agriculture

MDPI

Article

Hot Water Disinfestation Treatment Does Not Affect Physical and Biochemical Properties of Export Quality Mango Fruit [*Mangifera indica* L.]

Shepard Ndlela [1,*], Francis Obala [1], Nelson L. Mwando [1], Abdullah M. Mkiga [2], Abdelmutalab G. A. Azrag [1] and Samira A. Mohamed [1]

[1] International Centre of Insect Physiology and Ecology (ICIPE), Nairobi P.O. Box 30772-00100, Kenya; fobala@icipe.org (F.O.); nmwando@icipe.org (N.L.M.); agesmalla@icipe.org (A.G.A.A.); sfaris@icipe.org (S.A.M.)

[2] Tanzania Agricultural Research Institute (TARI)-Ukiriguru Centre, Mwanza P.O. Box 1433-33517, Tanzania; abdullah.mkiga@tari.go.tz

* Correspondence: sndlela@icipe.org

Abstract: There are various postharvest treatments currently available in the market. Among these, heat-based treatments are very effective. Several hot water treatment (HWT) protocols at various temperature regimes and time durations have been developed for different mango cultivars and varieties. However, many concerns have been raised regarding the quality of fruits subjected to HWT, particularly on physical and biochemical properties. The purpose of this study was to generate empirical evidence on the effect of the HWT protocol currently recognized and accepted by the EU for Apple mango cultivar from Africa. We subjected mango to HWT at 46.1 °C for 68, 75, and 84 min and evaluated various physical and biochemical properties at 1, 3, 5, and 7 days post-treatment. Conventional methods of analysis were used to test acidity, antioxidants, minerals, nutrients, and physical properties of treated mangoes, and comparisons against untreated controls were made. We found no significant differences in pH, various acid content, total carotenoids, β-carotene content, vitamin A, aromatic volatiles, total phenolics, total antioxidant activity, various minerals, electrolytic leakage, crude protein, total carbohydrates, total sugars, crude fat, moisture content, dry matter, total soluble solids, firmness, or weight between treated and untreated mangoes. We conclude that HWT presents a viable alternative for postharvest treatment of export mangoes provided that quality attributes are maintained from preharvest, harvesting, transportation, treatment, and post-treatment handling.

Keywords: physicochemical; hot water treatment; postharvest processing; fruit; vegetable; export; antioxidants; trade of fruits; fruit quality; postharvest quality; disinfestation protocol

Citation: Ndlela, S.; Obala, F.; Mwando, N.L.; Mkiga, A.M.; Azrag, A.G.A.; Mohamed, S.A. Hot Water Disinfestation Treatment Does Not Affect Physical and Biochemical Properties of Export Quality Mango Fruit [*Mangifera indica* L.]. *Agriculture* **2022**, *12*, 570. https://doi.org/10.3390/agriculture12050570

Academic Editor: Giacomo Cocetta

Received: 4 March 2022
Accepted: 6 April 2022
Published: 19 April 2022

1. Introduction

Fruit and vegetable production and sale is a huge business creating employment, income-generating opportunities, and offering food security and nutrition to millions of people worldwide [1]. This can only be attained when growers and various other actors along the value chain approach the sector holistically. Global trade of fruits and vegetables continues to grow due to a marked increase in consumer interest, household and individual incomes, and demand for nutritious food, coupled with advancement in production technology and availability of markets [2,3].

Exports of fruits and vegetables from Sub-Saharan Africa into mainland USA and Europe are on the rise [4,5]. Among the most produced and exported fruits are mangoes, *Mangifera indica* L. (Anacardiaceae), which are in great demand because of their nutritional value and taste. For example, mango is rich in β-carotene, antioxidants, polyphenols, various flavour compounds, dietary fibre, and different micronutrients and minerals [6,7].

However, the production and eventual sale of mango are constrained by serious insect pests at the pre-and postharvest stages, leading to huge losses. Chief among the pests are invasive fruit fly species, particularly the devastating Oriental fruit fly *Bactrocera dorsalis* Hendel (Diptera: Tephritidae) [8], which is a quarantine pest and not yet present in lucrative export markets such as the USA and Europe [9,10]. Due to the fear that *B. dorsalis* may find its way to Europe and the USA via infested fruits and vegetables, the importing authorities have increased restrictions on all produce entering these markets.

A quarantine pest is absent from an area perceived as endangered and thus becomes of interest to regulatory bodies who officially control the entry of host plants into the receiving area [11]. Following the first report of the occurrence of *B. dorsalis* in Africa [8], the USA government enacted the U.S. Federal Order which banned the importation into the USA of fruits and vegetables known to be hosts of the devastating pest [12]. The EU also passed strict quarantine regulations requiring a holistic approach for exported fruits [13]. Pre-harvest management techniques for fruit flies are available [14] but have holistically failed to achieve 100 % freedom from infestation, especially in fruits. This has led to interceptions at ports of entry forcing, for example African countries, to enforce a self-ban on mango exports until such a time that they demonstrate the ability to export pest-free commodities. There are various postharvest handling methods and treatments currently available in the market [15–17]. Among the treatments, heat-based treatments are very effective [18,19]. Several hot water treatment protocols at various temperature regimes and time durations on different mango cultivars and varieties have been developed in the past [20–28] and more recently by Ndlela et al. [29], Ocitti et al. [30], and Mwando et al. [31]. However, various concerns have been raised regarding the quality of fruit subjected to hot water treatment (HWT). For example, the margin of safety has been cited as a major factor impacting the quality of commodities, because most systems are unable to maintain the temperature within set ranges [32]. In addition, some temperature-treatment duration regimes have been shown to affect the appearance and quality of some fruits [33,34]. Self et al. [28] reported adverse effects on mangoes treated at temperatures between 46.5 °C and 51.0 °C, while undesirable effects were less pronounced at 42.0 °C and were mostly observed on immature fruits. Contrary to these reports, hot water treatment has been shown to confer desirable effects such as delayed ripening [35], reduced decay by pathogens [36], and increased shelf life [19].

Most countries are unable to export fruits to lucrative export markets due to stringent phytosanitary requirements. In response, there has been heightened interest in pursuing hot water treatment of mango, but temperature and time regimes for treatment are largely unknown, and extrapolation from work conducted on varieties and cultivars from Asia and South America may not be practical. It is against this background that this current work sought to evaluate the effect of hot water treatment on "Apple mango", a common cultivar in Africa and popular in lucrative export markets, particularly European markets. We hypothesized that HWT has no negative effect on the physical and chemical properties of mango provided the right protocol determined experimentally is used. Therefore, we explore its effect on the physical, organoleptic, and biochemical properties of "Apple mango" in the quest to guide treatment and provide empirical evidence and assurance to exporters, regulatory bodies, and consumers on the safety and non-damaging effect of HWT on mango.

2. Materials and Methods

2.1. Mango Fruits and Treatment

Physiologically mature mango, Apple cultivar, for the experiment were obtained from a farm approximately 3 ha in size, in Kilifi, North Coast Kenya (03°58′90″ S, 39°86′482″ E, 27 m above sea level). At flowering, the trees were treated with a non-systemic fungicide to control fungal diseases as described by Ndlela et al. [29], and control of fungal diseases at flowering, bagging of fruits, harvesting, and selection for subjection to hot water treatment (HWT) were done as per procedures described by Ndlela et al. [29]. Fruits were then

subjected to hot water at 46.1 °C (this is the temperature generally accepted by many authorities such as the United States Department of Agriculture (USDA) in their guidelines to HWT [37]) in a double-walled stainless-steel machine (insulated with 50 mm mineral wool and cladded with a 1.5 mm stainless steel sheet), measuring 1600 L in volume (Figure 1). The heating was achieved by 16 × 3 kW immersion heaters, controlled by a digital control panel with 0–100 °C precision PT100 sensors (Type: TLS5R-E3A11J2 + F3; Endress + Hauser, Switzerland), and 48 × 48 mm Precision Pid Temperature Controller (Omron, Osaka, Japan) hot water at 46.1 °C was circulated by a stainless-steel hot water pump (Desbro Engineering Ltd., Nairobi, Kenya) with a flow rate of 4000 litres per hour (LPH) and 12 m head to maintain a uniform temperature. Fifty mango fruits for each treatment duration were packed in perforated stainless-steel baskets (560 × 400 × 230 mm) and submerged in water at least 15 cm from the surface for 68, 75, and 84 min. An equal number of mangoes was kept untreated as a control. A subset of treated and untreated mangoes was randomly chosen at 1-, 3-, 5-, and 7-days post-treatment, and various tests were conducted in triplicate (Figure 2).

Figure 1. Insulated stainless steel hot water treatment machine. Lids were only in use during the water heating process and opened once the treatment started.

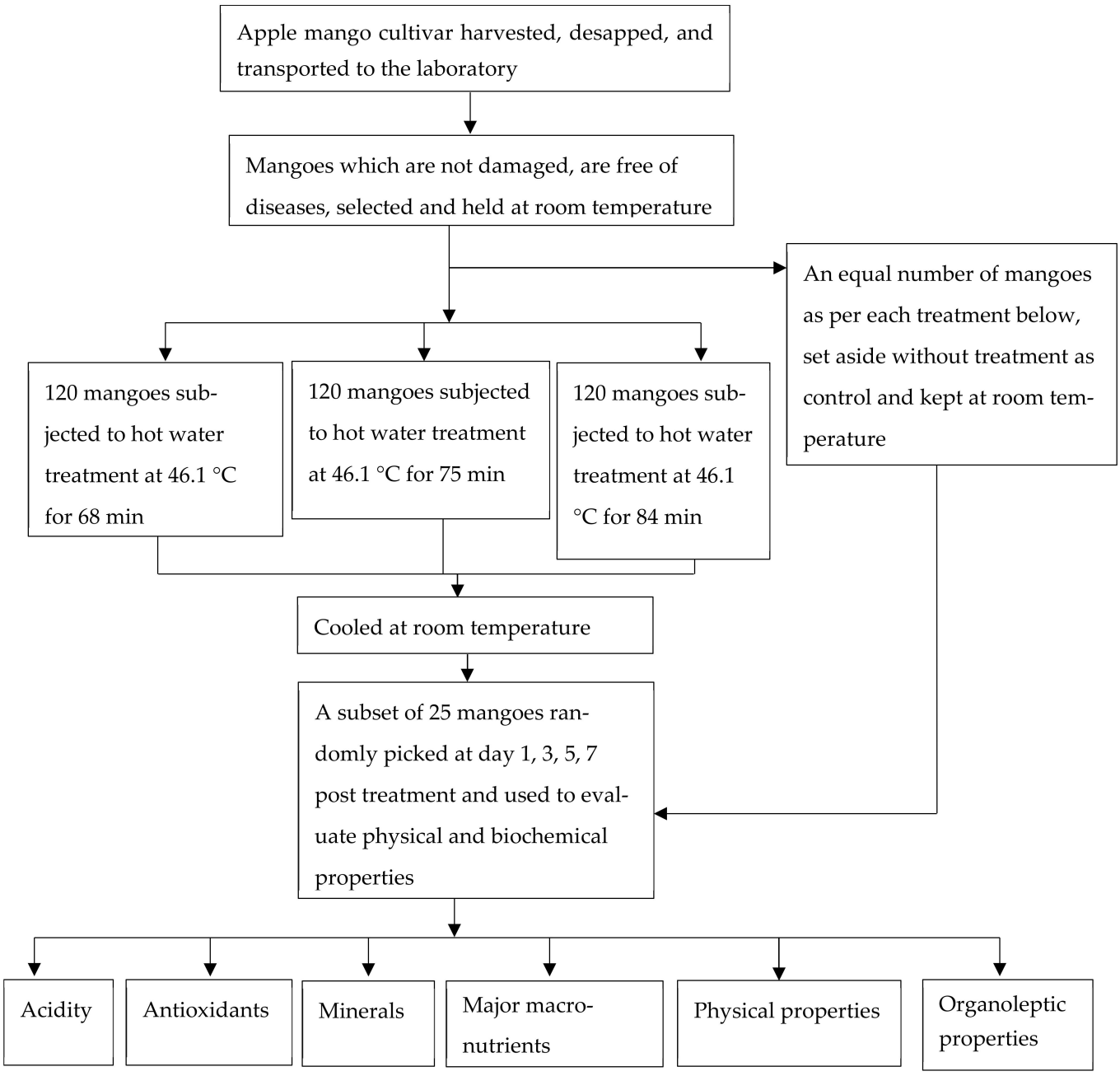

Figure 2. The general workflow of the methodology used to treat Apple mango cultivar using hot water disinfestation treatment and evaluate the treatment effect on physical and biochemical properties of the mango fruits.

2.2. Effect of Hot Water Treatment on Mango Acidity

2.2.1. Mango Pulp pH

A digital benchtop Hanna 2210-01 pH meter (Hanna Instruments, Padova, Italy) was standardized using a fresh aliquot of buffer solution before the pH of the mango juice sample was read from the digital display.

2.2.2. Titratable Acidity (TA)

Titratable acidity was determined as percent citric, tartaric, and malic acid in the mango sample using the AOAC 942:15 methods. Mango pulp (10 g) was mixed with distilled water and homogenized in a blender. The fine blended solution was then filtered into a

100 mL flask and topped up to volume with distilled water. Three drops of phenolphthalein indicator were added to 10 mL of the solution and mixed by shaking. This was then titrated against 0.1 N NaOH solution from a burette until the end-point of pink colour was attained. Titratable acidity (% citric, tartaric, and malic acid) was calculated by using the following formula:

$$\% \text{ Titratable acidity } = \frac{(T \times N \times V1 \times E)}{(V2 \times W \times 1000)} \times 100 \quad (1)$$

where T is the titre volume, N is the normality of the sodium hydroxide, V1 is the dilution factor/(volume of the sample was made up to), E is the equivalent weight of the acid, V2 is the volume of the extract/sample, and W is the weight of the sample. To express the results as % citric, tartaric, or malic acids, the milli-equivalent factors were applied as follows: (i) malic acid = 0.067; (ii) citric Acid = 0.064; and (iii) tartaric acid = 0.075.

