. Indeed, PAL activity decreases progressively with the storage time and with the pre-storage time at 27 °C. It is observed that this decrease is less significant in the mangoes stored at 4°C than at 10 and 14 °C as previously. PAL activity of M0 mangoes, which was at the beginning of storage at 4 °C of 24.16 mM/min/g FM, increases to 20.60 and 17.95 mM/min/g FM after 14 and 21 days of storage, respectively. However, there was little change with the storage temperature.

In addition, a significant decrease in PAL activity was observed with mangoes pre-stored at 27 °C as a function of time and cold storage temperature. Thus, the mangoes pre-preserved for 5 days (M5) and then stored at 14 °C. have a PAL activity, which varies from 11.03 to 1.71 mM/min/g FM. In short, the longer the mangoes are stored (27 °C), the lower the PAL activity and this is inversely proportional when the storage temperature increases, i.e. from 4 to 10 °C.

Table 6 Change of phenylalanine ammonia-lyase activity in mango during storage time under low temperatures

PAL activity (mM/min/ g FM)					
Lot of mangoes	**Temperature (°C)**	**Storage time (days)**			
		0 (control)	**7**	**14**	**21**
M0	4	24.16 ± 0.96aA	23.88±0.16aA	20.60±0.80bA	17.95±0.12cA
	10	23.96 ± 0.73aA	21.51±0.20bB	17.50±0.44cB	13.98±0.25dB
	14	24.34 ± 0.85aA	19.68±0.60bC	14.62±0.25cC	10.63±0.27dC
M1	4	24.08 ± 1.13aA	22.63±0.22bA	20.73±0.05cA	16.86±0.47dA
	10	23.78 ± 0.73aA	20.71±0.16bB	17.86±0.33cB	12.71±0.38dB
	14	24.06 ± 0.19aA	18.69±0.39bC	16.62±0.24cC	10.92±0.06cC
M2	4	19.65 ± 0.11aA	20.68±0.52aA	17.40±0.40bA	13.82±0.69cA
	10	19.33 ± 0.91aA	19.50±0.15aB	15.52±0.40bB	12.80±0.1cA
	14	18.80 ± 0.51aA	17.56±0.28aC	14.47±0.22bC	10.43±1.25cB
M3	4	15.41 ± 0.73aA	16.84±0.60bA	14.54±0.21cA	11.74±0.60dA
	10	16.12 ± 0.33aA	15.83±0.20bA	11.88±0.25cB	7.61±0.20dB
	14	14.92 ± 0.94aA	13.22±0.11bB	10.11±0.41cC	4.83±0.94dC
M4	4	13.07 ± 0.21aA	15.48±0.32bA	13.60±0.11cA	12.61±0.12dA
	10	12.46 ± 0.21aA	13.38±0.43bB	10.40±0.29cB	6.51±0.06dB
	14	12.95 ± 0.21aA	11.75±0.52bC	9.33±0.28dC	5.89±0.78cB
M5	4	10.84 ± 0.62aA	12.54±0.29bA	11.53±0.352cA	8.57±0.09dA
	10	11.04 ± 0.62aA	10.12±0.05bB	7.57±0.36cB	4.28±0.32dB
	14	11.038 ± 0.62aA	8.21±0.05bC	3.72±0.56cC	1.71±0.14dC

Values followed by the same lowercase letter in the same row and by the same uppercase letter in the same column in each batch of mangoes are not significantly different (Tukey's HSD test at 5%)

3.2.6. Polyphenoloxidase activity

The analysis of Table 7 showed that the activity of polyphenol oxidase (PPO) increases steadily during storage time and with temperature. Similarly, PPO activity evolves significantly with the pre-storage time at 27°C. In addition, PPO activity of mangoes varies from 0 to 7 days. It is observed that this increase in activity becomes greater in the mangoes stored at 14°C followed by 10 and 4°C. The PPO activity of the mangoes M0 that at the start of storage at 4°C was 14.05 mM/min/g FM reaches 18.59 and 21.84 mM/min/g FM after 14 and 21 days of storage, respectively. However, there was little change with the storage temperature.

In contrast, a significant increase in PPO activity was observed with mangoes pre-stored at 27 °C. as a function of time and treated at low temperatures. Thus, the mangoes pre-preserved for 5 days (M5) and then stored at 14 °C. have a PPO activity, which increases from 27.93 to 43.26 mM/min/g FM. Furthermore, PPO activity was found to be positively correlated with the duration of mango pre-storage at 27 °C, temperature increase and storage time.

