Characterisation of fruit juices and effect of pasteurisation and storage conditions on their microbial, physicochemical, and nutritional quality

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Abstract

Characterization, pasteurization and storage are essential steps in fruit juice processing. Watermelon, pineapple, and mango juices were pasteurized at 80 ± 2°C and held at different treatment times (1, 2.5, 5, 10, and 15 min). Juice yield, pH, proximate composition, total soluble solids, color, vitamin C, microbial quality, mineral content, enzyme activity (polyphenol oxidase (PPO), and peroxidase (POD)), total phenolic content, and antioxidant capacity were measured during pasteurization and cold storage (4°C). Results showed that watermelon juice had the highest crude protein, pH, and moisture content while pineapple juice had the highest titratable acidity, vitamin C and mineral content (potassium, calcium, magnesium, manganese, and zinc) and mango juice had the highest juice yield, and total soluble solids. Regardless of the holding time, pasteurization reduced total plate counts and yeast and molds to below detectable limits (1 log CFU/mL). Vitamin C was undetectable in watermelon juice after 10 min of pasteurization compared to mango juice with a 27% reduction. Pasteurization preserved mango juice color, but watermelon juice became less red and more yellow with increasing treatment time. POD was more thermoresistant than PPO and needed a treatment time of at least 5 min to obtain 80% reduction. Storage of more than 9 days negatively affected the watermelon color, total phenolic content and antioxidant capacities of watermelon juice pasteurized at 15 min and vitamin C content of control mango juice. Thus, pasteurization and storage affect the quality of fruit juices depending on the fruit types and their composition.

Keywords: thermal processing, enzymes, fruit quality, fruit juice, nutrient composition

1. Introduction

Consumers nowadays are health cautious and demand healthy foods with enhanced shelf life. Fruits are nutritious, with a low caloric value and rich in vitamins, minerals, phenolic compounds, organic acids, and carotenoids. These bioactive compounds have antibacterial, antioxidant, anti-inflammatory, and radioprotective properties that reduce incidences of heart disease and cancer (Dhalaria et al., 2020). However, not all fruits have the same nutritional value and chemical composition. These properties vary depending on botanical variety, cultivation practices, weather, maturity, and processing techniques (Lozano, 2006; Tzia et al., 2015). Fruit quality influences consumer acceptability. Therefore, their characterization is important to evaluate quality and obtaining this information is an essential step in food product development as it provides insights that can be used as decisive factors.

Fruits are usually consumed fresh. However, their edible portion has a high moisture content, making them highly susceptible to spoilage from microorganisms, physical damage, and degradation. Untreated fruit juices have been associated with the breakout of food-borne diseases due to contamination by pathogenic microorganisms such as *Escherichia coli* O157:H7, *Listeria monocytogenes,* or *Salmonella* spp (Tribst, Sant́ Ana, & de Massaguer, 2009). Therefore, thermal treatment such as pasteurization is an intrinsic part of fruit juice processing to ensure microbial safety and to inactivate enzymes such as polyphenol oxidase (PPO), and peroxidase (POD) that could lead to undesirable sensory and nutritive changes (Petruzzi et al., 2017). However, fruit juices are thermo-sensitive and may undergo physical and chemical changes that impair their organoleptic quality and reduce the content or bioavailability of bioactive compounds (Petruzzi et al., 2017). Pasteurization may negatively affect juice quality factors, such as color, antioxidant activity or polyphenols and vitamin C content of fruit juice depending on the processing conditions, fruit variety and type.

Currently, fruit juices are heated at varying temperatures and time combinations (72 – 108 °C, > 15s or > 30s) (Chen, Yu, & Rupasinghe, 2013) which makes comparison of results difficult. Therefore, efforts are needed to modify the pasteurization temperature/time combinations to obtain suitable conditions that minimize biochemical and nutritional changes. Although thermal treatment increases the shelf-life of food products, food quality is not constant and, it continuously changes from time to time (Wibowo et al., 2015a). During storage, several deteriorative chemical reactions may degrade the quality characteristics of fruit products depending on the type of fruit, juice composition, storage conditions, packaging material, and storage temperature (Aguiló-Aguayo et al., 2009; Vásquez-Caicedo, et al., 2007).

Therefore, in this context, watermelon (*Citrullus lanatus cv* sugar baby), pineapple (*Ananas Comosus*), and mango (*Mangifera indica, L. cv* Kagoogwa) juices were characterized for their physicochemical, chemical, and microbial quality. The pasteurization holding time at 80 °C was optimized, and the quality changes of watermelon and mango juices were investigated after pasteurization and throughout the 14-day refrigerated storage.

2. Materials and methods

2.1. Media and chemicals

De Man-Rogosa-Sharpe (MRS), Rose Bengal chloramphenicol agar (RBC), plate count agar (PCA), Xylose Lysine Deoxycholate medium (X.L.D), Rapid' *E. coli* agar and bacteriological agar were purchased from Oxoid LTD (Basingstoke, Hampshire, England). ABTS (2,2'-azino-bis (3-ethylbenzothiazoline-6-sulfonic acid)), Trolox (6-hydroxyl-2,5,7,8-tetramethylchroman-2-carboxylic acid), DPPH (2,2-diphenyl-1-picrylhydrazyl), gallic acid, Folin–Ciocalteu (FC) reagent, sodium dodecyl sulfate, ascorbic acid, L-proline, saponin, tropolone and hydrogen peroxide were purchased from Sigma-Aldrich Co. (Overijse, Belgium). Kjeldahl tablet, and indicators (tashiro, phenolphthalein, and 2,6-dichloroindophenol) were purchased from VWR International (Leuven, Belgium). Inductively coupled plasma (ICP) multi-element standard solution IV was procured from Merck KGak (Darmstadt, Germany), and pyrocatechol was purchased from Union Chimique Belge (Brussels, Belgium).