2.3. Effect of Hot Water Treatment on Dietary Antioxidants

2.3.1. Total Carotenoids

Fresh mango samples were used to determine total carotenoids using a spectrophotometer as described comprehensively by de Carvalho et al. [38]. The processed extract was placed in a volumetric flask (50 mL), with anhydrous sodium sulphate (15 g) and volume made up by adding petroleum ether before reading at 450 nm. The total carotenoid content was then calculated using the following mathematical relationship:

$$\text{Total Carotenoid content } (\mu g/g) = \frac{A \times V(mL) \times 10^4}{A_{1cm}^{1\%} \times P(g)} \quad (2)$$

where A = absorbance, V = total extract volume, P = sample, $A_{1cm}^{1\%}$ = 2592 (β-carotene extinction coefficient in petroleum ether).

2.3.2. β-Carotene

Approximately 2 mL of extract from Section 2.3.1 above was dried under nitrogen flow and then diluted in 100 µ of acetone and subjected to high-performance liquid chromatography (HPLC) for analysis as described by de Carvalho et al. [38]. β-Carotene was then estimated using the following formula:

$$\beta - \text{Carotene } (\mu g/g) = \frac{A_X \times C_s\left(\frac{\mu g}{mL}\right) \times V(mL)}{A_s \times P(g)} \quad (3)$$

where A_X = carotenoid peak area, C_s = standard concentration, V = total extract volume, As = standard area, and P = sample weight.

2.3.3. Vitamin A

Vitamin A was calculated as provitamin A (substances found in fruits and vegetables, which act as precursors to vitamin A) using the retinol activity equivalent (RAE) concept. The following conversion factors were used: 12 µg of β-carotene, 24 µg of α-carotene, and 24 µg of β-cryptoxanthin stands for 1 RAE [39].

2.3.4. Aromatic Volatiles as Terpenoids

Terpenoid content was determined according to the method using linalool as the standard for estimation described by [40]. Reagents used were sulfuric acid, methanol, the standard linalool, and chloroform. After the nine steps of sample handling described by Ghorai et al. [40], an aliquot of the sample was transferred to the colorimetric cuvette, and absorbance read at 538 nm against a 95 % (v/v) methanol blank. Terpenoid content was then determined by calibrating the linalool curve and expressing the result as weight equivalents of linalool per weight of dry weight (mg linalool/g DW) using the regression equation of the linalool standard curve.

2.3.5. Total Phenolics

Mango pulp was centrifuged at 1000× *g* for 10 min and used in assays using the Folin–Ciocalteu method employed by Kaur and Kapoor [41]. The methods are summarized by Baba and Malik [42]. Approximately 1 mg/mL of the centrifuged mango sample was topped up to 3 mL with distilled water and then mixed with the test reagent (Folin–Ciocalteu) and 2 mL sodium carbonate (20 % (*w*/*v*)) and placed in the dark for one hour before reading absorbance at 650 nm with methanol as a blank. The calibration curve was then used to quantify the total phenolic content expressed as mg of gallic acid equivalent per g dry weight.

2.3.6. Total Antioxidant Activity

Total antioxidant activity was quantified using the 2-diphenyl-1-picrylhydrazyl (DPPH) method as outlined by Pavithra and Vadivukkarasi [43]. Approximately 1 mL of mango sample was thoroughly mixed with a similar volume of 0.8 mmol/L DPPH solution. After 30 min, the absorbance was read at 517 nm against a blank (gallic acid and butylated hydroxytoluene (BHT) were used as standards). The antioxidant activity was then estimated as percent inhibition for scavenging DPPH using the following formula:

$$\% \text{ decolourization} = \left[1 - \left(\frac{\text{Absorbance of sample}}{\text{Absorbance of control}}\right)\right] \times 100 \quad (4)$$

2.4. Effect of Hot Water Treatment on Minerals

2.4.1. Total Iron

A 10 g sample of mango pulp was ashed in the furnace at 550 °C for 4 h and thereafter allowed to cool. Distilled water was then added to wet the sample, and 2 mL of 65% nitric acid was added to the mixture. The mixture was evaporated to dryness and reheated for 60 min at a similar temperature used previously for ashing. Thereafter, the sample was cooled, and 5 mL of hydrochloric acid (1:1 by volume) was added topped to the mark in a 50 mL flask with distilled water. Hydroxylamine hydrochloride (1 mL) was added to 10 mL of the test substance and left for 5 min, after which ammonium acetate buffer (5 mL) and the inhibitor, 1,10-phenanthroline (4 mL), were added and allowed to stand for 20 min. Absorbance on the spectrophotometer was then read at 510 nm using calibration curves of standards in the range 0–2.5 ppm prepared similarly to the test samples.

2.4.2. Copper

Sample processing was similar as in iron determination (Section 2.4.2) except that after the addition of hydrochloric acid, the solution was passed through medium filters into plastic bottles. Copper was determined by an atomic absorption spectrometer using an air/acetylene flame. Analyses were carried out at the Cu 324.8 nm spectral line. The calibration line was determined at a concentration between 0.00 and 5.00 μg mL^{-1}.

2.4.3. Potassium

Potassium content was determined as in Sections 2.4.2 and 2.4.3 except that the analysis was conducted at analytical spectral line K 766.5 nm.

2.4.4. Calcium

Calcium content in the fruits was determined using the atomic absorption spectrophotometric (AAS) method Siong et al. [44] at a wavelength of 422.7 nm using an air/acetylene flame. Ten grams of homogenized sample was dried in an oven at 105 °C for 2 h and thereafter charred until smoking ceased completely. The resulting sample was then ashed in a muffle furnace at 550 °C for 6 h and then placed in a 250 mL flask. This was made up to volume, and then an aliquot of the same was used in the calcium determination process. Four calcium concentrations were used to prepare a calibration curve using calcium carbonate as a blank. Lanthanum was added to the test ash solution calcium carbonate standard

solution to eliminate phosphorous interference. Three readings of calcium concentration were obtained from the prepared standard curve and averaged.

2.4.5. Electrolyte Leakage

A cock bore was used to cut the mango into disks measuring (7 × 10 mm), which were then rinsed with deionized water and mixed with 30 mL of 0.65 M isotonic mannitol solution at room temperature (25–27 °C) for 4 h. The samples were taken through 2 cycles of freezing at −20 °C and thawing at room temperature, after which total electrolytes were determined. Electrical conductivity was measured using a conductivity meter (Hanna Instruments, Padovana, Italy), and electrolyte leakage was calculated as percentage of the conductivity of total tissue electrolytes.

2.4.6. Residue on Ignition

A porcelain crucible was ignited at 550 °C for 30 min and cooled in a desiccator and then weighed. Ten grams of mango sample was placed in the crucible and moistened with 1 mL of sulphuric acid and gently heated at low temperature until charred. This was cooled and moistened again with sulphuric acid as above. This was then subjected to heat at 550 °C, with no flames until no more white fumes were emitted and the residue completely incinerated. The crucible was cooled in a desiccator and then weighed to calculate percentage of residue.

2.5. Effect of Hot Water Treatment on Major Macronutrients

2.5.1. Crude Protein

Total nitrogen (crude protein (N × 6.25)) of Apple mango pulp was determined by the micro-Kjeldahl procedure [45]. The method uses a semi-automatic digestion system (Model DK-20/26; Velp Scientifica, Usmate Velate, Italy) and distillation by a glass distillation apparatus (Pyrex East Africa, Nairobi, Kenya). The protein nitrogen was transformed to ammonium sulphate by hot digestion of the pre-dried sample with 98 % concentrated sulfuric acid in the presence of 1 g of sodium sulphate mixture (a catalyst) mixed with anhydrous copper sulphate in a ratio of 10:1. Ammonia was liberated from the sulphate by distillation in the presence of 40 % sodium hydroxide and driven into a known volume of 4 % boric acid solution. From the ammonium borate complex formed, the amount of ammonium ion attached to borate was titrated with standardized 0.1 M hydrochloric acid (HCL). A blank test and a urea control were used for each sample determination. The percent of nitrogen content was determined as follows:

$$\text{Nitrogen \%} = \frac{\text{V(HCL)} \times \text{N(HCL)} \times 14(\text{Relative molecular weight of Nitrogen})}{\text{Sample weight on a dry matter basis}} \quad (5)$$

where V is the volume of HCL in litres consumed to the endpoint of the titration, N is the normality of HCL used (often 0.1 N), and 14.00 is the relative molecular weight of nitrogen.

The percent of nitrogen was converted to percent of protein by using an appropriate conversion factor:

$$\%\ Protein = \%\ N \times 6.25 \quad (6)$$

2.5.2. Total Carbohydrates

Analytical grade glucose (Rankem, Radnor City, PA, USA), fructose, sucrose, starch, phenol, and potassium hydroxide (obtained from Loba Chemie), concentrated sulfuric acid (obtained from ACROS), polygalacturonic acid (PGA), xanthan and dextran, and agarotetraitol (Central Drug House (P) Ltd—CDH, New Delhi, India) were used in this experiment. A stock solution of each carbohydrate was prepared by dissolving 0.1 g of dry carbohydrate in 1 L of double Millipore water (DDI). Since PGA is insoluble in water, it was dissolved to completion by the addition of potassium hydroxide, until the pH of the solution was 12.4. Thereafter, various dilutions of the stock carbohydrate solutions were prepared by pipetting a known volume of the stock solution and completing the volume

with DDI water. Absorption measurements were then made on a Spectrophotometer (Specord 210-model, Analytic Jena, Jena, Germany).

2.5.3. Total Sugars

Sugar content in mango samples was quantified using the Lane and Eynon titration method. Five grams of mango pulp was mixed with 100 mL of warm water in a beaker and stirred to allow the soluble matter to dissolve completely. The resulting solution was then filtered into a 250 mL volumetric flask using Whatman filter paper. Soon after, 100 mL of the solution was pipetted into a conical flask, and 10 mL of diluted hydrogen chloride was added and boiled for 5 min. This was allowed to cool before 10 % sodium hydroxide was added to neutralize phenolphthalein and topped to 250 mL. The solution was then titrated against Fehling's solution, and readings were calculated using the following formula:

$$\% \text{ Total sugar} = \frac{\text{Factor } (4.95) \times \text{Dilution}(250)}{\text{Titre } \times \text{Weight of sample } \times 10} \quad (7)$$

2.5.4. Ether Extracts

The gravimetric Mojonnier tube AOAC method 925 was modified to accommodate working with mango pulp. Ten grams of mango pulp was placed into the borosilicate Mojonnier tube and mixed thoroughly with 1 mL of 0.88 ammonia and 10 mL of ethanol. The mixture was left to cool, and 25 mL of diethyl ether was added and mixed by shaking. Thereafter, 25 mL of petroleum ether was added and left to stand for 1 h. The extraction process was repeated 3 times using a mixture of ethanol (5 mL), diethyl ether (25 mL), and petroleum ether (25 mL). A rotary evaporator was then used to distil the solvents, and residues were dried in a flask, then weighed. The content of fat (%) was then estimated using the formula:

$$\% \text{ Fat content} = \frac{W1 - W2}{W3} \times 100 \quad (8)$$

where $W1$ is the weight of the empty flask (g), $W2$ represents the weight of flask plus the fat (g), and $W3$ is the weight of sample taken (g).

2.6. Effect of Hot Water Treatment on Physical Properties

2.6.1. Moisture Content

Aluminium dishes and mango puree were weighed separately using an analytical scale (Radwag model RS 310), and their weights were recorded as M_0 and M_1, respectively. The puree samples were dried overnight in an oven (Nabertherm oven, model RT-120), set at 105 °C, and the new weight was recorded as M_2. The moisture content (M), as a percentage by mass of the puree sample (g per 100 g), was calculated as

$$M = \frac{M_1 - M_0}{M_1 - M_2} \times 100 \quad (9)$$

where M_0 is the mass of the aluminium dish (g), M_1 is the mass of the dish and the puree sample before drying (g), and M_2 is the mass of the dish and the sample after drying (g).

2.6.2. Dry Matter

A fresh sample of mango was taken and weighed before drying in an oven until all the moisture had evaporated. Thereafter, the sample was weighed again to obtain the weight when dry. The following formula was then used to estimate the dry weight:

$$\% \text{ dry matter } = \frac{\text{weight after drying in the oven}}{\text{weight before drying}} \times 100 \quad (10)$$

2.6.3. Crude Fibre

Two grams of mango sample was placed in a tall 600 mL beaker and digested using 1.25 % sulphuric acid by boiling for 30 min. Thereafter, this was washed three times using distilled water and then boiled for 30 min in 1.25 % sodium hydroxide solution to further digest the sample. This was then filtered using a Gooch crucible (75–76 µm, coarse porosity) under vacuum, refluxed, and the residue washed with distilled water. The residue was dried in an oven for one hour, cooled in a desiccator, and weighed (weight recorded as *W*1). This was followed by ashing at 550 °C until a constant weight was attained using the procedure for crude ash determination described in this paper, cooled in desiccators, weighed, and recorded as *W*2. The total crude fibre was estimated using the following mathematical expression:

$$\% \text{ Fiber content } = \frac{W1 - W2}{W3} \times 100 \quad (11)$$

2.6.4. Total Soluble Solids

A drop of pure mango juice was placed on the prism plate of a digital refractometer (Model AR2008/AR4, Kruess optronics, Hamburg, Germany) with an inbuilt automatic temperature correction system set at 20 °C. The reading was taken directly from the LCD screen and expressed as degree Brix (°Bx).

2.6.5. Fruit Firmness

Fruit firmness was measured using a penetrometer. Firmness was estimated as the maximum force required to penetrate 5 mm of the mango using an 8 mm flat-tipped cylindrical stainless-steel probe. This was recorded in kg/cm^2.

2.6.6. Weight Loss

Mango fruits were weighed soon after being subjected to hot water treatment. The same fruits were subsequently weighed every day at the same time of the day. Weight loss was then estimated as percent loss in weight in relation to the initial weight on day one.

2.7. Effect of Hot Water Treatment on Organoleptic Properties

A panel of 8 judges was employed to carry out a sensory evaluation of the skin colour, flesh colour, flavour, aftertaste, and texture on both treated and untreated mango fruits using a scoring scale as shown in Table 1. Three mangoes were randomly picked from each treatment for the sensory evaluation with three replications.

Table 1. Scoring scale for organoleptic properties of Apple mango.

