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Original Article

Quantification of Phenolics, Flavonoids and Carotenoids in Mango Pulps and Byproducts: Ripeness Variability in Twenty-two Mango Varieties

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ABSTRACT

Background and Objectives: This study assessed the effect of ripening on total phenolics, flavonoids and carotenoids in pulps, peels, seeds and kernels of 22 indigenous and non-indigenous mango varieties. Distribution of bioactive compounds was compared in the varieties.

Materials and Methods: Total phenolics, flavonoids and carotenoids were quantified using UV-vis spectrophotometry with Gallic acid, quercetin and beta-carotene as the standards, respectively.

Results: The concentration of bioactive compounds was highest in mango peels followed by pulps, seeds and kernels. Total phenolic content was within the range of 70.49–270.26, 59.45–227.27, 41.70–173.85 and 40.41–70.52 mg GAE 100 g^{-1} FW in peels, pulps, seeds and kernels, respectively. Flavonoid levels were highest in peel ranging from 208.00–329.36 mg QE 100 g^{-1} FW followed by pulps with concentrations of 189.34–325.78 mg QE 100 g^{-1} FW. Kernels and seeds contained low quantities of flavonoids. Similarly, peels showed higher carotenoid quantities (44.27–83.54 µg g^{-1}) than pulps with quantities of 34.15–57.16 µg g^{-1}. Carotenoid concentrations of kernels and seeds were below the detection limit of 1 µg g^{-1}. Indigenous mango varieties contained significantly ($p < 0.05$) higher concentrations of bioactive compounds than non-indigenous varieties. The highest concentration of phenolics was recorded at mature green stage. Flavonoid concentration reached peak levels at partially ripe stage while carotenoids reached maximum levels at overripe stage.

Conclusion: Mango pulps and peels show potential for commercial uses due to the rich composition of bioactive compounds. These characteristics make them valuable for antioxidant extraction and development of nutraceutical and pharmaceutical products that possess health-promoting characteristics.

Keywords: Mango pulp, Ripening, Phenolics, Flavonoids, Carotenoids

Highlights

- Mango peels and pulps are rich sources of antioxidants and appropriate for developing health-promoting products.
- The UV-vis spectrophotometry effectively quantified total phenolics, flavonoids and carotenoids in mango byproducts.
- Mango peels contained the highest total phenolic (270.26 mg GAE 100 g^{-1} FW) and flavonoid (329.36 mg QE 100 g^{-1} FW) content, while carotenoids peaked in peels (85.69 µg g^{-1}) and pulps (57.16 µg g^{-1}).
- Phenolics peaked at the mature green, flavonoids at the partially ripe and carotenoids at the overripe stages.
- Indigenous mangoes showed higher bioactive concentrations in pulps and byproducts than the non-indigenous varieties

Introduction

The global fruit industry generates 1.3 billion tons of wastes per annum from processing consumer products (1). Fruit byproducts contain substantial quantities of bioactive compounds (2). The recovery and valorization of bioactive compounds create an opportunity for production of high-value products (3). Mango (*Mangifera indica* L.) is widely

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cultivated and processed into juices, jams and nectars. However, 30-50% of the fruits is discarded as wastes in form of peels, kernels and seeds (4). The pulps are the most commercially used (5). Byproducts are used as animal feeds and composts with minimal enrichment to realize reasonable economic benefits.

Mango peels are rich in bioactive compounds such as phenolics, flavonoids and carotenoids, which possess antioxidant and health promoting characteristics (2). Studies show that dietary intake of flavonoids particularly from fruits may decrease the risk of cardiovascular diseases (CVD), hypertension and type-2 diabetes mellitus (6). Extracts from peels have been reported to include cardio-protective effects by protecting against vascular damages induced by low-density lipoprotein oxidation, a key factor in development of atherosclerosis (7). Kernel extracts have shown potentials for enhancing stability of edible oils by preventing oxidation and decreasing microbial contamination in foods; thus, making them useful preservatives (8). In addition, mango byproducts have been reported as functional ingredients in bakery products due to their high dietary fiber, vitamin and antioxidant contents (9). The increasing use of mango peels, kernels and seeds demonstrate their potentials for diverse use in the food industry.

Maturity, environmental factors and genetic diversity affect polyphenol levels in mango pulp and byproducts (2). As mangoes ripen, biochemical changes occur leading to changes in the concentration of bioactive compounds (10). During ripening, chlorophyll degradation within the chloroplasts results in pigment shifts, which contribute to the accumulation of carotenoids responsible for fruit coloration (11). Pectinase enzyme breaks down pectic substances causing texture softening and increased solubilization of pectin and thus increasing the availability of bioactive compounds (12). However, accumulation of bioactive compounds varies in mango varieties during ripening (13). Studies indicate that mature green mangoes contain nearly 45% more total phenolics than ripe mangoes (14). This has been observed in other tropical fruits such as papayas and nectarines, where ripening process leads to decreases in phenolic contents (14). The diverse range of indigenous and non-indigenous mango varieties grown in Uganda offer potentials for use of byproducts generated from the mango processing industry (15). This study aimed at describing and comparing effects of ripening on bioactive compounds in pulps, peels, seeds and kernels of indigenous and non-indigenous mango varieties in Uganda.