2.2. Plant Materials

Mature watermelon (*Citrullus lanatus cv* sugar baby), pineapple (*Ananas Comosus*), and mango fruits (*Mangifera indica, L. cv* Kagoogwa) were purchased from Nakasero market, Kampala, Uganda (latitude: 00°18’42.34” N, longitude: 32°34’46.34” E). The fruits were physically checked for integrity, insect contamination, and size/color uniformity. The screened samples were then packaged in air-tight boxes and cold transported by air to the Research Unit VEG-i-TEC of Ghent University, Kortrijk, Belgium. Upon arrival, the fruits were again inspected and kept for a maximum of 3 days at 4°C before analysis.

2.3. Sample preparation

The fruits were washed in distilled water. Thereafter, the fleshy mesocarp was sliced from the peel/ rind and seed, manually diced, and mixed using a domestic blender (Joseph, MI USA) to obtain juice. This juice was then homogenized using an Ultra-Turrax (IKA T18, Staufen, Germany) at 10,000 rpm for 15 min. No water, additional sugar, or preservative was added. Each fruit part was determined and reported as a percentage proportion of the whole fruit.

2.4. Pasteurization and storage

Fruit juice (25 mL) was pasteurized according to Shaheer et al. (2014) in sterile glass containers (previously sterilized at 121 °C for 15 min) in a warm water bath (Memmert WNB 45, Schwabach, Germany) under continuous shaking. The time taken for heat transfer from the external temperature (95°C) to the internal sample temperature at the center of the bottle (central geometrical point) was monitored using a digital thermometer (TFA Dostmann/Werthein) sterilized with 90% ethanol. Samples were pasteurized at 80 ± 2°C and held at different treatment times of 1, 2.5, 5, 10, and 15 min corresponding to P1, P2.5, P5, P10, P15, respectively. The samples were rapidly cooled thereafter in an ice-water bath (0 °C). The control was unpasteurized fruit juice.

The samples were then stored in the dark in sterile 25 mL Schott Duran glass bottles at 4°C for 14 days. The glass bottles were tightly closed with screw caps. Analyses including microbiological quality, color, fruit quality (total soluble solids, pH, titratable acidity, vitamin C), enzyme activity, antioxidant capacity, and total phenolic content were determined before pasteurization, after pasteurization and at 0, 2, 5, 9, 14 days of storage. Both treatments and determinations were carried out in duplicates.

2.5. Microbiological analyses

All samples were analyzed for *Escherichia coli*, total coliforms, *Salmonella* spp, aerobic plate count, yeast and molds as recommended by the European Commission regulation (EC 1441), (2007) using Rapid' *E.coli* agar, X.L.D agar, PCA agar and RBC agar supplemented with 100 mg/L chloramphenicol, respectively. Briefly, aliquots of each sample (1 mL) were mixed thoroughly with 9 mL sterile saline diluent for 1 min using a vortex (Vortex-genie 2, Thermo Fisher Scientific Inc., Waltham, MA, USA) and serially diluted (10^{-1} – 10^{-7}). Subsequently, 0.1 mL aliquots of each dilution were dispensed on appropriate plates using the standard spread plate method. The plates were incubated for 24 h (Rapid' *E. coli* and X.L.D), 3 days (PCA), and 5 days (RBC) at optimal temperatures of 44°C (Rapid' *E. coli*) and 37°C (Rapid' *E. coli* and X.L.D) and

20°C (plate count agar and RBC) under microaerophilic conditions (Downes & Ito, 2001). Results were expressed as colony-forming units per mL (log CFU/mL).

2.6. Determination of physicochemical properties

pH and total soluble solids (TSS) were measured at 20°C by direct reading on a digital pH meter (FC 2020) and refractometer (Carl Zeiss Abbe 13641, Germany), respectively. The pH meter was calibrated with buffer solutions (4, 7, and 10) before use, and the refractometer prism was cleaned with distilled water before each analysis. Total soluble solids were determined using a refractometer and reported as degrees Brix (°Brix). Titratable acidity (TA) was determined by titrating 5 mL juice sample diluted in 50 mL distilled water with 0.1 M sodium hydroxide to the endpoint (pH 8.2 ± 0.1 and phenolphthalein indicator turn to light pink) (Tyl & Sadler, 2017). Total acidity was expressed as grams of citric acid equivalents per 100 mL (g CAE/100 mL) for pineapple and mango juice and as malic acid equivalents (g MAE/100 mL) for watermelon juice.