Flesh Colour %	white to deep yellow				
	0–20	21–40	41–60	61–80	81–100
Skin Colour %	green to orange				
	0–20	21–40	41–60	61–80	81–100
Texture @ Tasting (Mouth Feel) %	very tender	slightly tender	tender	not tender (a bit crunchy)	hard to press (very crunchy)
	0–20	21–40	41–60	61–80	81–100
Flavour %	bland	bitter	sour	sweet	very sweet
	<10	11–30	31–55	56–79	80–100
Aftertaste %	bland	bitter	sour	sweet	very sweet
	<10	11–30	31–55	56–79	80–100

2.8. Statistical Analysis

The effect of days post-treatment at each exposure time on the physical and biochemical parameters of hot water treated and untreated mangos were analysed using two-way analysis of variance (ANOVA). Similarly, the effect of exposure time on these parameters (overall mean for each parameter) was analysed using ANOVA. Once a significant difference was detected, data were subjected to post hoc analysis using the Tukey test at $\alpha = 0.05$. The overall means for each parameter (mean of 7 days post-treatment) at each exposure time were compared between treated and untreated samples using a *t*-test. All analyses were performed using R software version 4.0.0.

3. Results

3.1. Effect of Hot Water Treatment on Mango Acidity

Subjecting physiologically mature Apple mango fruits to hot water at 46.1 °C for 68, 75, and 84 min did not have a significant effect on mango pulp pH, citric, tartaric, or malic acid levels between the treated and untreated (control) (Table 2). However, all the above four acidity parameters decreased with an increasing number of days post-treatment in all treatment durations between treated and untreated fruits (Table 2). Moreover, there was significant interaction effects between storage time (days) and exposure time (min) for mango pulp pH ($F = 6.358$, df = 3.88, $p < 0.001$), citric ($F = 8.980$, df = 3.88, $p < 0.001$), tartaric ($F = 0.334$, df = 3.88, $p < 0.001$), and malic acid ($F = 0.334$, df = 3.88, $p < 0.001$).

3.2. Effect of Hot Water Treatment on Dietary Antioxidants

Total carotenoids increased throughout the post-treatment period in both the treated and control fruits. This was also true for β-carotene, vitamin A, aromatic volatiles, and total antioxidant activity (Table 3). Total antioxidant activity generally increased for both treated and untreated fruits over the first six days post-treatment and then decreased slightly on day 7 (Table 3). However, there was a general decrease in total phenolic content over the same duration. The overall mean of the six tested antioxidant contents was not significantly different between the treated and control fruits (Table 3) except for total antioxidant activity, which differed significantly at 68 and 84 but not at 75 min treatment duration. There was significant interaction effect between mango storage time (days) and exposure time (min) for only total antioxidant activity ($F = 5.086$, df = 3.88, $p = 0.0027$). The other parameters total carotenoids ($F = 2.190$, df = 3.88, $p = 0.0949$), β-carotene ($F = 0.864$, df = 3.88, $p = 0.4629$), vitamin A ($F = 0.864$, df = 3.88, $p = 0.4629$), aromatic volatiles ($F = 15.488$, df = 3.88, $p < 0.001$), and total phenolics ($F = 2.225$, df = 3.88, $p < 0.0908$) were not affected by the interaction of the two factors.

3.3. Effect of Hot Water Treatment on Minerals

Total iron and copper were trace elements in the mango and were detected at very low levels. Potassium, calcium, electrolyte leakage, and residue on ignition varied significantly when mangoes were kept for 7 days post-treatment for both treated and untreated fruits (Table 4). Electrolyte leakage varied significantly over duration in storage following subjection to hot water treatment for 68, 75, and 84 min and also in the untreated control. A similar trend was observed on mangoes treated for 75 and 84 min. The overall effect of time in days post-treatment on electrolyte leakage between hot water treated and untreated fruits also differed significantly at 68 min but not on the overall effect of time in days post-treatment in treated and untreated fruits at 75- and 84-min exposure times (Table 4). There was a significant interaction effect between storage time in days and exposure time (min) on potassium ($F = 3.182$, df = 3.88, $p = 0.0278$) and electrolyte leakage ($F = 3.132$, df = 3.88, $p = 0.0296$) but not on calcium ($F = 0.719$, df = 3.88, $p = 0.543$) and residue on ignition ($F = 2.476$, df = 3.88, $p = 0.0666$).

3.4. Effect of Hot Water Treatment on Major Macronutrients in Apple Mango Cultivar

Crude protein varied significantly among days post-treatment for 68 and 84 min of submersion in hot water for both treated and untreated (but not at 75 min). The overall effect of time in days post-treatment on crude protein between hot water treated and untreated fruits also differed significantly at 84 and 75 min but not at 68 min exposure times (Table 5). The highest crude protein content was recorded on untreated mango fruits on day five for 84 min of exposure, while the lowest was recorded on treated fruits on day seven post-treatment for 68 min of exposure (Table 5).

Carbohydrates, total sugars, and ether extracts varied significantly among days post-treatment for 68, 75, and 84 min of submersion in hot water for both treated and untreated fruits. The overall effect of time in days post-treatment on carbohydrates between hot water treated and untreated fruits also differed significantly at 68 min treatment duration (Table 5). The highest carbohydrate content was recorded on treated mango fruits on day five for 84 min of exposure, while the lowest was recorded on treated fruits on day one post-treatment for 68 min of exposure (Table 5).

Total sugars and total soluble solids increased with an increase of time in days for both hot water treated and untreated fruits at all fruit exposure times (Table 5). There was a significant interaction effect between storage time (days) and treatment exposure time (min) on the parameters crude protein ($F = 3.244$, $df = 3.88$, $p = 0.0257$), carbohydrates ($F = 1.572$, $df = 3.88$, $p = 0.202$), ether extracts ($F = 3.948$, $df = 3.88$, $p = 0.0108$) and total soluble solids ($F = 4.931$, $df = 3.88$, $p = 0.00327$); however, the total sugar ($F = 0.621$, $df = 3.88$, $p = 0.6033$) was not affected by the interaction of the factors.

3.5. Effect of Hot Water Treatment on Physical Properties in Apple Mango Cultivar

Moisture content decreased significantly in both treated and untreated fruit as days in storage increased. Overall, there was a slight difference in moisture content between mangoes subjected to treatment at 68 min and the untreated lot after 7 days of storage, while no significant differences were observed with mangoes treated at 75 and 84 min (Table 6).

Dry matter content varied significantly among the three treatment regimens over the seven days storage period in both treated and untreated fruits. Dry matter was lower in treated than in control fruit but significantly so at 68 min compared to 75 and 84 min (Table 6). The other physical properties tested were crude fibre, total soluble solids (TSS), fruit firmness, and weight. Overall, crude fibre content was comparable between the treated and untreated fruits at all treatment durations. However minor variations were observed during the storage period from treatment to seven days (Table 6). Fruit firmness decreased gradually in both treated and untreated fruit at all durations of treatment. However, overall firmness after 7 days of storage was comparable between the treated and untreated fruits.

Both treated and untreated mangoes significantly lost weight over the storage period regardless of the treatment duration. The greatest weight loss was recorded between days 3 and 5 and stabilized thereafter to minimal levels in both treated and untreated fruits (Table 6). Nonetheless, the overall weight after 7 days of storage was comparable between the treated and untreated fruits.

There was a significant interaction effect between storage time (days) and exposure time (min) on the parameters fruit firmness ($F = 5.546$, $df = 3.88$, $p < 0.001$) and weight ($F = 11.93$, $df = 3.88$ $p < 0.001$) but not on the moisture content ($F = 1.466$, $df = 3.88$, $p = 0.22934$), dry matter content ($F = 1.466$, $df = 3.88$, $p = 0.229$), or crude fibre ($F = 0.392$, $df = 3.88$, $p = 0.759$).

Table 2. Effect of hot water treatment at 46.1 °C for different treatment durations on the acidity of Apple mango cultivar stored over 7 days post-treatment.

Parameter	Time	Days Post-Treatment (Means ± Standard Error)										Statistics			
		1		3		5		7		Overall		Treatment		Storage for 7 Days	
		Treated	Untreated	Treated	Untreated	Treated	Untreated	Treated	Untreated	Treated	Untreated	t	*p*	F	*p*
pH (1–14)	68	2.90 ± 0.01 a	2.83 ± 0.00 a	3.06 ± 0.00 b	2.83 ± 0.00 b	4.10 ± 0.00 c	3.79 ± 0.00 c	4.28 ± 0.00 d	4.64 ± 0.00 d	3.58 ± 0.18 A	3.62 ± 0.20 A	0.15	0.88	17,627	**
	75	2.89 ± 0.00 a	2.75 ± 0.00 a	3.31 ± 0.01 b	3.35 ± 0.01 b	3.46 ± 0.00 c	3.83 ± 0.00 c	4.28 ± 0.00 d	4.64 ± 0.00 d	3.58 ± 0.18 A	3.62 ± 0.20 A	0.55	0.59	6397	**
	84	2.82 ± 0.00 a	2.85 ± 0.00 a	3.37 ± 0.00 b	3.02 ± 0.01 b	3.85 ± 0.01 c	3.98 ± 0.00 c	4.24 ± 0.00 d	4.41 ± 0.01 d	3.57 ± 0.16 A	3.56 ± 0.20 A	0.02	0.98	12,943	**
Citric Acid %	68	1.39 ± 0.00 d	1.82 ± 0.00 d	1.09 ± 0.00 c	0.87 ± 0.01 c	0.56 ± 0.00 b	0.56 ± 0.01 b	0.25 ± 0.00 a	0.19 ± 0.00 a	0.82 ± 0.13 A	0.87 ± 0.18 A	0.19	0.85	28,018	**
	75	1.76 ± 0.02 d	2.38 ± 0.03 d	0.94 ± 0.00 c	0.83 ± 0.02 c	0.83 ± 0.01 b	0.49 ± 0.00 b	0.24 ± 0.00 a	0.18 ± 0.00 a	0.95 ± 0.16 A	0.97 ± 0.26 A	0.56	0.97	3639	**
	84	1.96 ± 0.03 d	1.88 ± 0.01 d	0.78 ± 0.00 c	1.32 ± 0.01 c	0.49 ± 0.00 b	0.37 ± 0.00 b	0.24 ± 0.00 a	0.19 ± 0.00 a	0.87 ± 0.20 A	0.94 ± 0.21 A	0.29	0.78	2771	**
Tartaric Acid %	68	1.62 ± 0.01 d	2.12 ± 0.01 d	1.26 ± 0.02 c	1.03 ± 0.01 c	0.66 ± 0.00 b	0.66 ± 0.00 b	0.30 ± 0.00 a	0.22 ± 0.00 a	0.96 ± 0.15 A	1.01 ± 0.21 A	−0.24	0.81	1911	**
	75	0.99 ± 0.00 d	2.77 ± 0.06 d	2.08 ± 0.01 c	1.00 ± 0.02 c	0.28 ± 0.00 b	0.57 ± 0.00 b	1.10 ± 0.00 a	0.21 ± 0.00 a	1.11 ± 0.19 A	1.14 ± 0.30 A	−0.09	0.93	12,101	**
	84	2.36 ± 0.02 d	0.43 ± 0.00 d	0.91 ± 0.00 c	2.20 ± 0.01 c	0.58 ± 0.00 b	0.22 ± 0.00 b	0.28 ± 0.00 a	1.53 ± 0.01 a	1.03 ± 0.24 A	1.20 ± 0.24 A	−0.21	0.83	5909	**
Malic Acid %	68	1.44 ± 0.01 d	1.90 ± 0.01 d	1.15 ± 0.00 c	0.91 ± 0.01 c	0.59 ± 0.00 b	0.59 ± 0.00 b	0.27 ± 0.00 a	0.20 ± 0.00 a	0.86 ± 0.12 A	0.90 ± 0.19 A	−0.20	0.84	5910	**
	75	1.85 ± 0.01 d	2.54 ± 0.03 d	0.99 ± 0.00 c	0.89 ± 0.02 c	0.89 ± 0.00 b	0.51 ± 0.00 b	0.25 ± 0.00 a	0.19 ± 0.00 a	0.99 ± 0.17 A	1.03 ± 0.27 A	1.97	0.10	10,396	**
	84	2.02 ± 0.04 d	1.96 ± 0.01 d	0.81 ± 0.00 c	1.37 ± 0.00 c	0.52 ± 0.00 b	0.38 ± 0.00 b	0.25 ± 0.00 a	0.20 ± 0.00 a	0.90 ± 0.20 A	0.98 ± 0.22 A	−0.31	0.76	1715	**

Means within each column for each parameter followed by the same small letter are not significantly different, while means (treated vs. control) for each treatment duration for each day across the rows followed by the same small letter are also not significantly different according to the Tukey test, at $\alpha = 0.05$. Overall, means between treatment and control within a row followed by the same capital letter are not significantly different according to the *t*-test. ** Denotes significant differences ($p < 0.01$) in means of parameters for storage periods from day 1 to 7.

Table 3. Effect of hot water treatment at 46.1 °C for different treatment durations on the dietary antioxidants of Apple mango cultivar stored over 7 days post-treatment.