Materials and Methods

Sample collection

A total of 22 (13 indigenous and 9 non-indigenous) mango varieties commonly grown in Uganda were studied. The sampling protocol of Akhter *et al.* (2021) (16) was followed. Five trees for every mango variety were selected from orchards located in Luweero, Budaka and Nakaseke Districts, Uganda. Ten green mature mango fruits were randomly hand-picked per tree (16). The fruits were selected based on a flat shoulder at the stem ends, full cheeks, presence of blooms and changes in peel color from dark to light green. A batch of 150 mangoes per variety at the green mature stage with no visible physical damages and free of pest injuries were collected. The fruits were cleaned with water and sanitized with chlorinated water containing 200 mg l^{-1} sodium hypochlorite (Sigma-Aldrich, St. Louis, MO, USA). The mangoes were stored in crates at room temperature (RT) (27 °C) to allow natural ripening.

Identification of ripening stage

Ripening stages were defined based on standardized physiological parameters including peel and pulp colors, flesh firmness and total soluble solids (TSS) based on the USA National Mango Board guidelines (17). Mangoes were categorized into five stages of unripe (firmness, 40 to60 N; TSS, 8–9.9 °Brix), early ripe (21–39 N, 10–12.9 °Brix), partially ripe (10–20 N, 13–15.9 °Brix), ripe (5–9 N, 16–18.9 °Brix) and overripe (< 5 N, 19–22 °Brix). One mango per variety was picked daily for firmness, total soluble solids and internal color assessment (17). Mechanical fruit pressure tester with an 8-mm probe (Model FT 327, Ravenna, Italy) was used to investigate flesh firmness. The total soluble solid of the fresh juice, expressed as °Brix was assessed using digital refractometer (Model DBR95, Modena, Italy).

Preparation of samples

Three mango fruits per variety were sectioned into peels, pulps, kernels and seeds by hand using sterile stainless-steel knives at every ripening stage (17). Samples were weighed (100 g), crushed and blended separately for 3 min using blender (Model BL770, Ninja, China). The blended samples were homogenized in 10 ml of 80% methanol using homogenizer (Ultra-Turrax T25, Germany). The homogenate was sonicated (Branson Sonifier 250, USA) for 30 min and centrifuged (Hermle Z200-A, Germany) at 9400× g for 25 min at 4 °C. The extraction process was carried out thrice to maximize the yield. The supernatant was collected, filtered using Whatman filter papers no. 1 and then stored at -20 °C.

Assessment of total phenolic content

The total phenolic content was assessed using Folin-Ciocalteu method. The extracts (0.1 ml) from peels, pulps, kernels and seeds of each mango variety were added to separate test tubes followed by addition of 0.5 ml of 10% Folin-Ciocalteu reagent (Sigma-Aldrich, St. Louis, MO, USA). The mixture was vortexed (Vortex-Genie 2 SI-0236, USA) and set to stand for 5 min at 25 ℃. Then, 2.5 ml of 7.5% sodium carbonate solution were added to each test tube, mixed and incubated at RT for 2 h in dark. After incubation, absorbance of each solution was measured at

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765 nm using UV-vis spectrophotometer (Model UV-1800, Shimadzu, Kyoto, Japan). Gallic acid (Sigma-Aldrich, St. Louis, MO, USA) was used as standard reference and a stock solution was prepared by dissolving 0.1 g of Gallic acid in 100 ml of methanol. A calibration curve was prepared with concentrations ranging 10–100 mg l^{-1} resulting in the standard curve equation (y = 0.0123x + 0.0894, R^2 = 0. 9987). The total phenolic content was assessed by comparing absorbance to the standard curve. The values were expressed as mg Gallic acid equivalent (GAE) per 100 g fresh weight.

Assessment of total flavonoids

Flavonoid content was quantified using aluminum chloride colorimetric method. A 100-µl aliquot of mango extract was mixed with 60 µl of 5% sodium nitrite, incubated for 5 min. This was followed by addition of 50 µl of 10% aluminum chloride. After 5 min, 30 µl of 1 M sodium hydroxide were added to the mixture. The mixture was incubated at RT for 5 min in dark. The absorbance was measured at 510 nm using UV-vis spectrophotometer (Model UV-1800, Shimadzu, Kyoto, Japan). Quercetin was used to prepare the standard curve and the calibration curve equation was prepared (y = 0.0107x + 0.0758, R^2 = 0.9956). The total flavonoid content was expressed as mg quercetin equivalent (QE) per 100 g fresh weight.