2.7. Determination of vitamin C

Vitamin C (ascorbic acid) was determined using a titration method described by Nielsen (2017) using 2,6-dichloroindophenol dye as the indicator. Briefly, fresh metaphosphoric acid-acetic acid solution was prepared by mixing 20 mL acetic acid, 100 mL distilled water, and 7.5 g metaphosphoric acid in a 250 mL volumetric flask and filled to the mark with distilled water. Indophenol standard solution was prepared by dissolving 42 mg sodium bicarbonate in 50 mL distilled water and adding 50 mg 2,6-dichloroindophenol sodium salt. The mixture was thoroughly mixed and brought to the 200 mL mark with distilled water. The mixture was further filtered in a fluted filter paper (particle retention 5 – 13 μm). into an amber bottle. Ascorbic acid standard (1 mg/mL) was prepared in the metaphosphoric-acetic acid solution immediately before use. To 5 mL metaphosphoric acid - acetic acid solution, 2 mL ascorbic acid standard solution or juice sample was added and titrated against indophenol solution until a light but distinct rose-pink color persisted for 5 s. Results were expressed as mg of ascorbic acid equivalents (AAE) per 100 mL of fruit juice and calculated as;

$$\text{Ascorbic acid (mg/mL)} = (X-B) * (F/E) * (V/Y) \quad (1)$$

where: X = mL for sample titration, B = average mL for sample blank titration, F= titer of dye, E = mL assayed, V = volume of initial assay solution, Y = volume of sample aliquot titrated

2.8. Color assessment

Color was determined using a Hunter colorimeter (HunterLab Colorflex EZ, Hunter Associates Laboratory, Virginia, U.S.A.) at illuminant D65, 10° standard observer, 45°/ 0° geometry and quantified based on the CIELAB color scales adopted as a standard by the International Commission on Illumination, *i.e.*, L***** (lightness and luminance), a***** (red and green), b***** (blue and yellow) scales. The instrument was calibrated with a white standard plate. Ten coordinate readings were taken at different random points of each sample and the average value was calculated. The hue angle (h°) and chroma (C) and total color difference (ΔE) were calculated using the following equations, according to Perkins-Veazie & Collins (2004), *i.e.*,

$$h° = \tan^{-1}(b^*/a^*) \quad (2)$$

$$C = \sqrt{(a^{*2}+b^{*2})} \quad (3)$$

$$\Delta E = \sqrt{(\Delta L^*)^2+(\Delta a^*)^2+(\Delta b^*)^2} \quad (4)$$

2.9. Determination of chemical composition of fruit juices

The moisture and protein content of each sample were determined using International Organization of Standardization (ISO) 1442-1997 and ISO 937-1978 respectively.A factor of 6.25 was used for the conversion of nitrogen to crude protein. Crude ash was determined according to AOAC (2010) method number 945.46. About 2 g fruit juice was completely carbonized over low heat in a high-form porcelain crucible and ashed overnight at 550°C in a Muffle oven. The weight difference was calculated after cooling in a desiccator to room temperature. Crude ash content was expressed as g/100mL of fruit juice.

Essential minerals; iron (Fe), zinc (Zn), manganese (Mn), copper (Cu), magnesium (Mg), potassium (K), calcium (Ca), and sodium (Na) were determined using the inductively coupled plasma optical emission spectrometry (ICP-OES) (Varian, PTY Ltd., Victoria, Australia) as described by Ashoka et al. (2009). In brief, obtained crude ash was subsequently dissolved in 5 mL 65% nitric acid, filtered, and mineral content measured using ICP-OES with Thermo iCAP 7200 Spectrometer (Thermo Fisher Scientific Inc., Waltham, MA, USA) which was equipped with a peristaltic pump (0.76 mm), cyclonic spray chamber, concentric nebulizer, quartz plasma torch, and 2.0 mm alumina internal diameter injector. The instrumental parameters used were: 1180 W RF power, 12.0 L/min plasma flow rate, 0.5 L/min auxiliary gas flow rate, 0.5 L/min nebulizer flow rate, radial view, 15 min UV exposure time, 5 min VIS exposure time, 10 min warm-up, and 40 min wash time. The wavelengths selected for Cu, Fe, Mn, Zn, K, Na, Ca, and Mg were 224.7, 239.6, 260.6, 202.6, 766.5, 589.6, 422.7, and 285.2 nm, respectively. Standard plot analytical curves for each element with a fit factor of above 0.99 were used to calculate the concentration of the elements in the samples compared to multi-element stock standard. Results were expressed as mg/100 mL of fruit juice.

2.10. Analysis of polyphenol oxidase (PPO) and peroxidase (POD) activities

Enzyme extractions were prepared as previously described by Wulfkuehler et al. (2013). For each juice extract (5 mL), 25 mL of 50 mM chilled citrate-phosphate buffer (pH 6.5), 150 mg polyvinyl polypyrrolidone, 400 mg sodium chloride and 50 mg saponin were added. The mixture was homogenized using Ultra-Turrax at 6000 rpm for 2 min and incubated on a shaker (BioSan PSU-10i Orbital Shaker, Riga, Latvia) at 250 rpm, 7°C for 2 h. The extracts were then centrifuged (Hermle Z 300 K, Wehingen, Germany) at 4000 rpm for 20 min at 4°C and the supernatants were filtered through a filter paper. The clarified supernatants were kept on ice until PPO and POD activity assays were performed on the same day.