Parameter	Time	Days Post-Treatment (Means ± Standard Error)								Statistics			
		1		3		5		7		Overall		Treatment		Storage for 7 Days	
		Treated	Untreated	Treated	Untreated	Treated	Untreated	Treated	Untreated	Treated	Untreated	t	*p*	F	*p*
Total Carotenoids (mg/kg)	68	24.51 ± 0.86 a	40.91 ± 0.64 a	54.19 ± 0.51 b	42.32 ± 0.34 a	61.48 ± 0.20 c	60.18 ± 0.09 b	88.02 ± 0.60 d	98.45 ± 0.67 c	57.05 ± 6.82 A	60.47 ± 7.00 A	0.41	0.69	1942	**
	75	30.68 ± 0.16 a	35.86 ± 0.13 a	33.91 ± 2.56 a	52.95 ± 4.40 b	48.57 ± 0.62 b	56.32 ± 0.46 c	104.26 ± 0.71 c	118.12 ± 0.36 d	54.35 ± 8.94 A	65.81 ± 9.45 A	26.12	16.79	625.6	**
	84	35.86 ± 0.13 a	31.91 ± 0.62 a	52.95 ± 4.40 b	42.19 ± 0.21 b	56.32 ± 0.46 b	66.36 ± 0.16 c	118.12 ± 0.36 c	129.57 ± 0.21 d	65.81 ± 9.45 A	67.51 ± 11.4 A	0.13	0.89	263	**
β-Carotene Content (mg/kg)	68	7.78 ± 0.35 a	27.61 ± 0.78 a	35.10 ± 1.20 b	27.94 ± 0.96 a	42.11 ± 1.33 c	40.86 ± 0.62 b	59.04 ± 0.89 d	59.25 ± 1.23 c	36.01 ± 5.59 A	38.92 ± 3.9 A	0.50	0.62	441.2	**
	75	20.55 ± 0.33 a	21.67 ± 0.56 a	23.66 ± 2.35 a	32.96 ± 0.58 b	34.83 ± 0.56 b	35.52 ± 0.80 b	77.17 ± 0.68 c	78.52 ± 0.45 c	39.05 ± 6.85 A	42.17 ± 6.52 A	0.38	0.70	425.3	**
	84	21.57 ± 0.61 a	20.50 ± 0.62 a	33.85 ± 1.57 b	30.87 ± 0.40 b	41.49 ± 0.39 c	50.30 ± 0.58 c	85.13 ± 0.55 d	89.89 ± 1.48 d	45.51 ± 7.23 A	47.89 ± 7.10 A	0.26	0.80	935.3	**
Vitamin A (mcg Retinol)	68	1.30 ± 0.06 a	4.61 ± 0.13 a	5.86 ± 0.20 b	4.67 ± 0.16 a	7.03 ± 0.22 c	6.82 ± 0.10 b	9.86 ± 0.15 d	9.90 ± 0.21 c	6.01 ± 0.93 A	6.50 ± 0.65 A	0.43	0.67	441.2	**
	75	3.43 ±0.06 a	3.62 ± 0.09 a	3.95 ± 0.39 a	5.50 ± 0.10 b	5.82 ± 0.09 b	5.93± 0.13 b	12.89 ± 0.11 c	13.11 ± 0.07 c	6.52 ± 1.14 A	7.04 ± 1.09 A	0.33	0.75	425.3	**
	84	3.60 ± 0.10 a	3.42 ± 0.10 a	5.65 ± 0.26 b	5.16 ± 0.07 b	6.93 ± 0.07 c	8.40 ± 0.10 c	14.22 ± 0.09 d	15.01 ± 0.25	7.60 ± 1.21 A	7.10 ± 1.34 A	0.22	0.83	935.3	**
Aromatic Volatiles: Terpenoids (mg/kg)	68	0.01 ± 0.00 a	0.01 ± 0.00 a	0.09 ± 0.01 a	0.90 ± 0.05 b	1.76 ± 0.06 b	1.23 ± 0.02 b	2.86 ± 0.05 c	3.34 ± 0.32 c	1.18 ± 0.31 A	1.24 ± 0.30 A	0.36	0.72	572.9	**
	75	0.01 ± 0.00 a	0.01 ± 0.00 a	0.20 ± 0.04 a	0.24 ± 0.04 a	0.96 ± 0.06 b	1.46 ± 0.06 b	4.50 ± 0.23 c	4.97 ± 0.23 c	1.42 ± 0.48 A	1.67 ± 0.52 A	0.31	0.76	229.3	**
	84	0.01 ± 0.00 a	0.01 ± 0.00 a	0.23 ± 0.02 a	0.21 ± 0.01 a	1.06 ± 0.03 b	1.48 ± 0.08 b	4.50 ± 0.23 c	4.97 ± 0.31 c	1.45 ± 0.47 A	1.67 ± 0.52 A	0.26	0.79	240	**
Total Phenolics (mg/kg)	68	1328.79 ± 36.75 a	1365.68 ± 18.01 a	1427.65± 10.71 b	1314.43 ± 7.68 a	1591.90 ± 0.50 c	1473.88 ± 39.46 b	1386.41 ± 16.62a b	1522.27 ± 10.18 b	1433.69 ± 30.82 A	1419.07 ± 26.77 B	20.56	<0.001	29.32	**
	75	1282.29 ± 14.5 b	785.13 ± 25.01 a	817.43 ± 70.12 a	869.38 ± 25.25 a	793.63 ± 25.08 a	1195.89± 6.64 b	1438.09 ± 15.63 b	1366.88 ± 20.17 c	1082.86 ± 86.87 A	1054.32 ± 71.96 A	0.36	0.72	71.11	**
	84	1240.76 ± 10.05 b	1289.54 ± 0.08a b	1252.48 ± 25.52 b	1440.49 ± 20.09 b	831.25 ± 1.09 a	1057.98 ± 133.88 a	1250.89 ± 28.17 b	1334.71 ± 71.37a b	1143.85 ± 55.07 A	1280.68 ± 53.30 B	0.25	0.80	112.4	**
Total Antioxidant Activity (%)	68	9.75 ± 0.02 c	7.91 ± 0.05 a	9.88 ± 0.00 d	9.65 ± 0.00 b	9.61 ± 0.00 b	9.63 ± 0.00 b	9.54 ± 0.00 a	9.55 ± 0.00 a	9.69 ± 0.04 A	9.19± 0.22 B	2.64	0.01	173.9	**
	75	9.74 ± 0.01 d	9.76 ± 0.01 d	9.64 ± 0.02 c	9.67 ± 0.00 c	9.59 ± 0.04 b	9.63 ± 0.00 b	9.52 ± 0.00 a	9.54 ± 0.01 a	9.62 ± 0.03 A	9.65 ± 0.02 A	0.07	0.04	21.4	**
	84	9.72 ± 0.00 d	9.74 ± 0.01 c	9.67 ± 0.00 c	9.69 ± 0.01 c	9.60 ± 0.00 b	9.61 ± 0.00 b	9.52± 0.00 a	9.53 ± 0.01 a	9.63 ± 0.02 A	9.64 ± 0.03 A	0.81	0.42	1556	**

Means within each column for each parameter followed by the same small letter are not significantly different, while means (treated vs. control) for each treatment duration for each day across the rows followed by the same small letter are also not significantly different according to the Tukey test, at $\alpha = 0.05$. Overall, means between treatment and control within a row followed by the same capital letter are not significantly different according to the *t*-test. ** Denotes significant differences ($p < 0.01$) in means of parameters for storage periods from day 1 to 7.

Table 4. Effect of hot water treatment at 46.1 °C for different treatment durations on the minerals of Apple mango cultivar stored over 7 days post-treatment.

Parameter	Time	Days Post-Treatment (Means ± Standard Error)										Statistics			
		1		3		5		7		Overall		Treatment		Storage for 7 Days	
		Treated	Untreated	Treated	Untreated	Treated	Untreated	Treated	Untreated	Treated	Untreated	t	*p*	F	*p*
Total Iron (mg/kg)	68	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	-	-	-	-
	75	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	-	-	-	-
	84	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	-	-	-	-
Copper (mg/kg)	68	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	-	-	-	-
	75	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	-	-	-	-
	84	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	-	-	-	-
Potassium (mg/kg)	68	0.22 ± 0.01 c	0.26 ± 0.00 c	0.15 ± 0.00 b	0.12 ± 0.00 a	0.13 ± 0.00 a	0.10 ± 0.00 a	0.14 ± 0.01 ab	0.14 ± 0.01 b	0.15 ± 0.01 A	0.15 ± 0.02 A	0.26	0.80	73.49	**
	75	0.11 ± 0.02 a	0.28 ± 0.01 c	0.17 ± 0.01 b	0.12 ± 0.00 a	0.15 ± 0.00 ab	0.14 ± 0.00 b	0.13 ± 0.00 ab	0.12 ± 0.01 a	0.14 ± 0.00 A	0.17 ± 0.02 A	1.31	0.20	6.38	**
	84	0.26 ± 0.00 c	0.14 ± 0.01 a	0.12 ± 0.00 a	0.13 ± 0.01 a	0.17 ± 0.00 b	0.13 ± 0.01 a	0.16 ± 0.01 b	0.14 ± 0.01 a	0.18 ± 0.02 B	0.13 ± 0.00 A	3.04	<0.001	281.8	**
Calcium (mg/kg)	68	118.42 ± 0.41 c	157.42 ± 0.71 d	36.89 ± 0.16 a	74.50 ± 0.22 a	74.61 ± 0.93 b	118.04 ± 0.32 c	73.10 ± 0.05 b	114.21 ± 1.37 b	75.76 ± 8.71 A	116.04 ± 8.86 B	3.79	<0.001	4186	**
	75	119.01 ± 0.24 d	152.69 ± 3.57 b	37.85 ± 0.34 b	111.10 ± 0.12 a	111.94 ± 0.36 c	112.01 ± 0.05 a	75.10 ± 0.10 b	114.53 ± 2.39 a	85.97 ± 9.77 A	122.58 ± 5.33 B	3.84	<0.001	17,965	**
	84	141.85 ± 12.31 bc	157.74 ± 0.25 c	152.07 ± 0.38 c	152.85 ± 0.75 b	110.23 ± 0.26 a	113.89 ± 0.22 a	115.25 ± 2.00b c	115.80 ± 0.45 a	129.85 ± 5.93 A	135.07 ± 6.13 A	0.72	0.47	87.72	**
Electrolytic Leakage (%)	68	22.74 ± 0.12 a	23.47 ± 2.51 a	30.72 ± 0.36 b	20.71 ± 1.00 a	30.89 ± 0.19 b	31.49 ± 0.90 ab	32.59 ± 0.32 c	26.12± 0.08 b	29.24 ± 1.16 B	25.45 ± 1.34 A	0.69	0.50	275.3	**
	75	20.54 ± 0.62 a	21.58 ± 0.53 a	26.46 ± 0.25 b	23.76 ± 0.12 b	29.63 ± 0.19 c	33.56 ± 0.12 c	36.49 ± 0.98 d	41.18 ± 0.12 d	28.28 ± 1.75 A	30.02 ± 2.37 A	0.36	0.72	121.9	**
	84	23.86 ± 0.09 a	22.31 ± 0.02 a	25.06 ± 1.03 a	24.50 ± 0.31 b	38.03 ± 0.06 b	31.96 ± 0.04 c	40.94 ± 0.03 c	44.75 ± 0.07 d	31.97 ± 2.30 A	30.88 ± 2.65 A	0.36	0.72	1018	**
Residue on Ignition (%)	68	0.59 ± 0.05 b	0.53 ± 0.01 c	0.32± 0.01 a	0.28 ± 0.01 a	0.312 ± 0.01 a	0.25 ± 0.01 a	0.34 ± 0.01 a	0.35 ± 0.01 b	0.39 ± 0.04 A	0.35 ± 0.03 A	0.93	0.359	25.22	**
	75	0.44 ± 0.02 b	0.49 ± 0.02 c	0.34 ± 0.01 a	0.41 ± 0.02 b	0.31 ± 0.01 a	0.31 ± 0.00 a	0.32 ± 0.00 a	0.29 ± 0.01 a	0.35 ± 0.02 A	0.37 ± 0.03 A	0.84	0.405	27.72	**
	84	0.56 ± 0.05 b	0.44 ± 0.03 b	0.26 ± 0.02 a	0.29 ± 0.00 a	0.37 ± 0.00 a	0.27 ± 0.01 a	0.37 ± 0.01 a	0.33 ± 0.00 a	0.39 ± 0.04 A	0.33 ± 0.02 A	1.63	0.113	38.16	**

Means within each column for each parameter followed by the same small letter are not significantly different, while means (treated vs. control) for each treatment duration for each day across the rows followed by the same small letter are also not significantly different according to the Tukey test, at $\alpha = 0.05$. Overall, means between treatment and control within a row followed by the same capital letter are not significantly different according to the *t*-test. ** Denotes significant differences ($p < 0.01$) in means of parameters for storage periods from day 1 to 7.

Table 5. Effect of hot water treatment at 46.1 °C for different treatment durations on major macronutrients of Apple mango cultivar stored over 7 days post-treatment.