Assessment of total carotenoid

The total carotenoid content was assessed using UV-vis spectrophotometry. A 15-g sample was homogenized with 3 g of celite 454 (Tedia, Ohio, USA) and 25 ml of 85% acetone (Ultra-Turrax T25 IKA, Staufen, Germany). The mixture was filtered through a sintered funnel connected to a 250-ml Buchner flask and vacuum. Extraction was repeated until the mixture was colorless. The extract was transferred to a separator funnel containing 40 ml of petroleum ether. Residual acetone was removed from the extract by washing with distilled water (DW). The upper phase was collected in a 50-ml volumetric flask and filled with petroleum ether. A UV-vis spectrophotometer (Shimadzu, Japan) at 450 nm was used to measure the carotenoid levels. Detection limit of the method was 1 µg g^{-1} based on the minimum absorbance value compared to the blank. Calibration curve based on β-carotene standards was used and the equation was created (y = 0.0154x + 0.0621, R^2 = 0. 9963). Total carotenoid content was calculated using the following formula:

Carotenoids (µg g^{-1}) = $(A.V.10^4)$ / ($A_{1cm}^{1\%}$. sample weight)

Where, A was absorbance of the sample solution; V was the total volume of the extract; $A_{1cm}^{1\%}$ was the β-carotene extinction coefficient in petroleum ether as 2592.

Statistical analysis

Data on total phenolic, flavonoid and carotenoid contents in peels, pulps, kernels and seeds of 22 mango varieties were analyzed using SPSS software v.21 (IBM, USA) (18). Descriptive statistics was used to compute mean and standard deviation (SD). Two-way ANOVA test was used to assess the independent effects of mango varieties and parts on the mean values of bioactive compounds. Bonferroni's post-hoc test was used for pairwise comparisons between group means to report mango varieties and parts that were statistically different at $p < 0.05$.

Results

Bioactive compositions of mango pulps, peels, seeds and kernels

Total phenolic content

The total phenolic content (TPC) varied significantly in various mango varieties. Peels contained the highest TPC varying from 70.49–270.26 mg GAE 100 g^{-1} FW (Table 1). Indigenous mango varieties contained higher ($p < 0.05$) TPC in the peels compared to non-indigenous varieties. Kagoogwa variety recorded the highest concentration of phenolics in the peels followed by Sejjembe variety. The pulps showed high TPC with a range of 59.45–227.27 mg GAE 100 g^{-1} FW. The indigenous mango varieties showed an average TPC of 115.53 ±53.60 mg GAE 100 g^{-1} FW in the pulps compared to 103.52 ±24.81 mg GAE 100 g^{-1} FW for non-indigenous varieties ($p < 0.05$). High quantities of phenols were observed in the pulps of Ssejjembe and Sayuni varieties. Seeds and kernels showed low levels of phenolics with ranges of 41.70–173.85 and 40.41–70.52 mg GAE 100 g^{-1} FW, respectively. No significant differences ($p > 0.05$) were observed in TPC of the mango seeds of indigenous and non-indigenous varieties. Indigenous mangoes showed higher TPC than non-indigenous varieties in pulps and byproducts (Table 1).

Total flavonoid

Total flavonoid content (TFC) was in the range of 208.40–329.36 mg QE 100 g^{-1} FW in the peel (Table 2). Asante and Apple mango peels showed the highest TFC of 329.36 ±0.21 and 325.78 ±0.13 mg^{-1} QE 100 g^{-1} FW, respectively. The flavonoid content of pulps varied from 189.71–322.53 mg QE 100g^{-1} FW. The pulps of Asante and Koona contained significantly higher ($p < 0.05$) flavonoid levels compared to other mango varieties. Kernels and seeds showed low flavonoid concentrations with no statistical differences ($p > 0.05$). Flavonoid concentration of indigenous mangoes was 292.01 ±27.60 mg QE 100 g^{-1} FW in peels and 251.48 ±44.0 mg QE 100 g^{-1} FW in pulps. Non-indigenous mangoes showed mean flavonoid levels of 262.01 ±32.57 mg QE 100 g^{-1} FW in peels and 225.11 ±31.24 mg QE 100 g^{-1} FW in pulps. Indigenous mango varieties showed significantly higher flavonoid concentrations in peels and pulps compared to non-indigenous varieties. These findings indicated that indigenous mango varieties were superior sources of flavonoids compared to non-indigenous varieties.

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Table 1. Total phenolic content of peels, pulps, kernels and seeds of 22 mango varieties