PPO and POD activities were assayed as described by Baur et al. (2004) with some modifications. Total PPO was determined in the presence of sodium dodecyl sulfate (SDS) and the reaction mixture comprised of 1.5 mL reaction buffer (RB) (2 mM SDS in citrate–phosphate buffer (pH 6.5)), 0.2 mL 0.5 M L-proline in RB, and 0.1 mL enzyme extract. After 40 s incubation at 37 °C, the reaction was started by the addition of 0.2 mL pyrocatechol and product formation was continuously measured by the accumulation of the pink proline-catechol adduct at 525 nm (ε = 550 L M^{-1} cm^{-1}) for 3 min using a Spectrophotometer (Shimadzu UV-1800 spectrophotometer, Kioto, Japan). The enzyme activity (U/mL) was calculated from the slope of the linear part of the absorbance time plot. One unit of enzyme activity is defined as the amount of PPO that produces 1 µmol of the reaction product in 1 min under the specified conditions.

For POD activity, 0.3 mL aliquot of enzyme extract was added to 1.95 mL substrate buffer (SB) comprising 12 mM tropolone in citrate–phosphate buffer (pH 6.5). After 40 s incubation at 37 °C, the reaction was started by adding 75 µL of 31 mM hydrogen peroxide. Product formation was followed by measuring the accumulation of the yellow product Spectrophotometrically at 418 nm (ε = 2075 L M^{-1} cm^{-1}) for 3 min. The enzyme activity (U/mL) was calculated from the slope of the linear part of the absorbance time plot. One unit of enzyme activity is defined as the amount of POD that produces 1 µmol of the reaction product in 1 min under the specified conditions.

2.11. Determination of total phenolic content (TPC)

Total phenolic compounds were extracted using 80% methanol, as described by Gonzales et al. (2014). Briefly, 5 mL juice sample was added to 15 mL methanol (80%) and homogenized using Ultra-Turrax homogenizer at 10,000 rpm for 45 s and immediately kept on ice for 15 min. The homogenate was then centrifuged at 4000 rpm, 4°C for 15 min, filtered in the dark, and the obtained pellets were re-extracted with 10 mL methanol (80%) using the same procedure. The collected supernatants were then pooled, filled to 25 mL with methanol, and stored at -20°C in the dark until further analyses.

Total phenolic content (TPC) was determined using the Folin–Ciocalteu (FC) method according to Huynh et al. (2014). About, 1 mL methanolic extract was added to 1 mL deionized water and vortex mixed with 0.5 mL of 10 times diluted FC reagent in deionized water. After 6 min of standing, 1.5 mL sodium carbonate (20% w/v) and 1 mL deionized water was added, vortex mixed, and incubated in the dark for 2 h at ambient temperature. The absorbance of the mixture was then measured using a Spectrophotometer at 760 nm and TPC was expressed as mg gallic acid equivalent (GAE)/100 mL of fruit juice.

2.12. Antioxidant activities

A stock solution of ABTS+ was prepared by mixing equal amounts of 7 mM ABTS radical cation and 2.45 mM potassium persulfate, which were left to react for 12 – 16 h in the dark at ambient temperature. The working solution was subsequently prepared by diluting the stock solution with methanol (90%) to an absorbance of 0.70 ± 0.02 at 734 nm equilibrated at 30 °C. Aliquots (20 µL) of each sample extract or Trolox standard solution or methanol (90%) (blank) were then added to 2 mL of the ABTS+ solution, vortex mixed, and incubated for 5 min in the dark at room temperature. Thereafter, the absorbance of the resulting solution was measured

Spectrophotometrically at 734 nm, and results were expressed in mg Trolox equivalent (TE)/100 mL of fruit juice (Re et al., 1999).

The reducing ability of antioxidants in the samples towards DPPH was also measured using the procedure by Brand-Williams et al. (1995). Aliquots (200 µL) of sample extracts/Trolox standards solutions were vortex mixed for 10 s with 4 mL DPPH solution (prepared by dissolving 3.94 mg DPPH in 100 mL pure methanol) and incubated for 30 min at room temperature in the dark. The absorbance of the mixture was then measured using a Spectrophotometer at 517 nm. Results were expressed in mg TE/100 mL of fruit juice.

2.13. Statistical analysis

Statistical analysis was done using GraphPad Prism (Version 8.0.0 for macOS, San Diego, CA, USA). One-way analysis of variance (ANOVA) was used to analyze any variations in the fruit juice characteristics and during the treatments. Multiple range test (Tukey's HSD test) was further used to compare any significant differences in their means. Significance difference was accepted at $p < 0.05$ and values are expressed as mean ± SD of two independent samples. Student t-test was used to check any differences between two groups.

3. Results and discussion

3.1. Proportion of fruit parts

The different proportions of watermelon, pineapple, and mango fruits parts are shown in Table S1. Mango juice had the highest juice yield (70.3% w/w) followed by watermelon (52.2% w/w) and pineapple (48.4% w/w). This is an important parameter in the food industry to estimate profit margins from fruit juice yields. Overall, the fruits exhibited a by-product proportion that ranged from 51% w/w in pineapple to 30% w/w in mango. These findings are consistent with other studies that showed a by-product proportion of 54.9% in pineapple (Misran et al., 2019) and 35% in mango (Tesfaye, 2017). Peels made up the largest by-product proportion (16.2 – 43.3% w/w) compared to the seeds, pomace, and crown. These by-products are often discarded as waste that contributes to environmental impact.