Parameter	Time	Days Post-Treatment (Means ± Standard Error)								Statistics					
		1		3		5		7		Overall		Treatment		Storage for 7 Days	
		Treated	Untreated	Treated	Untreated	Treated	Untreated	Treated	Untreated	Treated	Untreated	t	*p*	F	*p*
Crude Protein (%)	68	1.11 ± 0.04 a	1.19 ± 0.00 c	1.42 ± 0.11 b	1.12b ± 0.03 c	1.16 ± 0.01 ab	1.08 ± 0.01 ab	1.00 ± 0.00 a	1.01 ± 0.03 a	1.17 ± 0.05 A	1.09 ± 0.02 A	1.58	0.125	8.692	**
	75	1.63 ± 0.19 a	1.83 ± 0.00 a	1.51 ± 0.21 a	1.51 ± 0.02 a	1.36 ± 0.16 a	1.59 ± 0.00 a	1.08 ± 0.01 a	1.75 ± 0.01 a	1.39 ± 0.09 A	1.67 ± 0.06 B	3.19	0.003	2.11	0.18
	84	1.47 ± 0.1 b	1.22 ± 0.01 a	1.23 ± 0.01 ab	1.54 ± 0.18 ab	0.99 ± 0.01 a	1.89 ± 0.16 b	1.18 ± 0.01 ab	1.59 ± 0.05 ab	1.22 ± 0.06 A	1.56 ± 0.09 B	3.83	0.001	5.89	*
Total Carbo-hydrates (%)	68	9.09 ± 0.18 a	11.2 ± 0.08 a	12.29 ± 0.80 b	15.9 ± 0.06 c	14.40 ± 0.11 c	13.1± 0.02 b	12.08 ± 0.41 b	14.5 ± 0.05 c	11.96 ± 0.60 A	13.67 ± 0.55 B	2.46	0.019	22.23	**
	75	9.27 ± 0.24 a	9.13 ± 0.45 a	12.85 ± 0.43 b	12.34 ± 1.13 ab	11.68 ± 0.35 b	15.66 ± 0.33 b	14.40 ± 0.18 c	14.02 ± 1.85 ab	12.05 ± 0.58 A	12.79 ± 0.87 A	0.84	0.403	47.59	**
	84	8.45 ± 0.48 a	12.6 ± 0.62 a	18.14 ± 0.22 c	15.17± 0.10 b	11.69 ± 0.59 b	12.16 ± 0.16 a	13.16 ± 0.25 b	12.34 ± 0.03 a	12.94 ± 1.07 A	13.08 ± 0.40 A	0.14	0.888	110.4	**
Total Sugars (%)	68	1.52 ± 0.01 a	1.45 ± 0.01 a	3.79 ± 0.04 b	4.06 ± 0.03 b	5.29 ± 0.05 c	5.27 ± 0.03 c	5.37 ± 0.01 c	5.42 ± 0.02 d	3.99 ± 0.47 A	4.05 ± 0.48 A	0.06	0.94	2931.0	**
	75	1.57 ± 0.02 a	1.52 ± 0.02 a	3.79 ± 0.05 b	4.14 ± 0.02 b	5.32 ± 0.03 c	5.39 ± 0.04 c	5.32 ± 0.01 c	5.34 ± 0.01 c	4.01 ± 0.46 A	4.09 ± 0.47 A	0.18	0.859	5531	**
	84	1.53 ± 0.00 a	1.47 ± 0.01 a	3.92 ± 0.01 b	3.86 ± 0.01 b	4.74 ± 0.01 c	5.33 ± 0.03 c	5.34 ± 0.02 d	5.31 ± 0.02 c	3.88 ± 0.44 A	4.14 ± 0.47 A	0.49	0.626	6862	**
Ether Extracts (%)	68	0.57 ± 0.02 c	0.15 ± 0.00 b	0.13 ± 0.00 a	0.08 ± 0.00 a	0.25 ± 0.00 b	0.21 ± 0.00 c	0.72 ± 0.01 c	0.43 ± 0.01 d	0.41 ± 0.07 A	0.23 ± 0.04 B	2.754	0.009	771.8	**
	75	0.30 ± 0.06 c	0.16 ± 0.00 a	0.24 ± 0.02 b	0.74 ± 0.02 d	0.18 ± 0.01 a	0.52 ± 0.00 c	0.44 ± 0.00 d	0.23 ± 0.00 b	0.29 ± 0.03 A	0.41 ± 0.07 A	5.35	0.001	74.56	**
	84	0.15 ± 0.00 a	0.99 ± 0.01 d	0.15 ± 0.01 a	0.66 ± 0.02 c	0.13 ± 0.00 a	0.21 ± 0.00 a	0.29 ± 0.00 b	0.47 ± 0.00 b	0.18 ± 0.02 A	0.58 ± 0.09 B	1.85	0.074	1196	**
Total Soluble Solids (°Brix)	68	11.85 ± 0.12 b	11.33 ± 0.19 a	12.00 ± 0.00 b	12.92 ± 0.07 b	13.20 ± 0.00 c	13.17 ± 0.03 b	10.83 ± 0.17 a	13.17 ± 0.17 b	11.97 ± 0.26 A	12.53 ± 0.24 A	1.58	0.125	86.95	**
	75	9.41 ± 0.01 a	7.00 ± 0.00 a	12.37 ± 0.03 c	12.07 ± 0.07 b	13.03 ± 0.03 d	13.13 ± 0.13 c	11.12 ± 0.07 b	12.17 ± 0.08 b	11.33 ± 0.42 A	11.19 ± 0.72 A	0.19	0.85	1362	**
	84	8.61 ± 0.01 a	10.12 ± 0.01 a	12.38 ± 0.017 c	10.07 ± 0.03 a	12.39 ± 0.01 c	12.61 ± 0.02 b	11.83 ± 0.05 b	12.64 ± 0.04 b	11.39 ± 0.47 A	11.36 ± 0.38 A	0.08	0.938	4882	**

Means within each column for each parameter followed by the same small letter are not significantly different, while means (treated vs. control) for each treatment duration for each day across the rows followed by the same small letter are also not significantly different according to the Tukey test, at $\alpha = 0.05$. Overall, means between treatment and control within a row followed by the same capital letter are not significantly different according to the *t*-test. * Denotes significant differences, $p < 0.05$ while ** Denotes significant differences, $p < 0.01$, in means of parameters for storage periods from day 1 to 7.

Table 6. Effect of hot water treatment at 46.1 °C for different treatment durations on physical properties of Apple mango cultivar stored over 7 days post-treatment.

Parameter	Time	Days Post-Treatment (Means ± Standard Error)										Statistics			
		1		3		5		7		Overall		Treatment		Storage for 7 Days	
		Treated	Untreated	Treated	Untreated	Treated	Untreated	Treated	Untreated	Treated	Untreated	t	*p*	F	*p*
Moisture (%)	68	87.42 ± 0.39 c	85.74 ± 0.09 c	85.31 ± 0.89 bc	81.95 ± 0.51 a	82.60 ± 0.04 a	84.22 ± 0.19 b	85.07 ± 0.37 b	82.71 ± 0.05 a	85.12 ± 0.55 B	83.65 ± 0.45 A	2.45	0.02	15	**
	75	87.82 ± 0.11 c	87.76 ± 0.49 b	84.31 ± 0.50 ab	84.07 ± 0.95 ab	85.34 ± 0.19 b	80.77 ± 0.29 a	83.04 ± 0.17 a	83.19 ± 1.72 ab	85.13 ± 0.54 A	83.95 ± 0.88 A	1.37	0.179	49.62	**
	84	88.78 ± 0.41 d	84.33 ± 0.64 b	79.69 ± 0.10 a	81.97 ± 0.04 a	85.49 ± 0.72 c	83.96 ± 0.06 b	83.95 ± 0.04 b	84.42 ± 0.28 b	84.48 ± 0.99 A	83.67 ± 0.34 A	0.91	0.372	7.986	*
Dry Matter (%)	68	12.58 ± 0.39 a	14.26 ± 0.09 a	14.68 ± 0.89 ab	18.05 ± 0.51 c	17.30 ± 0.03 c	15.78 ± 0.19 b	14.92 ± 0.37 b	17.29 ± 0.05 c	14.88± 0.55 A	16.35 ± 0.45 B	2.452	0.021	15	**
	75	12.18 ± 0.11 a	12.24 ± 0.49 a	15.69 ± 0.50 bc	15.93 ± 0.96 ab	14.66 ± 0.01 b	19.23 ± 0.29 b	17.05 ± 0.17 c	16.81 ± 1.72 ab	14.87 ± 0.54 A	16.05 ± 0.88 A	1.37	0.179		**
	84	11.22 ± 0.41 a	15.67 ± 0.64 a	20.31 ± 0.10 d	18.03 ± 0.04 b	14.51 ± 0.38 b	16.04 ± 0.06 a	16.04 ± 0.04 c	15.58 ± 0.28 a	15.52 ± 0.99 A	16.33 ± 0.34 A	0.91	0.372		**
Crude Fibre (%)	68	1.22 ± 0.89 b	1.23 ± 0.01 c	0.54 ± 0.01 a	0.64 ± 0.08 a	1.19 ± 0.09 b	1.19 ± 0.03 c	0.79 ± 0.04 ab	0.98 ± 0.02 b	0.93 ± 0.10 A	1.01 ± 0.07 A	0.74	0.467	9.603	**
	75	0.53 ± 0.05 a	0.63 ± 0.04 ab	0.74 ± 0.09 a	0.93 ± 0.01 bc	1.14 ± 0.06 b	1.15 ± 0.04 c	0.73 ± 0.00 a	0.53 ± 0.14 a	0.78 ± 0.07 A	0.81 ± 0.08 A	0.27	0.789	15.6	**
	84	0.59 ± 0.03 a	0.38 ± 0.02 a	0.54 ± 0.05 a	0.37 ± 0.04 a	1.31 ± 0.12 b	1.50 ± 0.04 c	1.05 ± 0.28 ab	0.85 ± 0.09 b	0.85 ± 0.12 A	0.78 ± 0.14 A	0.477	0.637	5.73	**
Fruit Firmness kg/cm^2	68	30.11 ± 0.14 c	32.18 ± 0.21 d	28.81 ± 0.32 c	25.37 ± 0.15 c	19.68 ± 0.35 b	23.48 ± 0.04 b	16.02 ± 0.46 a	12.32 ± 0.18 a	23.66 ± 1.80 A	23.34 ± 2.15 A	0.13	0.895	422.4	**
	75	28.43 ± 0.76 c	33.35 ± 0.58 d	27.72 ± 0.28 c	23.76 ± 0.18 c	21.68 ± 0.54 b	19.05 ± 0.41 b	15.59 ± 0.75 a	13.51 ± 1.22 a	23.36 ± 1.59 A	22.42 ± 2.22 A	0.40	0.689	95.78	**
	84	34.17 ± 0.82 d	33.57 ± 1.51 c	28.27 ± 0.68 c	30.83 ± 0.86 c	22.57 ± 0.91 b	22.53 ± 1.02 b	13.35 ± 0.68 a	13.55 ± 0.74 a	24.59 ± 2.34 A	25.12 ± 2.40 A	0.19	0.854	128.5	**
Weight Loss (%)	68	0.00 ± 0.00 a	0.00 ± 0.00 a	2.66 ± 0.00 b	2.47 ± 0.00 b	23.19 ± 0.00 d	25.07 ± 0.00 d	8.71 ± 0.00 a	8.47 ± 0.00 c	8.64 ± 2.71 A	9.00 ± 2.95 A	0.12	0.902	2764	**
	75	0.00 ± 0.00 a	0.00 ± 0.00 a	2.58 ± 0.00 b	2.38 ± 0.00 b	23.74 ± 0.00 d	15.98 ± 0.00 d	8.77 ± 0.00 c	8.15 ± 0.00 c	8.77 ± 2.78 A	6.63 ± 1.86 A	0.90	0.375	1086	**
	84	0.00 ± 0.00 a	0.00 ± 0.00 a	2.47 ± 0.00 b	2.30 ± 0.00 b	23.94 ± 0.00 d	11.70 ± 0.00 d	8.67 ± 0.00 c	7.95 ± 0.00 c	8.77 ± 2.81 A	6.49 ± 1.39 A	1.48	0.153	1071	**

Means within each column for each parameter followed by the same small letter are not significantly different, while means (treated vs. control) for each treatment duration for each day across the rows followed by the same small letter are also not significantly different according to the Tukey test, at $\alpha = 0.05$. Overall, means between treatment and control within a row followed by the same capital letter are not significantly different according to the *t*-test. * Denotes significant differences, $p < 0.05$ while ** Denotes significant differences, $p < 0.01$, in means of parameters for storage periods from day 1 to 7.

3.6. Effect of Hot Water Treatment on Organoleptic Properties in Apple Mango Cultivar

The skin colour varied significantly amongst the days post-treatment in treated and untreated mangos (Table 7). The overall mean showed that there was no significant difference between the treatment and control at 68 min, but the skin colour was significantly higher in the control at exposure times of 75 and 84 min compared to the treatment. A similar trend was observed for the flesh colour, where the overall mean was significantly higher in control than in the treatment at exposure times of 75 and 84 min (Table 7). The mango flavour increased with an increase in time post-treatment in both treated and untreated mango. However, the overall mean for flavour between the treated and untreated fruits was comparable at only 68 min of exposure time. The aftertaste significantly varied with treatment duration in both the treatment and control. The overall mean for 7 days of storage was significantly higher in the untreated compared to the treated fruits. The firmness at tasting significantly decreased with time and reached its minimal level at day 7 post-treatment in both treated and control fruits (Table 7). However, the overall mean for 7 days post-treatment between the treated and untreated mangos was only significant at 75 min of exposure time (Table 7).

Table 7. Effect of hot water treatment at 46.1 °C for different treatment durations on organoleptic properties of Apple mango cultivar stored over 7 days post-treatment.