Mango type	Mango variety	Total phenolic content (mg GAE/100 g FW)			
		Peel	Pulp	Kernel	Seed
Indigenous	Apple mango	82.56±0.26^{r}	75.68±0.25^{p}	41.63±0.32^{k}	41.70±0.45^{t}
	Asante	70.77±0.25^{s}	67.31±0.15^{r}	44.52±0.30^{j}	61.35±0.19^{p}
	Batawi	70.49±0.43^{s}	59.45±0.07^{s}	45.63±0.32^{i}	49.37±0.37^{s}
	Bire	70.51±0.34^{s}	69.70±0.17^{q}	46.41±0.37^{i}	68.42±0.28^{kl}
	Boribo	181.24±0.97^{g}	154.41±0.29^{d}	49.41±0.31^{g}	86.57±0.34^{g}
	Doodo	124.30±0.13^{l}	103.39±0.21^{j}	53.57±0.34^{f}	102.13±0.40^{c}
	Kagoogwa	270.26±0.17^{a}	113.62±0.35^{h}	55.63±0.16^{e}	111.68±0.25^{b}
	Koona	92.41±0.39^{p}	86.56±0.17^{m}	60.41±0.44^{c}	63.27±0.18l^{no}
	Mabbere	252.28±0.19^{c}	125.77±0.19^{e}	41.52±0.16^{kl}	64.21±0.04^{n}
	Sayuni	224.32±0.13^{e}	221.75±0.71^{b}	58.52±0.03^{d}	67.43±0.21^{m}
	Ssejjembe	264.22±0.27^{b}	227.27±0.47^{a}	69.41±0.26^{b}	173.85±0.13^{a}
	Takataka	179.58±0.36^{h}	86.65±0.25^{m}	70.52±0.14^{a}	75.32±0.43^{i}
	Kakule	114.19±0.17^{m}	110.33±0.19^{i}	58.30±0.13^{d}	72.58±0.37^{k}
Non-indigenous	Duncan	127.47±0.12^{k}	95.51±0.24^{l}	40.52±0.36^{lm}	92.49±0.19^{f}
	Fairchild	248.35±0.26^{d}	121.54±0.12^{f}	41.63±0.31^{k}	99.37±0.22^{d}
	Julie	81.51±0.32^{r}	74.68±1.13^{p}	47.63±0.65^{h}	73.53±0.40^{jk}
	Kapisa	95.28±0.09^{o}	83.14±1.24^{o}	44.41±0.15^{j}	59.78±0.13^{q}
	Kent	104.33±0.51^{n}	95.57±0.32^{l}	50.52±0.45^{g}	62.44±0.21^{o}
	Ponde	171.49±0.21^{i}	159.63±0.13^{c}	56.63±0.39^{cd}	74.11±0.06^{j}
	Palmer	203.58±0.02^{f}	101.56±0.29^{k}	54.41±0.07^{f}	76.67±0.39^{h}
	Seena	131.83±0.18^{j}	115.17±0.02^{g}	58.30±0.08^{d}	94.46±0.34^{e}
	Tommy atkin	84.72±0.36^{q}	84.93±0.37^{n}	40.41±0.26^{m}	54.48±0.37^{r}
Indigenous (Mean±SD)		153.63±76.38^{A}	115.53±53.60 ^{A}	53.48±9.48 ^{A}	79.85±33.25 ^{A}
Non-indigenous (Mean±SD)		138.73±55.54^{B}	103.52±24.81 ^{A}	48.27±6.75 ^{B}	76.37±15.49 ^{A}

Mean values are reported on fresh weight (FW) basis; Superscripts a, b, c denotes significant differences in mango varieties, while A, B denote significant differences between mango types. Values with different superscript letters in the same column are significantly different ($p < 0.05$).

Table 2. Total flavonoid content of peels, pulps, kernels and seeds of 22 mango varieties

Mango type	Mango variety	Total flavonoids content (mg QE/100 g FW)			
		Peel	Pulp	Kernel	Seed
Indigenous	Apple mango	325.78±0.13^{b}	299.36±0.04^{c}	28.43±0.28^{a}	23.23±0.02^{g}
	Asante	329.36±0.21^{a}	322.53±0.32^{a}	24.63±0.32^{c}	22.43±0.06^{h}
	Batawi	302.71±0.11^{g}	296.72±0.19^{d}	25.43±0.32^{c}	18.30±0.42^{l}
	Bire	308.31±0.15^{e}	301.40±0.06^{b}	17.36±0.19^{h}	17.65±0.04^{m}
	Boribo	293.77±0.21^{i}	217.28±0.32^{n}	20.53±0.04^{f}	22.19±0.01^{h}
	Doodo	290.56±0.03^{j}	275.58±0.28^{g}	22.65±0.32^{de}	27.38±0.06^{f}
	Kagoogwa	295.79±0.10^{h}	221.75±0.11^{l}	28.11±0.32^{a}	22.12±0.01^{hi}
	Koona	310.60±0.04^{d}	228.62±0.28^{j}	24.45±0.39^{c}	19.48±0.07^{k}
	Mabbere	290.64±0.26^{j}	280.34±0.21^{f}	25.43±0.42^{c}	22.27±0.13^{h}
	Sayuni	251.30±0.19^{o}	192.70±0.36^{r}	22.47±0.32^{de}	32.16±0.03^{c}
	Ssejjembe	241.29±0.19^{r}	226.71±0.12^{k}	24.51±0.43^{c}	40.72±0.06^{a}
	Takataka	307.57±0.24^{f}	216.55±0.15^{n}	22.78±0.36^{d}	32.53±0.03^{c}
	Kakule	248.50±0.34^{p}	189.71±0.27^{s}	22.67±0.10^{de}	28.05±0.01^{e}
Non-indigenous	Duncan	238.43±0.24^{s}	190.53±0.40^{s}	14.72±0.28^{ij}	8.01±0.08^{q}
	Fairchild	234.27±0.23^{t}	212.67±0.39^{p}	19.39±0.49^{g}	16.01±0.19^{o}
	Julie	289.57±0.26^{k}	262.25±0.19^{h}	7.48±0.10^{l}	12.01±0.01^{p}
	Kapisa	282.50±0.27^{l}	219.68±0.38^{m}	26.51±0.11^{b}	16.81±0.21^{n}
	Kent	271.50±0.18^{m}	215.35±0.20^{o}	6.46±0.35^{l}	35.86±0.02^{b}
	Ponde	270.64±0.11^{n}	211.32±0.45^{q}	21.63±0.19^{e}	28.70±0.22^{d}
	Palmer	243.32±0.32^{q}	234.39±0.32^{i}	14.83±0.11^{i}	21.72±0.06^{i}
	Seena	208.40±0.27^{u}	190.48±0.37^{s}	13.66±0.67^{j}	20.72±0.10^{j}
	Tommy atkin	319.48±0.13^{c}	289.34±0.24^{e}	11.99±0.19^{k}	12.36±0.04^{p}
Indigenous (Mean±SD)		292.01±27.60 ^{A}	251.48±44.40 ^{A}	23.82±2.91 ^{A}	25.27±48 ^{A}
Non-indigenous (Mean±SD)		262.01±32.57 ^{B}	225.11±31.24 ^{B}	15.19±6.23 ^{B}	19.13±8.43^{B}