3.2. Characterization of fruit juices

3.2.1. Microbial quality

As shown in Table 1, all treatments showed acceptable microbiological quality (counts lower than the limit amount of 7 log cfu/mL for plate count and 4 log cfu/mL for yeasts and moulds) for human consumption (Uyttendaele et al., 2018). The samples were also safe as per the International Commission on Microbiology Specifications for Foods (ICMSF) (2011) guidelines given their *Escherichia coli*, total coliforms and *Salmonella* spp were below the detection limit of 1 log CFU/mL. Pineapple and mango juices had the lowest aerobic plate counts and yeasts and molds compared to the watermelon juice. The presence of these microorganisms in fresh produce is often a reflection of contact with the environment, *i.e.*, soil, water, and animals, contamination during harvest (equipment or handlers) and cross-contamination during processing (Gil et al., 2015).

3.2.2. Physicochemical characteristics

Pineapple juice had the lowest pH value (3.40) whereas watermelon juice had the highest value of 5.40. These findings are similar to other studies that reported a pH of 3.58 – 4.69 in pineapple juice (Lu et al., 2014) and 5.83 in watermelon juice (Liu et al., 2012). Titratable acidity of all the samples ranged between 0.14% and 1.04%. The dominant organic acids reported in watermelon, mango and pineapple juices are mainly malic acid, citric acid, oxalic acid, tartaric acid, and succinic acid (Jin et al., 2018). Juice acidity plays a key role in its sensory acceptability by consumers (Mandha et al., 2021). Total soluble solids varied in the fruit juices, with the highest value recorded in mango juice (13.6 °Brix) and lowest in watermelon juice (5.07 °Brix). This variability could be attributed to differences in fruit types, cultivars, fruit maturity, growing location, cultivation practices, harvest time, and climate (Lozano, 2006).

3.2.3. Vitamin C

Vitamin C is a chain-breaking antioxidant that inhibits the oxidation of lipids hence preventing the formation of free radicals that could lead to chronic diseases such as cancer (Padayatty et al., 2003). Pineapple and mango juices had the highest vitamin C contents at 63.7 mg AAE/100 mL and 61.2 mg AAE/100 mL, respectively. These results were higher than those reported by Chakraborty et al. (2015) in pineapple juice and Zaman et al. (2016) in mango juice at 54 mg/100 mL and 50.7 mg AAE/100 mL, respectively. Vitamin C content in watermelon juice was lower than the results reported by Olayinka and Etejere (2018) (2.27 mg/100 mL). The occurrence of vitamin C may depend on fruit type, fruit cultivars, and environmental conditions such as light, high temperature, oxygen and storage (Kabasakalis et al., 2000).

3.2.4. Color

Table 1 also depicts the color of the fruit juices. The CIE L*****, a*****, and b***** values varied within the fruit juices. The L* values show the lightness of the juices with 0 = black and 100 = white. Mango juice was the lightest, having the highest L* value, whereas watermelon juice was the darkest. Mango and pineapple juices tended to be more yellow (b*) than watermelon juice. Pineapple juice was more green than mango and watermelon juices, which were more red (a*). These findings are comparable to other similar studies (Tarazona-Díaz & Aguayo, 2013). Color pigments, mainly carotenoids are responsible for the attractive bright colors of juices. Lycopene makes up 90% of carotenoids in red-fleshed watermelon cultivars (Kyriacou et al., 2018). The color intensity (chroma) was strongest in mango juice (57.2) followed by pineapple juice (17.7) and then watermelon juice (5.86).

3.2.5. Chemical composition of fruit juices

Watermelon juice had the highest moisture content compared to mango and pineapple juices (Table 1). This finding agrees with other research that also found a high moisture content of watermelon pulp (94%) (Olayinka & Etejere, 2018). The high moisture content makes this juice an excellent food product to quench thirst, however, it becomes highly susceptible to microbial spoilage if unprocessed for a long period. Crude protein was significantly highest in watermelon juice, followed by mango juice and then pineapple juice. The ash content of watermelon and pineapple juice samples was significantly higher than in mango juice. Differences in the chemical composition of among the fruit juices may be due to their botanical variety, cultivation practices, weather, and maturity (Lozano, 2006).

Regarding minerals, K was the highest element followed by in decreasing order, Ca, Mg, Na, Fe, Zn, Mn and Cu. Considering the fruit juices, watermelon juice had the highest amounts of Na, Cu, and Fe contents, pineapple juice had the highest amounts of K, Ca, Mg, Mn, and Zn while mango juice had the lowest values except for Na, Mn, and Zn. Previous researchers have also described pineapple as a good source of minerals especially calcium (Lu et al., 2014). Differences in the mineral composition among the fruit types may be due to differences in the composition of the growing soil, irrigation water, harvesting seasons, and ripening stages (Camara et al., 2005). Minerals are needed for the body’s metabolism and homeostasis (Gharibzahedi & Jafari, 2017). Microelements play a vital role as structural parts of enzymes (metalloenzymes) such as superoxide dismutase (Cu, Zn, Mn, Fe), hydrogenase (Fe) and catalase (Fe) (Gupta, 2018). In addition, Fe is needed in the formation of hemoglobin in the red blood cell, Mn is a scavenger of free radicals and is important for normal functioning of the brain and proper activity of the nervous system and Zn, even at low levels, is essential in protein and nucleic acid synthesis (Gharibzahedi & Jafari, 2017).