Parameter	Treatment Duration (min)	Means at Different Intervals (Days) Post-Treatment Using Hot Water Treatment at 46.1 °C						Means at Different Intervals (Days) for Untreated Fruits (Not Subjected to Hot Water Treatment						Overall Mean for 7 Days Storage			
		1	3	5	7	F	*p*	1	3	5	7	F	*p*	Treated	Untreated	t	*p*
Skin colour (%)	68	25.0 ± 0.00 d	50.0 ± 2.88 c	75.0 ± 0.00 b	90.0 ± 2.88 a	130.67	**	30.0 ± 2.88 c	59.0 ± 0.5773 b	65.0 ± 0.00 b	90.0 ± 0.00 a	280.30	**	60.0 ± 7.54 A	61.0 ± 6.47 A	−0.41	0.69
	75	40.0 ± 0.00 c	50.0 ± 1.52 b	50.0 ± 0.00 b	90.0 ± 0.00 a	842.85	**	55.0 ± 0.58 d	70.0 ± 0.57 c	80.0 ± 1.0 b	90.0 ± 0.0 a	535	**	57.5 ± 5.79 A	73.8 ± 3.91 B	−4.92	**
	84	25.0 ± 1.15 c	65.0 ± 1.15 b	70.0 ± 2.89 b	95.0 ± 0.00 a	305.30	**	40.0 ± 0.00 d	80.0 ± 0.00 c	90.0 ± 0.00 b	100 ± 0.00 a	423.20	**	63.8 ± 7.59 A	77.5 ± 6.87 B	−7.69	**
Flesh colour (%)	68	30.0 ± 2.88 d	65.0 ± 1.15 c	85.0 ± 2.08 b	100 ± 0.00 a	261.91	**	35.0 ± 0.00 d	75.0 ± 2.08 c	85.0 ± 0.00 b	100 ± 0.00 a	713.46	**	70.0 ± 7.9 A	73.0 ± 7.2 A	−2.54	0.28
	75	50.0 ± 0.00 d	55.0 ± 0.00 c	66.0 ± 0.58 b	95.0 ± 0.00 a	4868	**	60.0 ± 1.53 d	75.0 ± 0.58 c	90.0 ± 0.00 b	95.0 ± 0.00 a	375.0	**	66.5 ± 5.26 B	80 ± 4.14 A	−4.77	**
	84	30.0 ± 0.00 d	80.0 ± 0.00 c	90.0 ± 2.88 b	100 ± 0.00 a	464	**	55 ± 2.88 c	85.0 ± 0.00 b	90.0 ± 0.00 b	100 ± 0.00 a	180	**	75.0 ± 8.14 B	82.5 ± 5.09 A	−2.32	0.04
Flavour (%)	68	55.0 ± 1.00 d	65.0 ± 1.00 c	60.0 ± 0.00 b	100 ± 0.00 a	416.67	**	55.0 ± 0.00 b	60.0 ± 2.51 b	100 ± 0.00 a	100 ± 0.00 a	382.89	**	70.0 ± 5.35 A	78.7 ± 6.45 A	−1.59	0.14
	75	25.0 ± 0.58 c	65.0 ± 0.00 b	70.0 ± 2.89 b	100 ± 0.00 a	438.46	**	40.0 ± 0.58 d	80.0 ± 0.00 c	90.0 ± 0.58 b	100 ± 0.00 a	4150	**	65.0 ± 8.07 B	77.5 ± 6.86 A	−5.38	**
	84	58.0 ± 0.50 d	75.0 ± 0.00 c	90.0 ± 0.00 b	100 ± 0.00 a	4027	**	66.0 ± 1.00 d	80.0 ± 0.00 c	95.0 ± 0.00 b	100 ± 0.00 a	947.66	**	80.75 ± 4.78 B	85.25 ± 4.02 A	−4.99	**
Aftertaste (%)	68	35.0 ± 0.00 d	60.0 ± 0.00 c	80.0 ± 1.53 b	100 ± 0.00 a	1325	**	45.0 ± 0.57 c	60.0 ± 0.58 b	100 ± 0.00 a	100 ± 0.00 a	4737.5	**	68.75 ± 7.27 B	76.25 ± 7.34 A	−2.97	0.013
	75	30.0 ± 0.00 d	70.0 ± 0.00 c	74.0 ± 1.53 b	100 ± 0.00 a	1432.57	**	35.0 ± 0.58 d	75.0 ± 0.00 c	90.0 ± 0.00 b	100 ± 0.00 a	9800	**	68.5 ± 7.56 B	75.0 ± 7.46 A	−3.61	**
	84	55.0 ± 0.00 d	70.0 ± 0.00 c	90.0 ± 0.00 b	100 ± 0.00 a	4127	**	50.0 ± 1.52 c	75.0 ± 2.87 b	95.0 ± 0.00 a	100 ± 0.00 a	193.7	**	78.75 ± 5.26 A	80.0 ± 5.98 A	−0.87	0.401
Texture at tasting (%)	68	85.0 ± 0.00 d	75.0 ± 1.15 c	15.0 ± 0.00 b	5.0 ± 0.57 a	4000	**	80.0 ± 1.15 d	40.0 ± 0.00 c	25.0 ± 0.58 b	10.0 ± 0.00 a	2175	**	45.0 ± 10.66 A	38.75 ± 7.86 A	1.185	0.261
	75	90.0 ± 0.00 a	85.0 ± 0.00 b	50.0 ± 0.00 c	7.0 ± 0.25 d	91,940.8	**	80.0 ± 0.00 a	50.0 ± 2.88 b	35.0 ± 0.00 c	5.0 ± 0.00 d	468	**	58.13 ± 9.96 A	42.5 ± 8.18 B	4.244	**
	84	80.0 ± 1.15 a	75.0 ± 0.00 b	15.0 ± 0.00 c	5.0 ± 0.00 d	4618.8	**	85.0 ± 0.00 a	60.0 ± 1.53 b	8.0 ± 0.00 c	5.0 ± 0.00 c	2670.3	**	43.75 ± 10.25 A	39.5 ± 10.31 A	1.843	0.092

For each parameter and treatment duration, means within a row followed by the small same letter are not significantly different according to the Tukey test, at $\alpha = 0.05$. For the overall, means within a row followed by the same capital letter are not significantly different according to *t*-test. ** Denotes significant differences ($p < 0.01$) in means of parameters for storage periods from day 1 to 7.

4. Discussion

Subjecting fruits and vegetables to hot water treatment (HWT) is currently a topical issue, particularly in Sub-Saharan Africa (SSA) where most economies are based on agriculture, and exports of agricultural commodities contribute significantly to gross domestic product. Pre-harvest integrated pest management (IPM) for fruit flies (i.e., the use of various pest management options such as pesticides, lures, orchard sanitation, protein baits) has not provided 100 % pest management to satisfy phytosanitary requirements of importing countries in lucrative but sensitive markets in the USA and Europe Union. A systems approach that excludes postharvest treatment has often resulted in interceptions at ports of entry, thus damaging the export status of SSA countries. Protocols for disinfesting fruits and vegetables using HWT have been developed worldwide, but issues regarding quality post-treatment have dominated the limelight with exporters and consumers raising quality concerns. Hot water treatment has been cited as causing scalds in fruit, and most accusations are based on perceptions due to a lack of empirically generated data applicable to commercial scales of treatment. Herein, we report empirical evidence of the effect of HWT on "Apple mango" treated using a commercially viable treatment already accepted by the EU as an appropriate means of postharvest treatment for mangoes [29,46].

The current study established that HWT did not affect the acidity, dietary antioxidants, minerals, major macronutrients, or physical properties of mangoes subjected to a treatment of 46.1 °C, for all the three tested durations viz 68, 75, and 84 min. At all levels, citric, tartaric, and malic acid decreased by 8–9 fold from day one to day seven post-treatment. The trend was similar in the control, but overall both treated and control mangoes experienced a similar decrease in acids. Correspondingly, an overall measure of acidity (pH) moved from extremely acidic to the lower levels of acidity. Under normal circumstances, an increase in temperature and storage period decreases acidity in mangoes [47]. Slight differences in pH, though not significant, were reported by Kumah et al. [48] in Keitt mango subjected to between 48 and 50 °C for 10 min. The same study reported a similar trend to our results, where titratable acidity (citric, tartaric, and malic acid) decreased as the mangoes ripened. Another study though on pear fruit showed that HWT at 35–45 °C for a period of 2 h 30 min did not significantly affect pH over a 7-day storage period. Acidity gives fruits their sweet organoleptic properties, and the loss of acidity in the mango fruits used in the current study is due to complex decarboxylation chemical processes that are natural (Etienne et al. [49]). During the ripening of mango fruits, acidity decreases [50], and thus in the present study, HWT did not affect acid levels, and observed trends are acceptable. The pH at day 7 post-treatment was around 4, which is deemed acceptable for mature ripe mangoes [51].

Regarding dietary antioxidants such as total carotenoids, β-carotene, vitamin A, aromatic volatiles in the form of terpenoids, total phenolics, and total antioxidant activity, the trend of all components increased gradually from day 1 to 7 in both the treated and control fruits, but the increase was not substantial. For example, total carotenoids increased by 3.4–3.5-fold in the treated fruit, while control fruits appreciated by up to four times. β-Carotene was highest after 7 days of storage in both the treated and control fruits, having increased gradually from day 1 to 7. Vitamin A in treated fruits increased by 3–8-fold over the 7-day post-treatment storage period across the treatment durations (65, 75, and 84 min). In the control, the increase was slower at between 1 and 2 fold. However, overall the average increase from days 1 to 7 did not substantially differ between the treated and control fruits. The increase in terpenoids, total phenolics, and total antioxidant activity was gradual, with no marked increase in either the treated or untreated fruits. Studies conducted by Djioua et al. [51] on Keitt mango fruits subjected to HWT at 46–50 °C for 30–75 min did not affect total carotenoids, but normal increases over time in storage were observed. Hot water treatment of Tommy Atkins mango cultivar conducted at a similar temperature as ours (46.1 °C) over 70–110 min [52] revealed that HWT had no immediate effect on antioxidant capacity, but four days of storage post-treatment resulted in decreased levels of soluble phenolics and antioxidant capacity. In other studies conducted on mango

varieties in Pakistan, HWT of mangoes resulted in higher levels of total phenolics and antioxidant activity [53]. In the current study, the increase was not significant, and there was no clear trend whether increasing temperature increased phenolics, but for total antioxidants, there was a slight upward trend, though insignificant. Findings by Hasan et al. [53] showed that HWT at 50 °C for a short duration of time (2 min) resulted in the decrease of antioxidant activity after 21 days of storing the Kumquat fruit (*Fortunella japonica* Lour. Swingle Cv. Ovale) [54]. However soon after treatment did not impact any significant change. Consequently, considering the long period in storage, the decrease is expected due to natural biochemical processes occurring in fruits, which may not necessarily be treatment dependent [55]. Under natural conditions, total phenolics and antioxidant capacity did not change at all or increased slightly in the "Ataulfo" mango cultivar due to ripening [56]. The antioxidant capacity of most fruits is correlated to their total phenolics, and various factors such as post-harvest treatment, stage of maturity, and type of cultivar are known to affect the content and biochemical process of the same [56,57]. The methods available for evaluating dietary antioxidants in fruits, especially antioxidant activity, always give contrasting values and trends; thus, the use of several methodologies has been proposed as one way to circumvent this issue. The present study evaluated antioxidant activity as percent inhibition for scavenging 2-diphenyl-1-picrylhydrazyl (DPPH), a method we consider robust enough to give consistent results. Antioxidants are vital components in plants that protect them against oxidative damage [58]. In fruits, they are essential in reducing senescence; thus, their rapid degradation either naturally or by some form of treatment results in quick spoilage and reduction in the shelf life of the fruits.

Various minerals are important components of biological structures and related plant processes, and their degradation results in damaging effects on enzymatic and DNA mediated processes [59]. In the present study, iron and copper were available as trace elements and were unaffected by HWT. For potassium and calcium, there were no considerable differences between treated and untreated fruits. Minerals such as calcium and potassium constitute important electrolytes, and a measure of their leakage is often associated with physical damage to cell membranes [60]. Electrolyte leakage was only higher in fruits subjected to HWT for 68 min but was comparable at 75 and 84 min. In both the treated and control fruit, electrolyte leakage was gradual from day 1 to 7 and there were no differences attributable to the treatment. Results obtained by Nyanjage et al. [61] indicate that heat generally increases electrolyte leakage in mango fruits. For example, HWT at 46.5 °C for 120 min resulted in higher electrolyte leakage but was lower when subjected to lower time thresholds, such as 60 min. When the fruits were stored at lower temperatures of approximately 13 °C, the damage was significantly slowed down. From our observations, electrolyte leakage may be aggravated by treatment protocols with poor temperature regulation during treatment. Observations of severe browning of the pulp around the seed by Nyanjage et al. [61] were also observed in our case but only in preliminary studies when mangoes that were not physiologically mature were used. This is the case when mango harvesters do not consider maturity indices but harvest according to commercial grading scales and requirements by exporters who capitalize on the reduced ripening processes of such mangoes harvested before full physiological maturity. The severe scalding of the outer skin of the mangoes in experiments by Nyanjage et al. [61] may be due to several factors such as the size of fruits used and also maturity. Our results show that even in untreated fruits, cell membrane permeability also takes place as a result of ripening [62]. We agree with the conclusions of Nyanjage et al. [61] that electrolyte leakage is a direct indicator of the integrity of the cell membrane, and damage is highly dependent on ripening, handling or any form of physical injury as well as levels of calcium in the fruit. This is in line with our thought processes that HWT is a garbage in–garbage out process [46]. A well-balanced treatment determined for each mango cultivar may be the antidote for reducing fruit damage during hydrothermal treatments.

Residue on ignition (ash content) is used to determine the amount of minerals present after burning away organic content. The amount of minerals after this procedure determines

the physicochemical properties of the fruits and gives a good indication of the effect of the treatment on the biochemical properties of the commodity. In both the treated and control fruits, residue on ignition decreased significantly by day 3 in storage and only minimally up to day 7, but overall the differences were not substantial. This result is in agreement with our observations above, where minerals slightly decreased with increasing days in storage, though there were no marked differences as a result of HWT. Not very many studies have evaluated ash content in mango subjected to HWT, but when physiologically mature green Basari bananas in Pakistan were treated in hot water for 40, 50, and 60 °C for 10 min, there were slight reductions in ash content over a 15 day storage period [63]. However, storing mangoes at low temperatures of 3–5 °C was shown to maintain ash content significantly, though minimal decreases may be observed [47]. Thus, considering that mangoes subjected to HWT are stored under low temperatures in transit to destination markets, the issue of maintaining quality post-treatment is addressed adequately.

Proteins, carbohydrates, and sugars from healthy sources such as fruits are considered vital components of a healthy diet. In the present study, crude protein decreased, with an increase in days in storage being significant for mangoes treated at 75 and 84 min but not for those treated for 68 min. However, the decreases from days 1, 3, 5, and 7 were minimal and gradual. Total carbohydrates showed a marked difference between the treated and control fruits treated at 68 min but not for those treated for 75 and 84 min. Total sugars were not affected by HWT and gradually increased by 2 fold in both the treated and control fruits. The 68 and 84 min treatment duration produced marked differences in ether extracts (crude fat) between treated and control fruits. Proteins occur in minute quantities in fruits, but we decided to evaluate the effect of HWT in the present scenario since they are building blocks of important molecules. Hot water treatment of mango (Okrong cultivar in Thailand) at 50 °C for 10 min resulted in unfolding and misfolding of existing and newly formed proteins, respectively [35]. Proteomic studies conducted on Keitt mango cultivar subjected to HWT at 46.1 °C for 90 min positively impacted the expression of heat shock proteins (HSP), which have the important function of stabilizing the cell membrane and proteins and thus increasing the activity of antioxidant enzymes and decreasing relative oxidative degradation [64]. This result is very significant considering that HSP is important in reducing chilling injury in hot water-treated mangoes, which are then stored under low temperatures during storage in transit. Rather than looking at the modification of proteins in isolation, there is a need to embrace proteomics and genomics to better understand the positive impacts of modified proteins resulting from HWT. Concerning sugar content, some studies have demonstrated that sugar content increases naturally in fruits during storage as a result of starch hydrolysis [63]. Hot water treatment on Sindhri mango cultivar from Pakistan at 45–48 °C for 60–75 min showed an increase in non-reducing sugars and a decrease in reducing sugars after 7 days in storage post-treatment [65]. Schirra et al. [54] reported no significant effect of HWT (50 °C for 2 min) on total sugars in Kumquat fruits. However after 21 days of storage, total sugar content decreased significantly in HWT treated fruits [54]. The ripening process increases the breaking down of starch into glucose, sucrose, and fructose, thus increasing the total sugar content. This occurs to a certain level where sugars start declining or remain unchanged. The same study reported that carbohydrate levels in fruits are a function of treatment applied, the fruit species and cultivar, as well as storage conditions. The trend shown on total sugars and carbohydrates in the present study attests to the effect heat has on complex or simple forms of sugar. Regarding fat content (ether extracts), Shahnawz et al. [47] reported a normal decrease in mango (Langra cultivar) stored between 3 and 5 °C, and the decrease was more pronounced in mangoes stored at ambient conditions. In our case, the decrease in both treated and control mangoes was gradual, and differences were not alarming. Total soluble solids (TSS) are used to estimate the internal quality of fruits [66]. They are solids dissolved mostly measured as sugar. In the trade of fruits, TSS is recognized as important in fruit maturation, and their quantification determines how fruits are accepted in the market [67]. When TSS and fruit acidity are considered together, they indicate the level of ripening of the fruit

and the relative biochemical processes of converting starch to sugars as well as amino and fatty acids used in the process of respiration [68]. In the present study, TSS was not affected by HWT at all three time regimes of treatment and the four storage periods. The TSS content increased with an increase in the number of days in storage. Our results are in agreement with findings by Kumah et al. [48], who demonstrated that subjecting Keitt mango to temperatures between 50 and 52 °C for 5–10 min did not influence TSS, even after storage for 21 days.