Table 7 Change of polyphenoloxidase activity in mango during storage time under low temperatures

Polyphenoloxidase activity (mM/min/ g FM)					
Lot of mangoes	**Temperature (°C)**	**Storage time (days)**			
		0 (control)	**7**	**14**	**21**
M0	4	14.05 ±0.75aA	16.71±0.20bA	18.59±0.34cA	21.84± 0.61dA
	10	14.85 ±0.55aA	17.04±0.159bA	22.72±0.756cB	24.63± 0.37dB
	14	14.70 ±0.39aA	18.50±0.71bB	23.54±0.08cC	28.98± 0.24dC
M1	4	15.15 ±0.43aA	16.50±0.30bA	18.23±0.66cA	20.85±0.24dA
	10	15.71 ±0.93aA	19.57±0.32bB	22.60±0.38cB	24.65±0.60dB
	14	15.66 ±0.23aA	21.56±0.46bC	25.07±0.72cC	30.79±0.44dC
M2	4	16.26 ±0.19aA	17.81±0.50bA	20.82±0.43cA	21.56±0.03cA
	10	16.73 ±0.11aA	19.35±0.40bA	23.64±0.57cB	26.69±0.17dB
	14	16.86 ±0.02aA	21.78±0.89bB	25.55±0.25cC	29.91±0.47dC
M3	4	18.41 ±0.41aA	20.21±0.03bA	22.81±0.39cA	23.54±0.33dA
	10	18.81 ±0.22aA	22.55±0.47bB	27.94±0.24cB	31.00±0.10dB
	14	18.01 ±0.98aA	24.81±0.37bC	26.53±0.43cC	32.33±0.13dC
M4	4	22.04 ±0.72aA	23.23±0.62bA	25.32±0.29cA	24.667±0.08cA
	10	21.53 ±0.88aA	25.52±0.31bB	27.74±0.60cB	31.323±0.17dB
	14	22.11 ±0.65aA	26.67±0.31bC	31.60±0.20cC	36.210±0.50dC
M5	4	27.11 ±1.63aA	29.76±0.44bA	31.13±0.12cA	33.78±0.39dA
	10	26.72 ±0.91aA	31.42±0.41bB	33.54±0.46cA	35.61±0.51dB
	14	27.93 ± 0.47aA	33.34±0.30bC	38.22±1.82cB	43.26±0.88dC

Values followed by the same lowercase letter in the same row and by the same uppercase letter in the same column in each batch of mangoes are not significantly different (Tukey's HSD test at 5%)

3.2.7. Peroxidase activity

The peroxidase (POD) activity of mangoes is reported in Table 8, which evolves in a similar manner to that of PPO. Indeed, POD activity increases steadily during storage time and with temperature. Then, it evolves significantly with the pre-storage time at 27° C. Enzyme activity increased in mangoes stored at 14°C followed by 10 and 4 °C. The POD activity of M0 mangoes at 4°C, which was 18.35 mM/min/g FM, increased to 22.57 and 25.02 mM/min/g FM after 14 and 21 days of storage, respectively. In addition, POD activity increases with storage temperature.

Furthermore, a significant increase in POD activity was observed in mangoes pre-stored at 27 °C as a time dependently of time and treated at low temperatures. Hence, the mangoes pre-preserved for 5 days (M5) and then stored at 14 °C. have a POD activity, which increases from 28.77 to 42.71 mM/min/g FM. Finally, it should be noted that the POD activity is positively correlated with the duration of the pre-storage of the mangoes at 27 °C, as well as with the increase in the temperature and the storage time.

Table 8 Change of peroxidase activity in mango during storage time under low temperatures