3.3. Effect of pasteurization and storage on quality attributes of watermelon and mango juices

Basing on the characterization, watermelon and mango juices were selected to be studied further. The initial temperature of both watermelon and mango juices was between 17°C and 20°C (**Table S2**). The temperature increase in mango juice was more gradual than in watermelon juice (**Fig. S1**). In addition, heat transfer time to obtain the internal temperature of 80°C was two-fold higher in mango juice than watermelon juice. Hence, mango juice had a lower heating rate (0.31 ± 0.03°C/s). This is maybe attributed to juice complexity, *i.e.,* texture, thickness, and type of fruit whereby watermelon juice had higher moisture content (92%) that absorbs heat faster by convection. There were no significant differences in the pasteurization holding temperature, external temperature, cooling medium, and cooling temperature.

3.3.1. Microbial quality

Regardless of the holding time, pasteurization reduced the total plate count and yeast and molds to below detectable limits of 1 log CFU/mL in both fruit juices (**Table 2**). Microorganisms are more vulnerable to increased temperature than physical and chemical changes and enzyme inactivation (Ryley & Kajda, 1994). Heat kills microorganisms by denaturing their enzymes and destroying their cell membrane. Pathogenic bacteria (*E. coli*, *Salmonella* spp. and total coliforms) were below detectable limits of 1 log CFU/mL in all the samples indicating their safety. Pasteurization maintained a good microbial quality of both juices during the entire storage period. However, there was a gradual increase of aerobic plate counts in unpasteurized (control) watermelon juice reaching a maximum of 8.33 log CFU/mL on day 14 and yeasts and molds of

6.99 log CFU/mL on day 9 (**Table 3**). This finding is consisted with the results of Ma et al. (2020) who showed a rapid microbial deterioration of non-industrial watermelon juice during storage. Watermelon juice had a pH of 5.40 might favor the growth of microorganisms (Hammes & Hertel, 2015)

3.3.2. Physicochemical properties

Pasteurization did not significantly affect the pH, TA and TSS of mango and watermelon juices. This finding match results observed in earlier studies in watermelon juice enriched with L-citrulline and pomegranate juice (Tarazona-Díaz et al., 2017; Turfan et al., 2011). During cold storage, the TA and pH of all the pasteurized juices did not change (**Table 3**). However, TSS of watermelon P10 and P15 increased during storage. Similar trends were also observed in roselle-mango juices and this was attributed to the hydrolysis of polysaccharides into monosaccharides during storage (Mgaya-Kilima et al., 2015).

All these quality parameters significantly changed in the unpasteurized juices during storage. For instance, the TA significantly increased to 0.27 on day 14 in unpasteurized watermelon juice. Similarly, Unluturk and Atilgan (2015) observed an increase in TA of white grape juice. This could be due to the metabolic activity of microorganisms or fermentation during storage resulting in the production short chain fatty acids (Feng et al., 2013). The total soluble solids of the unpasteurized mango juice decreased from 15.0 to 14.1 by day 14. TSS, pH, and TA are closely influence the juice sensory attributes of sweetness, acidity, and taste (Sarrwy et al., 2021) and are determined by genotype, maturity and growing conditions of the fruit (Yıkmış, 2020). The effect of cold storage on the physicochemical properties depended on the fruit type and thermal treatment.

3.3.3. Vitamin C

Table 2 also depicts the effect of pasteurization on the vitamin C content of the fruit juices. Vitamin C content gradually decreased with an increase in pasteurization time in both juices (r^2, 0.865, $p < 0.001$ in watermelon juice and r^2, 0.892, $p < 0.001$ in mango juices). At 10 min of pasteurization, a decrease of 27% was recorded in mango juice, while vitamin C was not detectable in watermelon juice. This result corroborates with previous research that showed a negative effect of temperature and temperature duration on vitamin C content of fruit juices (Tchuenchieu et al., 2018). Vitamin C is heat liable and is easily oxidized to dehydroascorbic acid on exposure to atmospheric oxygen (Ryley & Kajda, 1994).

Cold Storage (4°C) also had a substantial impact on the vitamin C content (**Table 3**). Vitamin C was not detected on day 2 in P5 and day 14 in P2.5 watermelon juices. A gradual decrease in vitamin C was recorded in the control mango juice. Other authors have also shown a reduction of vitamin C in mango juice during storage (Mgaya-Kilima et al., 2015). This may be attributed to oxidation due to the presence of oxygen in the headspace.

3.3.4. Color

Color is an important quality parameter for the marketability and consumer acceptability of fruit juices. Pasteurization did not affect the color attributes of mango juice. The carotenoids in mango juice, such as β-carotene, naturally occur in their stable form (*cis*-isomer), which may explain the color stability during processing (Vásquez-Caicedo et al., 2007). All the color components of watermelon juice significantly changed ($p < 0.05$) with increased pasteurization time. As illustrated in **Table 2**, the a* value which depicts redness, significantly decreased while the b* value (yellowness) increased. This led to an increase in the $h°$ and chroma of the pasteurized watermelon juice. Hence, watermelon juice changed from its natural characteristic red color to more yellow with the increment of pasteurization time. These results agree with previous research that reported an increase in b* values of watermelon juice subjected to heat treatment (90 °C, 60 s). The color pigments in watermelon juice, mainly lycopene, are thermolabile hence degraded during pasteurization following a first order kinetics modal *i.e.*, their degradation rate increases with treatment time (Sharma et al., 2008) and may also undergo oxidation. Lycopene may be fragmented into different molecules, such as acetone, methylheptenone, and laevulinic aldehyde, which leads to an apparent color loss (Xianquan et al., 2005). Formation of dark compounds could be attributed to Maillard reactions (Aguiló-Aguayo et al., 2009). Maillard reactions are a complex series of reactions between carbonyl-containing compounds namely, reducing sugars, aldehydes, or ketones with a free amino group of amino acids, peptides, or proteins (Vhangani & Van Wyk, 2021). They are may lead to the formation of furfural and 5-hydroxymethylfurfural (HMF) compounds which have been associated with cytotoxic, genotoxic, and mutagenic risks (Vollmer et al., 2020). 5-Hydroxymethylfurfural was not detected in thermally pasteurized pineapple (Vollmer et al., 2020) and orange juices (Vervoort et al., 2012), however, these compounds may further be investigated in pasteurized watermelon juice.