The physical properties of fruits are important as they objectively and visually depict the aesthetic value to the consumer. Thus, evaluation of moisture, dry matter, crude fibre, firmness, and weight is integral in determining the quality of the fruit post-treatment. In the current study, moisture content decreased gradually, and where differences were observed between the treated and control fruit, they were very minor and not a result of the treatment effect. Moisture loss is expected in fruits in storage due to physiological processes such as respiration [69]. Mango fruits not subjected to any treatment and stored at room temperature and 3–5 °C lost moisture due to respiration, but lower temperatures tended to reduce respiration rate and subsequently senescence [47]. Mwando et al. [31] demonstrated that subjecting Tommy Atkins mangoes to hot water treatment at 46.1 °C for 72.63 min did not affect the moisture content of the fruits, even 11 days post-treatment. Weight loss initially increased up to day 5 in storage and then decreased on day 7 in both treated and untreated fruit. Similar results were reported in pomegranate subjected to HWT at 50 and 70 °C for 2–5 min, in which weight loss increased with an increase in the temperature of water [70]. Kumah et al. [48] also reported a gradual increase in weight loss in Keitt mango after day 4 in storage, and the trend turned rapid as storage days were increased to day 21.

As would have been expected, fruit firmness decreased gradually with an increase in days in storage for both treated and control fruits. As mangoes ripen they become softer and lose their hardness. However, even at 7 days in storage, the fruits were still firm enough to be packaged and transported without being smashed. In Keitt mango treated at 46–50 °C for 30–75 min and store up to day 9 post-treatment, weight loss observed was attributed to softening related enzymes [51]. As the fruit ripens, enzymes start breaking down cell walls, and turgor pressure preserved in fruits while still attached to the tree begins to decrease. Ripening causes pectin content to decrease while TSS increases, and Rocha Ribeiro et al. [71] reported that firmness was uniform in Tommy Atkins and Haden mango cultivars, and this was a reliable indicator of ripeness.

Crude fibre evaluation quantifies indigestible lignin, celluloses, and other complex fibres in the fruit. Though of less nutritional value in humans, it is a vital component of roughage required in the process of digestion. The present study reports a stable quantity, neither increasing nor decreasing, for mangoes subjected to HWT at 68, 75, and 84 min and stored for 7 days. The trend was similar in the control mangoes, suggesting that HWT did not alter the physical properties of crude fibre. A slight decrease in crude fibre content was observed in untreated Dodo mangoes of Tanzania during ripening in storage. This is expected as a result of the breakdown of polysaccharide cell walls [72]. Dry matter varied in both treated and control fruits but with no clear trend, though seemingly increasing then decreasing particularly on day 7 of storage. It may seem that the slight differences are merely reflections of differences in water content, seed size, and overall mango size in terms of crude fibre. As has been mentioned before, carbohydrates, proteins, and sugars together with other nutrients were not affected by HWT; it then follows that dry matter did not change considerably, and differences are a result of water content in various fruits.

Organoleptic properties of mango such as skin colour, flesh colour, flavour and aftertaste play a crucial role in the marketability of the fruit, since they influence the attractiveness of the mango to the consumer. In the current study, exposure of mango to HWT for 68 min did not affect change in skin colour, flesh colour, flavour and aftertaste 7 days post treatment. However, there was a delay in skin colour change (ripeness) and increase in flavour in fruits treated for 75 and 84 min. These results are comparable to other studies. For examples "Sammar Bahisht Chaunsa" and "Sufaid Chaunsa" mango cultivars

subjected to HWT of 48 °C for 60 min maintained their skin and flesh colour as compared to untreated samples [53]. Similarly, there was retention of skin colour during storage of "Tuu Shien" mango fruit treated with hot water at 50 °C for 10 min [73]. Generally, an adequate temperature and time combination during HWT of fresh produce has been demonstrated to maintain the quality of the produce and delay senescence [74]. This may also explain the difference in flavour between mango fruits that were treated for 75 and 84 min and the untreated ones, 7 days post treatment. This occurrence positively influences the marketability index of the mango fruit and is therefore advantageous for export markets.

The evidence in support of HWT as a phytosanitary treatment for fruits and vegetables is overwhelming, and the positives far outweigh the drawbacks. If HWT is to be successful with the minimal negative effect on the physico-chemical properties of mango, then the process must begin in the field with preharvest management practices, harvesting, transportation, selection for treatment, treatment, and post-treatment processes. Poorly harvested mangoes with damage or diseases, or prematurely harvested mangoes often lead to disastrous results. Some studies have reported scalding, shrivelling, separation of seed from pulp, and rotting of mangoes subjected to HWT and blamed the treatment; yet the problem could be purely related to what was mentioned above. In the preliminary studies, as we sought to develop the protocol used in this study [29], we experienced all forms of problems related to the equipment used, quality of fruits, and handling. The temptation of harvesting mangoes before physiological maturity to increase their shelf life is so great, but the repercussions are dire. Hot water treatment is the future of postharvest treatments of fruits and vegetables, and thus future research must focus on precision equipment and its effects on proteomics.

5. Conclusions

The study evaluated the effects of HWT on Apple mango cultivar subjected to hot water at 46.1 °C for 68, 75, and 84 min and stored for up to 7 days. This treatment regime is a phytosanitary post-harvest treatment for mangoes destined for the European market from Africa. The protocol is already recognized by the EU, especially for mangoes from East Africa. Sixty-eight minutes of treatment is optimal, but a range of up to 84 min does not have detrimental effects. The research presented here lays a solid foundation for the application of HWT without fear or doubt. The most important guideline is that the quality of the mangoes subjected to HWT has a huge bearing on the quality parameters of the mangoes during storage, transportation, or on the shelf ready for sale.

Author Contributions: Conceptualization, S.N. and S.A.M.; methodology, S.N. and F.O.; validation, S.N., A.M.M. and A.G.A.A.; formal analysis, A.M.M. and A.G.A.A.; investigation, S.N., F.O. and N.L.M.; resources, S.A.M.; data curation, S.N.; writing—original draft preparation, S.N.; writing—review and editing, S.N., F.O., A.M.M., A.G.A.A., N.L.M. and S.A.M.; visualization, S.N. and S.A.M.; supervision, S.A.M.; project administration, S.N. and S.A.M.; funding acquisition, S.A.M. All authors have read and agreed to the published version of the manuscript.

Funding: The authors gratefully acknowledge the financial support for this research by the following organizations and agencies: BioInnovate Africa, grant number: BA-C1-2017-06_icipe; the Swedish International Development Cooperation Agency (Sida); the Swiss Agency for Development and Cooperation (SDC); the Federal Democratic Republic of Ethiopia; and the Government of the Republic of Kenya. The views expressed herein do not necessarily reflect the official opinion of the donors.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: All data are contained within the text.

Acknowledgments: The Authors greatly acknowledge the staff in the African Fruit Fly Programme for their various forms of assistance in the Postharvest laboratory.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Selwyn, B. The global retail revolution, fruiticulture and economic development in north-east Brazil. *Int. J. Polical Econ.* **2013**, *20*, 153–179. [CrossRef]
2. Diop, N.; Jaffee, S.M. Fruits and vegetables: Global trade and competition in fresh and processed product markets. In *Global Agricultural Trade and Developing Countries*; Aksoy, M., Beghin, J., Eds.; World Bank: Washington, DC, USA, 2005; pp. 237–257.
3. Ndlela, S. Development and Implementation of Pre- and Post-Harvest Management Measures for *Bactrocera dorsalis* (Hendel) and *Ceratitis cosyra* (Walker) (Diptera: Tephritidae) on Mango in Kenya. Ph.D. Thesis, University of Nairobi, Nairobi, Kenya, 2017.
4. Huang, S. Global trade of fruits and vegetables and the role of consumer demand. In *Trade Food Diet Health*; Perspective and Policy Options; Wiley-Blackwell: Oxford, UK, 2010; pp. 60–76.
5. Boon, J.K. European Union Sees Increase Of Fruit and Vegetable Imports. Available online: https://www.producebusiness.com/european-union-sees-increase-of-fruit-and-vegetable-imports/ (accessed on 8 February 2022).
6. Saleem Dar, M.; Oak, P.; Chidley, H.; Deshpande, A.; Giri, A.; Gupta, V. Nutrient and Flavor Content of Mango (*Mangifera indica* L.) Cultivars: An Appurtenance to the List of Staple Foods. In *Nutritional Composition of Fruit Cultivars*; Academic Press: Cambridge, MA, USA, 2016; pp. 445–467. [CrossRef]
7. Fam, V.W.; Holt, R.R.; Keen, C.L.; Sivamani, R.K.; Hackman, R.M. Prospective Evaluation of Mango Fruit Intake on Facial Wrinkles and Erythema in Postmenopausal Women: A Randomized Clinical Pilot Study. *Nutrients* **2020**, *12*, 3381. [CrossRef] [PubMed]
8. Lux, S.A.; Copeland, R.S.; White, I.M.; Manrakhan, A.; Billah, M.K. A New Invasive Fruit Fly Species from the *Bactrocera dorsalis* (Hendel) Group Detected in East Africa. *Int. J. Trop. Insect Sci.* **2003**, *23*, 355–361. [CrossRef]
9. Nugnes, F.; Russo, E.; Viggiani, G.; Bernardo, U. First Record of an Invasive Fruit Fly Belonging to *Bactrocera dorsalis* Complex (Diptera: Tephritidae) in Europe. *Insects* **2018**, *9*, 182. [CrossRef]
10. CABI. *Bactrocera dorsalis* (Oriental fruit fly). In *Invasive Species Compendium*; CAB International: Wallingford, UK, 2021; Available online: https://www.cabi.org/isc/datasheet/17685 (accessed on 2 October 2021).
11. IPPC International Plant Protection Convention. *ISPM 5: Glossary Of Phytosanitary Terms*; FAO: Rome, Italy, 2017.
12. USDA-APHIS [United States Department of Agriculture- Animal and Plant Health Inspection Service]. Federal Import Quarantine Order for Host Materials of Bactrocera invadens [Diptera: Tephritidae], Invasive Fruit Fly Species. 2009. Available online: https://www.aphis.usda.gov/import_export/plants/plant_imports/federal_order/downloads/BactroceraInvadensMay2009.pdf (accessed on 20 August 2021).
13. EU. Commission Implementing Directive [EU] 2019/523 of 21 March 2019 amending Annexes I to V to Council Directive 2000/29/EC on protective measures against the introduction into the Community of organisms harmful to plants or plant products and against their spread within the Community. *Off. J. Eur. Union* **2019**, *L86*, 41–68.
14. Ekesi, S.; De Meyer, M.; Mohamed, S.A.; Virgilio, M.; Borgemeister, C. Taxonomy, Ecology, and Management of Native and Exotic Fruit Fly Species in Africa. *Annu. Rev. Entomol.* **2016**, *61*, 219–238. [CrossRef]
15. Bachmann, J.; Earles, R. *Postharvest Handling of Fruits and Vegetables*; University of Arkansas: Fayetteville, NC, USA, 2000; pp. 1–19.
16. Mahajan, P.V.; Caleb, O.J.; Singh, Z.; Watkins, C.B.; Geyer, M. Postharvest treatments of fresh produce. *Philos. Trans. R. Soc. A* **2014**, *372*, 20130309. [CrossRef]
17. James, A.; Zikankuba, V. Postharvest management of fruits and vegetable: A potential for reducing poverty, hidden hunger and malnutrition in sub-Sahara Africa. *Cogent Food Agric.* **2017**, *3*, 1312052. [CrossRef]
18. Lurie, S. Postharvest heat treatments. *Postharvest Biol. Technol.* **1998**, *14*, 257–269. [CrossRef]
19. Escribano, S.; Mitcham, E.J. Progress in heat treatments. *Stewart Postharvest Rev.* **2014**, *10*, 1–6.
20. Sharp, J.L.; Ouye, M.T.; Ingle, S.J.; Hart, W.G. Hot-Water Quarantine Treatment for Mangoes from Mexico Infested with Mexican Fruit Fly and West Indian Fruit Fly (Diptera: Tephritidae). *J. Econ. Entomol.* **1989**, *82*, 1657–1662. [CrossRef]
21. Sharp, J.L.; Picho-Martinez, H. Hot-Water Quarantine Treatment to Control Fruit Flies in Mangoes Imported into the United States from Peru. *J. Econ. Entomol.* **1990**, *83*, 1940–1943. [CrossRef]
22. McGuire, R. Concomitant decay reductions when mangoes are treated with heat to control infestations of Caribbean fruit flies. *Plant Dis.* **1991**, *75*, 946–949. [CrossRef]
23. Gould, W.P. Heat quarantine treatments for guavas infested with the Caribbean fruit fly. *Proc. Fla. State Hortic. Soc.* **1994**, *107*, 240–242.
24. De la Cruz Medina, J.; Garcia, H.S. Mango post-harvest operations. In *Post-Harvest Compendium*; Mejia, D., Lewis, B., Eds.; AGSI, FAO: Mexico, NA, USA, 2002; p. 69.
25. Yahia, E.M.; Ortega, D.; Martinez, A.; Moreno, P. The mortality of artificially infested third instar larvae of *Anastrepha ludens* and *A. obliqua* in mango fruit with insecticidal controlled atmospheres at high temperatures. *Acta Hortic.* **2000**, *509*, 833–839. [CrossRef]
26. Verghese, A.; Sreedevi, K.; Nagaraju, D.K. Pre and Post harvest IPM for the Mango Fruit Fly, *Bactrocera dorsalis* (hendel). In *Fruit Flies of Economic Importance to Applied Knowledge, Proceedings of the 7th International Symposium on Fruit Flies of Economic Importance, Salvador, Brazil, 10–15 September 2006*; Office of Scientific and Technical Information: Salvador, Brazil, 2006; pp. 179–182.
27. Hernández, E.; Rivera, P.; Bravo, B.; Toledo, J.; Caro-Corrales, J.; Montoya, P. Hot-water phytosanitary treatment against *Ceratitis capitata* (Diptera: Tephritidae) in "Ataulfo" mangoes. *J. Econ. Entomol.* **2012**, *105*, 1940–1953. [CrossRef]