Peroxidase activity (mM/min/ g FM)					
Lot of mangoes	**Temperature (°C)**	**Storage time (days)**			
		0 (control)	**7**	**14**	**21**
M0	4	18.35 ±0.44aA	20.96±0.32bA	22.57±0.28cA	25.02±0.70dA
	10	18.04 ±0.83aA	21.63±0.29bA	24.71±0.53cB	27.59±0.33dB
	14	17.95 ±0.98aA	34.97±0.83bB	38.97±0.48cC	43.74±0.16dC
M1	4	18.72 ±0.02aA	20.97±0.46bA	23.43±0.54cA	25.47±0.17dA
	10	19.13 ±0.02aA	22.80±0.52bB	25.42±0.30cB	28.78±0.27dB
	14	19.46 ±0.02aA	24.68±0.27bC	29.69±0.52cC	33.56±0.34dC
M2	4	20.14 ±0.18aA	20.64±0.30bA	23.82±0.09cA	25.15±0.11dA
	10	19.85 ±0.71aA	23.37±0.86bB	26.58±0.20cB	29.81±0.59dB
	14	19.43 ±0.82aA	24.34±0.44bB	28.82±0.56cC	35.21±0.06dC
M3	4	22.22 ±0.83aA	24.36±0.52bA	26.67±0.44cA	28.66±0.44dA
	10	22.75 ±0.21aA	25.69±0.21bA	27.26±0.15cA	31.54±0.10dB
	14	22.05 ±0.99aA	28.45±0.27bB	30.89±0.12cB	25.59±0.10dC
M4	4	24.77 ±0.21aA	26.46±0.29bA	28.39±0.38cA	30.62±0.57dA
	10	25.18 ±0.21aA	27.67±0.21bB	31.71±0.39cB	33.52±0.41dB
	14	25.13 ±0.21aA	30.03±0.19bC	32.59±0.16cC	37.45±0.35dC
M5	4	28.93 ±0.47aA	31.67±0.43bA	33.44±0.285cA	35.62±0.65dA
	10	29.12 ±0.83aA	32.60±0.51bAB	35.55±0.30cB	39.51±0.22dB
	14	28.77 ±0.42aA	33.77±0.55bB	39.57±0.41cC	42.71±0.41dC

Values followed by the same lowercase letter in the same row and by the same uppercase letter in the same column in each batch of mangoes are not significantly different (Tukey's HSD test at 5%)

4. Discussion

The physicochemical parameters of mangoes change during storage time at room temperature (27 °C). This evolution, which was weak at the beginning of storage, becomes significant in the course of time. The softening of mangoes, which appears on the 3rd day of storage, was thought to be due to chemical and structural changes in cell wall polysaccharides. In addition, these changes accompany maturation. This would indicate that the ripening of mangoes begins after 3 days of storage at 27 °C in northern Côte d'Ivoire. This loss of firmness was due to the hydrolysis of mango pectins, which are a major component of the cell walls and contribute to the firmness of the fruit (23). In fact, it causes the degradation of the intercellular link leading to the change in texture and therefore the softening of the fruit (24). Then, these mangoes pre-stored at 27 °C were stored at low temperatures (4, 10 and 14°C). They remain practically firm after 7 days of storage. Low temperature storage appears to slow down the metabolic activity of plant tissues, as reported by **2**. However, after 14 days of storage at low temperatures, a significant loss of firmness was observed in mangoes stored at 14 °C. Hydrolysis of mango pectins, which are a major component of cell walls and contribute to fruit firmness, was reported **(23)**. Indeed, it causes the degradation of the intercellular bond thus causing the change in texture and therefore the softening of the fruit (**24**). In addition, mangoes would have lost much water through perspiration, so there would have been a loss of turgor, which is the consequence of changes in the hydrostatic pressure of the parenchymal cells of the fruit according to **25**. Furthermore, the results obtained make it possible to deduce that the respiratory intensity and the ethylene production are higher during storage at 14 °C. than during storage at 4 and 10 °C. Breathing and ethylene promote metabolic reactions such as the degradation of parietal polysaccharides by pectolytic enzymes (26).

Like firmness, the color of the mango pulp changes when the mangoes are stored at 27 °C. This color, which was initially light yellow, turns orange yellow after 3 to 4 days of storage at this temperature. This change in color shows that the mango continues to mature and mature in storage at 27 °C, confirming the climacteric fruit status of this fruit. Thus, there appears to be an intense biochemical activity in mangoes during their conservation and a relationship to the time of conservation. The change in flesh color was increased in mangoes after 7 days of storage at low temperatures, with the exception of mangoes not stored (M0) and stored at 4 °C. The coloration of the mango pulp would be due to compounds such as xanthophylls (yellow pigments), anthocyanins (red and violet pigments), flavonols (yellow pigments), carotenoids (yellow and orange pigments). These pigments give the pulp its more or less dark orange yellow color. Carotenoids are predominant in mango, and the majority compound is propylene carotene. They are responsible for the attractive color of ripe mangoes and their content increases during maturation (27); which translates into a change of color. Thus, the change in color observed at the different conservation temperatures indicates that the mangoes conserved at 14 °C change rapidly towards the ripening stage. For temperatures 4 and 10 °C, this change is almost non-existent during 14 days of storage, thus showing that these two temperatures are ideal for mango storage during exports.