On day 9 of storage, both unpasteurized and pasteurized watermelon juices became less red, less yellow and had lower chroma (**Fig. 1**). Tarazona-Díaz et al. (2017) attributed watermelon juice color changes during storage to loss of stability due to residual enzyme activity. Storage time did not affect the color of the pasteurized mango juices, but unpasteurized mango juice became darker and less red by the end of the 14-day. Similarly, other researchers have shown color degradation of mango juice during storage, and this was attributed to enzymatic or non-enzymatic browning from the oxidation of polyphenols and/or fading of naturally occurring the color pigments (Wibowo et al., 2018; Wibowo et al., 2015b).

3.3.5. Enzyme activity

Polyphenol oxidase (PPO) and peroxidase (POD) reduce the stability and quality of fruit juices, such as color, pigment, viscosity, formation of off-flavors, and loss of nutrients (Petruzzi et al., 2017; Taranto et al., 2017), hence their inactivation is important in the food industry. As presented in Table 2, the PPO activity was about 0.10 U/mL and 0.8 U/mL in the control watermelon juice and mango juice, respectively. Zhang et al. (2011) did not detect any PPO activity in watermelon juice. This may be due to differences in the fruit cultivars. PPO induces the conversion of phenolic compounds to quinones that polymerize with amino acids, proteins, or other compounds with brownish, black, or red color pigments hence changing the color quality of fruit juice (Taranto et al., 2017). Pasteurization strongly affected PPO leading to undetectable levels in mango juice after 1 min, and a reduction of 80% in watermelon juice after 5 min. These results are in accordance with other studies that demonstrated a reduction of PPO activity in watermelon juice and mango slices after heat treatment (Liu et al., 2012; Ndiaye et al., 2009).

POD catalyzes the oxidation of hydrogen-donor molecules (Ağçam et al., 2018). This enzyme activity was reduced proportionally to the increasing pasteurization holding time ($p < 0.05$). These results corroborate previous findings that similarly described a reduction of POD activity in watermelon and mango juice after heat treatment (Tarazona-Díaz et al., 2017; Vásquez-Caicedo et al., 2007). In comparison with PPO, POD was more thermoresistant and required a pasteurization time of at least 5 min to obtain 80% activity reduction in both juices.

3.3.6. Total phenolic content and antioxidant capacity

Mango juice had a five-folds higher TPC than watermelon juice. Pasteurization time did not change the TPC values of both watermelon and mango juices, demonstrating the thermal stability of these compounds. This finding is consistent with previous studies that showed no significant change of fruit juice TPC with conventional thermal treatment (Saikia et al., 2016). However, during storage, the TPC of pasteurized mango juices at P10 increased on day 5 (**Table 2**). Tchuenchieu et al. (2018) reported an increase of TPC in fruit juices heated (50 °C – 90 °C) for a longer treatment time. The authors attributed this effect to liberation of molecules previously complexed or polymerized and the retention of active molecules by the inactivation of enzymes. Pasteurization did not change the antioxidant capacity of the juices using both DPPH and ABTS assays. This trend continued during the storage period in mango juices. However, in P2.5 and P15 watermelon juice, antioxidant capacity using DPPH activity significantly decreased on day 9 and 5, respectively. This decline may be attributed to the oxidation of bioactive compounds in watermelon juice during storage (Tarazona-Díaz & Aguayo, 2013). Further research using sophisticated analytical tools may be conducted to estimate the changes of these bioactive compounds in fruit juices after pasteurization.

4. Conclusion

Considerable variations were shown in watermelon, pineapple, and mango juices' physicochemical, chemical composition, and quality parameters. Although pasteurization ensured and prolonged microbial safety of both juices, it had different effects on the color, vitamin C, PPO, and POD enzyme activities depending on the fruit juice and their composition. Watermelon color was negatively affected by pasteurization. A pasteurization time of 10 min strongly reduced the vitamin C content of both juices. POD was more thermoresistant than PPO requiring a pasteurization time of at least 5 min to obtain 80% activity reduction. During cold storage (4°C), watermelon juice color deteriorated after 9 days, and the vitamin C content of the control mango juice gradually decreased with storage time. Total phenolic content increased in mango juice pasteurized at 10 min but decreased in watermelon juice pasteurized at 15 min upon storage. Thus, to maintain fruit quality, eliminate background microflora and inactivate enzymes, in watermelon and mango juices, a pasteurization time of 5 min and cold storage of no more than 9 days may be applied.