Mean values are reported on fresh weight (FW) basis; Superscripts a, b, c denotes significant differences in mango varieties, while A, B denote significant differences between mango types. Values with different superscript letters in the same column are significantly different ($p < 0.05$).

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Total carotenoid

Mango peels and pulps contained significantly ($p < 0.05$) higher carotenoid levels than those in seeds and kernels (Table 3). Carotenoid content of peels varied from 44.27–85.69 µg g^{-1} and that of pulps ranged from 34.15–57.16 µg g^{-1}. The seeds and kernels showed carotenoid values less than the detection limits of 1 µg g^{-1}. The mango variety with the highest carotenoid concentration (85.69 ±0.40 and 49.40 ±0.13 µg g^{-1} respectively) in peels and pulps was Takataka with significant differences ($p < 0.05$), compared to other varieties. The carotenoid concentration in indigenous mango peels was 68.33 ±8.89 µg g^{-1}, which was higher ($p < 0.05$) than 67.66 ±11.00 µg g^{-1} in non-indigenous varieties. Similarly, pulps of indigenous mangoes showed a carotenoid content of 43.44 ±6.68 µ g^{-1}, which was significantly higher ($p < 0.05$) than 40.62 ±3.55 µg g^{-1} in non-indigenous varieties.

Variation in quantities of bioactive compounds of mango pulps and byproducts during ripening

Changes in total phenolic content

The total phenolic content of mango peels, pulps, kernels and seeds decreased with progression of ripening (Figure 1). The highest phenolic content in peels was observed at the mature green stage with 677 mg GAE 100 g^{-1} FW in indigenous mango varieties and 647 mg GAE 100 g^{-1} FW in non-indigenous mangoes. Phenolics decreased dramatically in peels from 677 to 112 mg GAE 100 g^{-1} FW in indigenous mango varieties and 647 to 80 mg GAE 100 g^{-1} FW in non-indigenous mangoes. Similar to peels, the level of phenolics in pulps was high at the mature green stage (584 mg GAE 100 g^{-1} FW for indigenous and 571 mg GAE 100 g^{-1} FW for non-indigenous mangoes) but respectively decreased to 80 and 60 mg GAE 100 g^{-1} FW at the overripe stage (Figure1). Kernels and seeds contained the lowest TPC in all ripening stages.

Table 3. Total carotenoid content of peels, pulps, kernels and seeds of 22 mango varieties

Mango type	Mango variety	Total carotenoids (µg/g)			
		Peel	Pulp	Kernel	Seed
Indigenous	Apple mango	63.80±0.15^{m}	48.51±0.42^{c}	<DL	<DL
	Asante	53.58±0.30^{o}	41.12±0.07^{gh}	<DL	<DL
	Batawi	67.74±0.05^{ij}	34.25±0.23^{m}	<DL	<DL
	Bire	51.54±0.43^{p}	42.40±0.29^{f}	<DL	<DL
	Boribo	72.48±0.05^{e}	35.32±0.52^{l}	<DL	<DL
	Doodo	66.44±0.48^{k}	36.73±0.18^{k}	<DL	<DL
	Kagoogwa	76.39±0.10^{d}	53.14±0.18^{b}	<DL	<DL
	Koona	65.47±0.03^{l}	41.14±0.05^{gh}	<DL	<DL
	Mabbere	67.43±0.45^{j}	40.61±0.26^{h}	<DL	<DL
	Sayuni	72.75±0.03^{e}	57.16±0.16^{a}	<DL	<DL
	Ssejjembe	76.31±0.21^{d}	43.79±0.13^{e}	<DL	<DL
	Takataka	85.69±0.40^{a}	49.40±0.13^{c}	<DL	<DL
	Kakule	68.66±0.07^{h}	41.09±0.06^{gh}	<DL	<DL
Non-indigenous	Duncan	70.39±0.03^{g}	34.15±0.13^{m}	<DL	<DL
	Fairchild	44.27±0.05^{q}	37.52±0.11^{k}	<DL	<DL
	Julie	77.37±0.15^{c}	44.46±0.47^{e}	<DL	<DL
	Kapisa	69.19±0.05^{h}	43.59±0.28^{e}	<DL	<DL
	Kent	71.48±0.45^{f}	40.27±0.15^{hi}	<DL	<DL
	Ponde	67.85±0.05^{ij}	39.55±0.21^{i}	<DL	<DL
	Palmer	56.30±0.06^{n}	41.60±0.46^{fg}	<DL	<DL
	Seena	68.53±0.34^{hi}	38.60±0.52^{j}	<DL	<DL
	Tommy atkin	83.54±0.03^{b}	45.86±0.13^{d}	<DL	<DL
Indigenous (Mean±SD)		68.33±8.89^{A}	43.44±6.68 ^{A}	-	-
Non-indigenous (Mean±SD)		67.66±11.00^{B}	40.62±3.55 ^{B}	-	-