28. Self, G.; Ducamp, M.N.; Vayssières, J.F. The effects of phytosanitary hot water treatments on west african mangoes infested with *Bactrocera invadens* (diptera: Tephritidae). *Fruits* **2012**, *67*, 439–449. [CrossRef]
29. Ndlela, S.; Ekesi, S.; Ndegwa, P.N.; Ong'amo, G.O.; Mohamed, S.A. Post-harvest disinfestation of *Bactrocera dorsalis* (Hendel) (Diptera: Tephritidae) in mango using hot-water treatments. *J. Appl. Entomol.* **2017**, *141*, 848–859. [CrossRef]
30. Ocitti, P.; Ndlela, S.; Akol, A.; Muyinza, M.; Mohamed, S.A. Non-chemical post-harvest disinfestation of *Bactrocera dorsalis* (Hendel) (Diptera: Tephritidae) in Tommy Atkins mango using hot-water immersion treatment. *Afr. Entomol.* **2021**, *29*, 238–247. [CrossRef]
31. Mwando, N.L.; Ndlela, S.; Meyhöfer, R.; Subramanian, S.; Mohamed, S.A. Hot Water Treatment for Post-Harvest Disinfestation of *Bactrocera dorsalis* (Diptera: Tephritidae) and Its Effect on cv. Tommy Atkins Mango. *Insects* **2021**, *12*, 1070. [CrossRef]
32. Kumar, R.; Vishwakarma, R. Preharvest Approaches to Control Insect Infestation in Fruit. *Preharvest Modul. Postharvest Fruit Veg. Qual.* **2018**, *2018*, 301–357. [CrossRef]
33. Wall, M.M.; Sivakumar, D.; Korsten, L. Rambutan (*Nephelium lappaceum* L.). *Postharvest Biol. Technol. Trop. Subtrop. Fruits* **2011**, *4*, 312–333, 334e–335e. [CrossRef]
34. Fallik, E.; Ilic', Z. Positive and Negative Effects of Heat Treatment on the Incidence of Physiological Disorders in Fresh Produce. In *Postharvest Physiological Disorders in Fruits and Vegetables*; CRC Press: Boca Raton, FL, USA, 2019; pp. 111–126.
35. Yimyong, S.; Datsenka, T.U.; Handa, A.K.; Seraypheap, K. Hot Water Treatment Delays Ripening-associated Metabolic Shift in 'Okrong' Mango Fruit during Storage. *J. Am. Soc. Hortic. Sci.* **2011**, *136*, 441–451. [CrossRef]
36. Chen, H.; Cheng, Z.; Wisniewski, M.; Liu, Y.; Liu, J. Ecofriendly hot water treatment reduces postharvest decay and elicits defense response in kiwifruit. *Environ. Sci. Pollut. Res.* **2015**, *22*, 15037–15045. [CrossRef]
37. USDA-APHIS. *Treatment Manual*; APHIS: Washington, DC, USA, 2016.
38. De Carvalho, L.M.J.; Gomes, P.B.; Godoy, R.L.d.O.; Pacheco, S.; do Monte, P.H.F.; de Carvalho, J.L.V.; Nutti, M.R.; Neves, A.C.L.; Vieira, A.C.R.A.; Ramos, S.R.R. Total carotenoid content, α-carotene and β-carotene, of landrace pumpkins (*Cucurbita moschata* Duch): A preliminary study. *Food Res. Int.* **2012**, *47*, 337–340. [CrossRef]
39. Trumbo, P.; Yates, A.A.; Schlicker, S.; Poos, M. Dietary reference intakes: Vitamin A, vitamin K, arsenic, boron, chromium, copper, iodine, iron, manganese, molybdenum, nickel, silicon, vanadium, and zinc. *J. Am. Diet. Assoc.* **2001**, *101*, 294–301. [CrossRef]
40. Ghorai, N.; Chakraborty, S.; Gucchait, S.; Saha, S.K.; Biswas, S. Estimation of total Terpenoids concentration in plant tissues using a monoterpene, Linalool as standard reagent. *Protoc. Exch.* **2012**. [CrossRef]
41. Kaur, C.; Kapoor, H.C. Anti-oxidant activity and total phenolic content of some Asian vegetables. *Int. J. Food Sci. Technol.* **2002**, *37*, 153–161. [CrossRef]
42. Baba, S.A.; Malik, S.A. Determination of total phenolic and flavonoid content, antimicrobial and antioxidant activity of a root extract of *Arisaema jacquemontii* Blume. *J. Taibah Univ. Sci.* **2015**, *9*, 449–454. [CrossRef]
43. Pavithra, K.; Vadivukkarasi, S. Evaluation of free radical scavenging activity of various extracts of leaves from *Kedrostis foetidissima* (Jacq.) Cogn. *Food Sci. Hum. Wellness* **2015**, *4*, 42–46. [CrossRef]
44. Siong, T.; Choo, K.; Shahid, S. Determination of calcium in foods by the atomic absorption spectrophotometric and titrimetric methods. *Pertanika* **1989**, *12*, 303–311.
45. Guebel, D.V.; Nudel, B.C.; Giulietti, A.M. A simple and rapid micro-Kjeldahl method for total nitrogen analysis. *Biotechnol. Tech.* **1991**, *5*, 427–430. [CrossRef]
46. Ndlela, S.; Mwando, N.L.; Mohamed, S.A. Advances in Postharvest Disinfestation of Fruits and Vegetables Using Hot Water Treatment Technology—Updates from Africa. In *Postharvest Technology—Recent Advances, New Perspectives and Applications [Working Title]*; IntechOpen: London, UK, 2021; ISBN 978-1-83969-924-5.
47. Shahnawz, M.; Sheikh, S.A.; Khaskheli, S.G. Effect of storage on the physicochemical characteristics of the mango (*Mangifera indica* L.) variety, Langra. *Afr. J. Biotechnol.* **2012**, *11*, 9825–9828. [CrossRef]
48. Kumah, P.; Appiah, F.; Opoku-Debrah, J.K. Effect of hot water treatment on quality and shelf-life of Keitt mango. *Agric. Biol. J. N. Am.* **2011**, *2*, 806–817. [CrossRef]
49. Etienne, A.; Génard, M.; Lobit, P.; Mbeguié-A-Mbéguié, D.; Bugaud, C. What controls fleshy fruit acidity? A review of malate and citrate accumulation in fruit cells. *J. Exp. Bot.* **2013**, *64*, 1451–1469. [CrossRef]
50. Jha, S.N.; Narsaiah, K.; Sharma, A.D.; Singh, M.; Bansal, S.; Kumar, R. Quality parameters of mango and potential of non-destructive techniques for their measurement—A review. *J. Food Sci. Technol.* **2010**, *47*, 1–14. [CrossRef]
51. Djioua, T.; Charles, F.; Lopez-Lauri, F.; Filgueiras, H.; Coudret, A.; Jr, M.F.; Ducamp-Collin, M.N.; Sallanon, H. Improving the storage of minimally processed mangoes (*Mangifera indica* L.) by hot water treatments. *Postharvest Biol. Technol.* **2009**, *52*, 221–226. [CrossRef]
52. Kim, Y.; Lounds-Singleton, A.J.; Talcott, S.T. Antioxidant phytochemical and quality changes associated with hot water immersion treatment of mangoes (*Mangifera indica* L.). *Food Chem.* **2009**, *115*, 989–993. [CrossRef]
53. Hasan, M.U.; Malik, A.U.; Khan, A.S.; Anwar, R.; Latif, M.; Amjad, A.; Shah, M.S.; Amin, M. Impact of postharvest hot water treatment on two commercial mango cultivars of Pakistan under simulated air freight conditions for China. *Pak. J. Agric. Sci.* **2020**, *57*, 1381–1391. [CrossRef]
54. Schirra, M.; Palma, A.; D'Aquino, S.; Angioni, A.; Minello, E.V.; Melis, M.; Cabras, P. Influence of Postharvest Hot Water Treatment on Nutritional and Functional Properties of Kumquat (*Fortunella japonica* Lour. Swingle Cv. Ovale) Fruit. *J. Agric. Food Chem.* **2007**, *56*, 455–460. [CrossRef]

55. Meitha, K.; Pramesti, Y.; Suhandono, S. Reactive Oxygen Species and Antioxidants in Postharvest Vegetables and Fruits. *Int. J. Food Sci.* **2020**, *2020*. [CrossRef]
56. Palafox-Carlos, H.; Yahia, E.; Islas-Osuna, M.A.; Gutierrez-Martinez, P.; Robles-Sánchez, M.; González-Aguilar, G.A. Effect of ripeness stage of mango fruit (*Mangifera indica* L., cv. Ataulfo) on physiological parameters and antioxidant activity. *Sci. Hortic.* **2012**, *135*, 7–13. [CrossRef]
57. Kevers, C.; Falkowski, M.; Tabart, J.; Defraigne, J.O.; Dommes, J.; Pincemail, J. Evolution of Antioxidant Capacity during Storage of Selected Fruits and Vegetables. *J. Agric. Food Chem.* **2007**, *55*, 8596–8603. [CrossRef]
58. Hernández, I.; Alegre, L.; Van Breusegem, F.; Munné-Bosch, S. How relevant are flavonoids as antioxidants in plants? *Trends Plant Sci.* **2009**, *14*, 125–132. [CrossRef]
59. Konczak, I.; Roulle, P. Nutritional properties of commercially grown native Australian fruits: Lipophilic antioxidants and minerals. *Food Res. Int.* **2011**, *44*, 2339–2344. [CrossRef]
60. Biswas, P.; East, A.R.; Hewett, E.W.; Heyes, J.A. Increase in electrolyte leakage as a function of chilling stress and ripening of tomato. *Acta Hortic.* **2012**, *945*, 283–290. [CrossRef]
61. Nyanjage, M.O.; Wainwright, H.; Bishop, C.F.H. Effects of hot-water treatment and storage temperature on electrolyte leakage of mangoes (*Mangifera indica* Linn.). *J. Hortic. Sci. Biotechnol.* **1999**, *74*, 566–572. [CrossRef]
62. Fuchs, Y.; Zauberman, G.; Rot, I.; Weksler, A. Chilling injury and electrolyte leakage in cold stored mango and avocado fruits. *Acta Hortic.* **1989**, *258*, 303–308. [CrossRef]
63. Kaka, A.K. Effect of hot water treatments and storage period on the quality attributes of banana (*Musa* sp.) fruit. *Pure Appl. Biol.* **2019**, *8*, 363–371. [CrossRef]
64. Salazar-Salas, N.Y.; Chairez-Vega, D.A.; Vega-Alvarez, M.; González-Nuñez, D.G.; Pineda-Hidalgo, K.V.; Chávez-Ontiveros, J.; Delgado-Vargas, F.; Lopez-Valenzuela, J.A. Proteomic changes in mango fruit peel associated with chilling injury tolerance induced by quarantine hot water treatment. *Postharvest Biol. Technol.* **2022**, *186*, 111838. [CrossRef]
65. Anwar, R.; Malik, A.U. Effect of hot water treatment on storage life and quality of mango (*Mangifera indica* L.). *Acta Hortic.* **2007**, *768*, 201–207. [CrossRef]
66. Golic, M.; Walsh, K.B. Robustness of calibration models based on near infrared spectroscopy for the in-line grading of stonefruit for total soluble solids content. *Anal. Chim. Acta* **2006**, *555*, 286–291. [CrossRef]
67. Li, J.L.; Sun, D.W.; Cheng, J.H. Recent Advances in Nondestructive Analytical Techniques for Determining the Total Soluble Solids in Fruits: A Review. *Compr. Rev. Food Sci. Food Saf.* **2016**, *15*, 897–911. [CrossRef]
68. Jacobi, K.K.; MacRae, E.A.; Hetherington, S.E. Effects of hot air conditioning of 'Kensington' mango fruit on the response to hot water treatment. *Postharvest Biol. Technol.* **2000**, *21*, 39–49. [CrossRef]
69. Frenkel, C.; Hartman, T.G. Decrease in Fruit Moisture Content Heralds and Might Launch the Onset of Ripening Processes. *J. Food Sci.* **2012**, *77*, S365–S376. [CrossRef]
70. Mirdehghan, S.H.; Rahemi, M. Effects of hot water treatment on reducing chilling injury of pomegranate (*Punica granatum*) fruit during storage. *Acta Hortic.* **2005**, *682*, 887–892. [CrossRef]
71. Rocha Ribeiro, S.M.; De Queiroz, J.H.; Lopes Ribeiro De Queiroz, M.E.; Campos, F.M.; Pinheiro Sant'Ana, H.M. Antioxidant in mango (*Mangifera indica* L.) pulp. *Plant Foods Hum. Nutr.* **2007**, *62*, 13–17. [CrossRef]
72. Canton, M.; Drincovich, M.F.; Lara, M.V.; Vizzotto, G.; Walker, R.P.; Famiani, F.; Bonghi, C. Metabolism of Stone Fruits: Reciprocal Contribution Between Primary Metabolism and Cell Wall. *Front. Plant Sci.* **2020**, *11*, 1054. [CrossRef]
73. Le, T.N.; Shiesh, C.C.; Lin, H.L. Effect of vapor heat and hot water treatments on disease incidence and quality of Taiwan native strain mango fruits. *Int. J. Agric. Biol.* **2010**, *12*, 673–678.
74. Sivakumar, D.; Fallik, E. Influence of Heat Treatments on Quality Retention of Fresh and Fresh-Cut Produce. *Food Rev. Int.* **2013**, *29*, 294–320. [CrossRef]