The study showed that the total sugar content changes with mangoes stored at room temperature (27 °C) as a function of time. During this storage, the total sugar content in the mangoes, which was low at the start of storage, becomes significant after 4 days. It continues to increase in mangoes pre-stored at 27 °C and then stored at low temperatures with the storage time as before. However, this increase in the total sugar content is small with mangoes stored at 4 and 10 °C and important for storage at 14°C. This rapid increase in total sugar content could be explained by a high respiratory intensity at 14°C. In fact, this would cause the starch to degrade into simple sugars, thus leading to an increase in the total sugar content. The results of the study are consistent with those of **28** who reported that fruit respiration increases with temperature. In addition, the results showed that the total sugar content of mangoes that took longer to preserve at low temperatures also showed a significant increase in total sugar content. In addition, 29 showed that the variation in total sugar levels corresponded to a significant increase in glucose, fructose and sucrose in mangoes due to hydrolysis of pulp polysaccharides. Similarly, (30) reported that the significant degradation of starch under the action of amylases during maturation results in a significant increase in total sugar content. These total sugar obtained are used in cell combustion or converted into sugar by decarboxylation, in the synthesis of aroma thanks to the activity of enzymes such as esterases (isoamyl acetate). In addition, the total phenol content, the activities of the biosynthetic (PAL) and oxidation (PPO, POD) enzymes also change in mangoes stored at 27°C over time. This phenolic metabolism evolves in a similar manner in mangoes pre-stored at 27°C and then stored at low temperatures with the storage time. According to 31, harvesting mango as a stressor tends to accelerate the maturation process, which would complete phenol metabolism. During mango storage, total phenol content and PAL activity decreased with storage time and temperature. This decrease, which was low at the start of storage, becomes significant after 4 days of storage at 27 °C concomitant changes in the level of PAL activity and phenols are evident in many tissues (32). This allows 33 to argue that PAL is the key enzyme in phenol synthesis. In many cases, this co-evolution is coordinated with the development of other enzymes associated with the phenol biosynthesis pathway. In contrast to PAL activity, PPO and POD activity, considered to be the key enzymes in fruit browning, increases over time during mango storage. This enzyme browning was the main reaction responsible for the alteration of the color of the fruit. This reaction would be responsible for the decrease in total phenol content in mangoes observed during storage at 27°C. In addition, 34 also maintain that the phenol content decreases during the ripening phase. The study showed that this decrease becomes significant after 3 days of storage. In mangoes pre-preserved at 27 °C and then stored at low temperatures, the phenol content was lower at 4 and 10 °C and high for storage at 14 °C. This result is in agreement with those of 35 who showed that the activity of degradation enzymes (PPO, POD) during fruit ripening was high and correlated with environmental factors including temperature. Phenolic compounds are localized in vacuoles and enzymes are located in cellular organelles such as mitochondria, chloroplasts and cytoplasm. The temperature favors the rupture of the cell walls under the action of certain enzymes and the bringing into contact of the enzyme systems and their substrates, which will induce these evolutions. This study indicates that the evolution of sugar levels and that of phenol metabolism are practically weak after storage at 4 °C. for 7 days [35].

This leads to deduce that the physical and chemical parameters of mangoes evolve little at this too low temperature and during this storage time. However, there is evidence that too low temperatures generate often-irreversible defects causing chilling injury to denote symptoms of cold-related illness. This damage may also not be immediately detectable and may appear later or increase when the product was brought back to room temperature (at retail outlets or at the consumer). This may be external damage and/or internal damage (browning); sometimes the damage was not visible but could negatively affect the taste quality of the mangoes.

5. Conclusion

The study showed that the physicochemical parameters of mangoes have a significant change after 3 to 4 days of storage at room temperature (27 °C). Therefore, a maximum storage time of 2 days in storage in warehouse seems to be more appropriate to store mangoes in refrigerated containers for export. This was to increase the commercial life and preserve the taste qualities of mangoes.

At the low temperature storage stage, results indicate that conservation slows down metabolic activity in mangoes. Mangoes pre-stored at 27°C and then stored at low temperatures (4, 10 and 14°C) keep their physicochemical parameters almost intact after 7 days of storage. However, after 14 days, these physicochemical parameters changed significantly in mangoes stored at 14 °C, unlike those stored at 4 and 10 °C. It is therefore advisable to store mangoes at 10°C for export. Indeed, the temperature of 4°C being too low, the risk for mangoes to develop cold-related diseases and to generate often irreversible defects such as chilling injury is high.

Compliance with ethical standards

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Disclosure of conflict of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Author's contribution

YEO Mohamed Anderson: Formal analysis, Writing – original draft. COULIBALY Gnougon Nina, Kouassi Léopold KOUAKOU, Dan Gbongué Lucien GOGBEU and Tanoh Hilaire KOUAKOU : Supervision, Formal analysis, Writing – original draft, Writing – review & editing. Lacina COULIBALY: Supervision, Formal analysis, Writing – review & editing.

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