Mean values are reported on fresh weight (FW) basis; < DL: below detection limit of 1 µg/g; Superscripts a, b, c denotes significant differences in mango varieties, while A, B denote significant differences between mango types. Values with different superscript letters in the same column are significantly different ($p < 0.05$).

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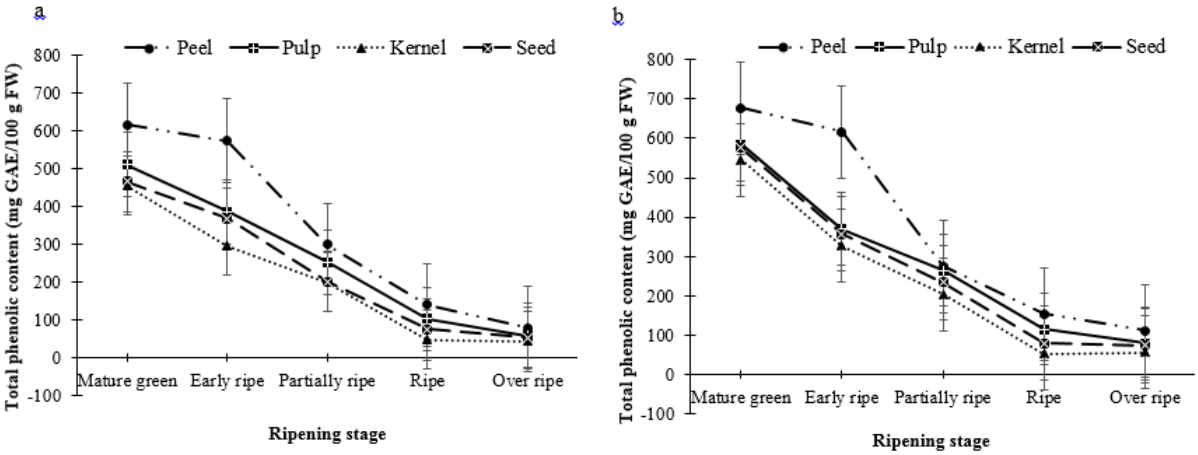

Figure 1. Total phenolic content of pulps, peels, kernels and seeds of indigenous (1a) and non-indigenous (1b) mangoes at various ripening stages

Changes in total flavonoid

Total flavonoid in peels and pulps increased from mature green stage, peaked at partially ripe stage and decreased from ripe to overripe stage (Figure 2). Flavonoid levels in peels of indigenous mango varieties increased from 42 mg QE 100 g^{-1} FW at the mature green stage to 324 mg QE 100 g^{-1} FW at the partially ripe stage and sharply decreased to 8 mg QE 100 g^{-1} FW at overripe stage. In non-indigenous mangoes, peels demonstrated a similar development, starting at 48 mg QE 100 g^{-1} FW at the mature green stage, increasing to 301 mg QE 100 g^{-1} FW at partially ripe and then decreasing to 9 mg QE 100 g^{-1} FW at overripe stage. Flavonoids in the indigenous mango pulp increased from 43 mg QE 100 g^{-1} FW at mature green to 311 mg QE 100 g^{-1} FW at partially ripe stage and then decreased to 45 mg QE 100 g^{-1} FW at overripe stage. A similar development was observed in pulps of non-indigenous varieties (Figure 2b). Levels of flavonoids in kernels and seeds were low with insignificant fluctuations during ripening.

Changes in total carotenoid

The concentration of carotenoids in mango peels increased with ripening in indigenous and non-indigenous mangoes (Figure 3). The highest carotenoid levels in peels were observed at the overripe stage, with 111 µg g^{-1} in indigenous varieties and 109 µg g^{-1} in non-indigenous varieties. There was a gradual increase in carotenoid levels from the mature green to the partially ripe stage. This became significant at the ripe stage and increased exponentially from ripe to overripe. In indigenous varieties, carotenoid levels in peels increased from 8 µg g^{-1} at the mature green stage to 111 µg g^{-1} at the overripe stage. Non-indigenous varieties showed a similar development with peel carotenoid levels starting at 7 µg g^{-1} in the mature green stage and increasing to 109 µg g^{-1} at the overripe stage. For the pulps, carotenoid levels in indigenous varieties increased from 3 µg g^{-1} at the mature green stage to 84 µg g^{-1} at overripe. Non-indigenous varieties showed a similar development with levels increasing from 3 to 82 µg g^{-1} as ripening progressed. Total carotenoid in kernels and seeds was low with no significant accumulation during ripening.

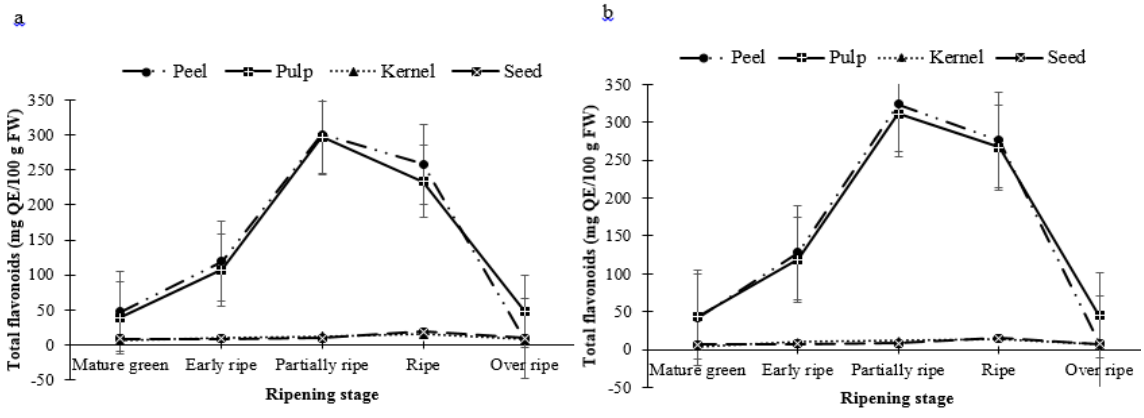

Figure 2. Total flavonoid in pulps, peels, kernels and seeds of indigenous (a) and non-indigenous (b) mango varieties at various ripening stages

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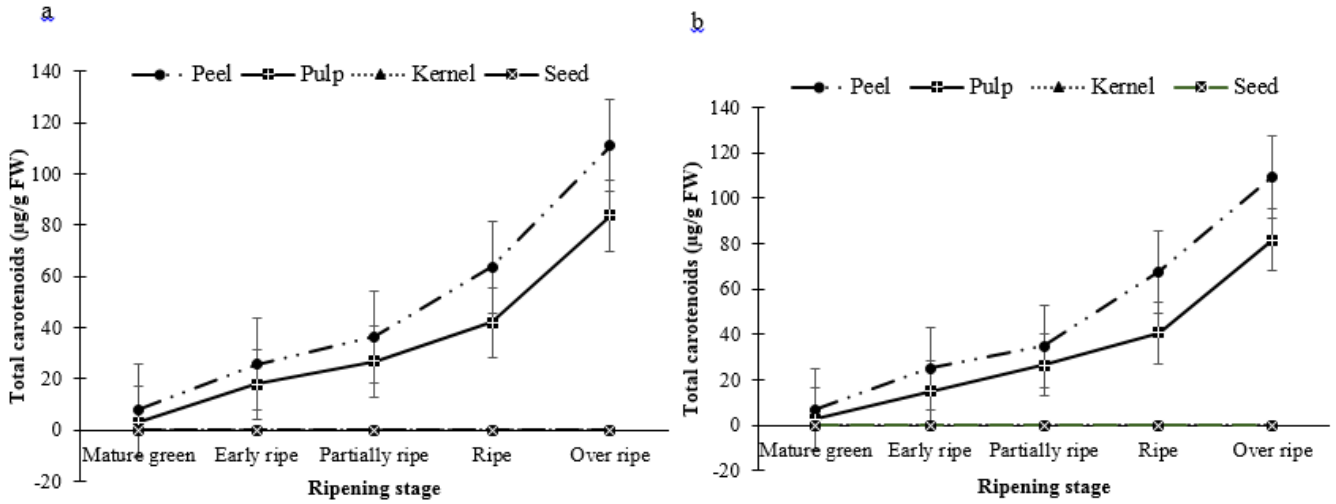

Figure 3. Total carotenoid in pulps, peels, kernels and seeds of indigenous (a) and non-indigenous (b) mango varieties at various ripening stages

Discussion

Total phenol varied in pulps, peels, seeds and kernels as observed in studies by Kaur *et al.* (2019) (19) and Ghasemzadeh *et al.* (2010) (20). The highest concentration of bioactive compounds was seen in peels, which was similar to those in other studies (21). This could be attributed to the peel function as a protective barrier against pathogens and UV radiation (21). The phenolic concentration in pulps was higher than the range of 33.61–120.14 mg GAE 100 g^{-1} FW reported by Deepa *et al.* (2015) (22) but lower than that of Rojas *et al.* (2023) (23). Variations in TPC in mangoes are affected by genotypic effects, varietal and regional differences and environmental factors (24). Low phenol levels were seen in kernels and seeds with earlier findings (25, 26). Despite low phenolic concentrations, kernels and seeds contain significant quantities of bioactive compounds (27). Kernel flour enhances the nutritional profile of bakery products (28). The antimicrobial characteristics of mango seed extracts help in shelf-life extension of food products (29). Indigenous varieties presented higher phytochemicals, which was seen in Brazil, where local mangoes showed superior nutritional contents, compared to exotic mangoes (30). Local mango varieties adapt well to environmental conditions such as soil, temperature and altitude, which affect phenolic biosynthesis (31).

Li *et al.* (2013) (32) reported higher flavonoid levels in mango peels than pulps, seeds and kernels. The hierarchical distribution is supported by Zhang *et al.* (2023) (33). The high flavonoid content (329 ±0.21 mg QE 100 g^{-1} FW) in peels of Asante was similar to findings of Monaco *et al.* (2014) (34). On the contrary, Zhang *et al.* (2020) (35) reported lower TFC (34.2, 31.8 and 29.6 mg QE 100 g^{-1} FW, respectively) in mango peels, compared to the current study. Environmental stressors such as drought and soil nutrient deficiencies alter flavonoid concentrations leading to variability (33). Pulps of mangoes showed TFC levels that surpassed 120.5 and 115.7 mg QE 100 g^{-1} FW reported for Mallika and Ataulfo varieties in Mexico and India, respectively (3, 31). The lower flavonoid content in seeds and kernels, comparing to peels and pulps, could be explained by structural and compositional differences (32). Seeds and kernels contain dense cellular structures that limit production of secondary metabolites such as flavonoids. They prioritize lipids and proteins for seed germination rather than flavonoid synthesis (36).

The high carotenoid accumulation in mango peels could be supported by increased carotenoid-synthesizing enzymes such as phytoene synthase and lycopene cyclase (37). During fruit ripening, carotenoid concentration in peels increases to enhance color development and visual appeal (38). Carotenoid concentrations in the kernels and seeds were less than the detection limit of 1 µg g^{-1}. This was similar to that of previous studies reporting low carotenoid contents in non-pigmented plant tissues (39). The kernels and seeds accumulate low quantities of carotenoids because they contain less chromoplasts, the organelles that generate and store carotenoids (37).

Phenolic compounds are abundant at the unripe stage and decrease as the mangoes ripen. Gil *et al.* (2002) (40) reported a similar pattern of TPC in nectarines, peaches and plums. A decrease in phenolic content of papayas was seen by Gonzalez-Aguilar *et al.* (2010) (41) with the highest values recorded at the mature green stage. During early stages of mango fruit development, phenolic compounds are synthesized at high levels to protect the fruits from environmental stresses (32). As mangoes ripen, energy and resources are diverted from the synthesis of phenolics to sugar accumulation and flavor development (42). Decreases in TPC during ripening could also be explained by increased polyphenol oxidase activity leading to the oxidation of phenolic compounds to quinones (43). Ripening increases

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permeability of cell membranes which allows phenolic compounds to interact with oxidizing agents leading to degradation (44).

Mid-ripening is a critical period for flavonoid accumulation in the peels and pulps of mangoes. This stage is characterized by increased activity of enzymes such as chalcone synthase, which plays a key role in flavonoid biosynthesis (43). Kernels and seeds contain low flavonoid concentration in mangoes because the genetic composition does not significantly affect flavonoid contents in seeds and kernels. These parts are responsible for energy storage and reproduction, not secondary metabolite production (43). Indigenous and non-indigenous mango varieties showed similar flavonoid concentrations in pulps and peels as ripening progressed. Muralidhara *et al.* (2019) (45) showed that flavonoid content in mangoes increased up to the ripe stage then decreased to senescence. As fruits transit from ripe to overripe stages, there is inhibition of flavonoid biosynthetic enzymes driven by the peak and subsequent drop in ethylene, redirecting the fruit focus to softening and sugar accumulation (46). This coupled with increased oxidative stress and senescence results in a decrease in flavonoid levels with ripening (47).

The activity of carotenoid biosynthetic enzymes such as phytoene synthase, phytoene desaturase and lycopene cyclase increase as mangoes transit from raw to ripe stages (48). These enzymes convert phytoene into various carotenoids, including β-carotene, lutein and zeaxanthin; thereby, increasing carotenoid concentrations (48). In addition, degradation of chlorophyll by chlorophyllase uncovers carotenoids that were previously masked by the green pigment (49). Seeds and kernels showed undetectable levels of carotenoids due to their low biosynthetic activities and structural differences (48). The seeds and kernels are designed for energy storage rather than pigment synthesis and their cellular structure is less conducive to carotenoid deposition (49, 50).

CONCLUSION

Mango peels and pulps are rich in phenolics, flavonoids and carotenoids, making them appropriate for commercial uses in antioxidant-rich beverages, dietary supplements and natural food colorants. The seeds and kernels may not provide significant quantities of bioactive compounds for practical benefits. Indigenous mangoes contain more bioactive compounds than those in non-indigenous mangoes. Kagoogwa, Sejjembe, Sayuni, Asante, Takataka and Apple are superior mango varieties with exceptionally high concentrations of bioactive compounds. Mango ripening leads to various changes in the quantities of bioactive compounds. Phenolics are most abundant compounds in mature green mangoes, flavonoids are detected in partially ripe mangoes and carotenoid concentration is highest in overripe mangoes. Identification of ripening stage with the highest bioactive compound concentration can help farmers to optimize harvest time to maximize nutritional values of mangoes.

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