Declarations of competing interest

The authors confirm that they have no conflicts of interest with respect to the work described in this manuscript.

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Table 1. Quality attributes, chemical composition, and mineral content of fruit juices

Attribute	Watermelon juice	Pineapple juice	Mango juice	P value
Microbial quality (log CFU/mL)				
Total plate count	5.45 ± 0.07[b]	4.49 ± 0.11[c]	6.11 ± 0.10[a]	< 0.001
Yeasts and molds	4.04 ± 0.06[b]	4.45 ± 0.10[a]	2.85 ± 0.20[c]	< 0.001
Physicochemical properties				
pH	5.40 ± 0.01[a]	3.40 ± 0.01[c]	3.77 ± 0.03[b]	< 0.001
Titratable acidity (%)	0.14 ± 0.01[c]	1.04 ± 0.04[a]	0.94 ± 0.02[b]	< 0.001
Total soluble solids (°Brix)	5.07 ± 0.06[c]	13.0 ± 0.01[b]	13.6 ± 0.06[a]	< 0.001
Vitamin C (mg AAE/100 mL)	0.59 ± 0.01[c]	63.7 ± 0.51[a]	61.2 ± 0.16[b]	< 0.001
Color				
L*	17.2 ± 0.41[c]	38.8 ± 1.63[b]	53.9 ± 0.24[a]	< 0.001
a*	5.34 ± 0.23[b]	-4.79 ± 0.11[c]	9.70 ± 0.29[a]	< 0.001
b*	2.42 ± 0.30[c]	17.0 ± 1.72[b]	56.4 ± 0.42[a]	< 0.001
H°	24.3 ± 1.85[c]	286 ± 1.35[a]	80.3 ± 0.22[b]	< 0.001
C	5.86 ± 0.33[c]	17.7 ± 1.67[b]	57.2 ± 0.46[a]	< 0.001
Chemical composition (g/100 mL)				
Moisture	92.4 ± 0.01[a]	87.8 ± 0.37[b]	84.6 ± 0.01[c]	< 0.001
Protein	0.61 ± 0.01[a]	0.37 ± 0.01[c]	0.41 ± 0.01[b]	< 0.001
Ash	0.25 ± 0.01[a]	0.28 ± 0.01[a]	0.18 ± 0.01[a]	0.006
Minerals (mg/100 mL)				
K	72.2 ± 1.46[b]	94.2 ± 4.93[a]	11.8 ± 0.33[c]	< 0.001
Na	10.1 ± 0.05[a]	5.19 ± 1.00[b]	8.52 ± 1.34[a]	0.003
Ca	9.44 ± 0.32[b]	21.5 ± 0.74[a]	4.44 ± 0.15[c]	< 0.001
Mg	7.99 ± 0.24[b]	12.1 ± 0.03[a]	4.96 ± 0.08[c]	< 0.001
Cu	0.17 ± 0.05[a]	0.15 ± 0.01[a]	0.02 ± 0.01[b]	0.002
Fe	0.57 ± 0.06[a]	0.46 ± 0.07[a]	0.08 ± 0.01[b]	< 0.001
Mn	0.13 ± 0.06[b]	0.35 ± 0.00[a]	0.33 ± 0.01[a]	0.001
Zn	0.08 ± 0.04[c]	0.69 ± 0.04[a]	0.32 ± 0.06[b]	< 0.001

Values expressed as means ± standard deviations. [a,b,c] Different small letters within a row denotes a significant difference ($p < 0.05$). $n = 2$. L* - lightness and luminosity, a* - green-red, b* - blue-yellow, H° - hue angle, C – chroma.

Table 2. Effect of pasteurization time on quality attributes of watermelon and mango juice

Attribute	Fruit juice	Control	Pasteurization time (min)					P value
			P1	P2.5	P5	P10	P15	
Microbial quality (log CFU/mL)								
Total plate count	Watermelon juice	5.45 ± 0.07^{a}	$< 1^{b}$	$< 1^{b}$	$< 1^{b}$	$< 1^{b}$	$< 1^{b}$	< 0.001
	Mango juice	5.02 ± 1.08^{a}	$< 1^{b}$	$< 1^{b}$	$< 1^{b}$	$< 1^{b}$	$< 1^{b}$	<0.001
Yeasts and molds	Watermelon juice	4.10 ± 0.02^{a}	$< 1^{b}$	$< 1^{b}$	$< 1^{b}$	$< 1^{b}$	$< 1^{b}$	<0.001
	Mango juice	3.57 ± 0.70^{a}	$< 1^{b}$	$< 1^{b}$	$< 1^{b}$	$< 1^{b}$	$< 1^{b}$	<0.001
Physicochemical properties								
Titratable acidity (%)	Watermelon juice	0.10 ± 0.05^{B}	0.15 ± 0.07^{B}	0.13 ± 0.00^{B}	0.10 ± 0.04^{B}	0.12 ± 0.02^{B}	0.15 ± 0.02^{B}	0.680
	Mango juice	1.07 ± 0.06^{A}	1.02 ± 0.08^{A}	0.83 ± 0.09^{A}	0.89 ± 0.08^{A}	1.02 ± 0.03^{A}	1.00 ± 0.06^{A}	0.962
pH	Watermelon juice	5.75 ± 0.01^{A}	5.73 ± 0.01^{A}	5.74 ± 0.03^{A}	5.76 ± 0.01^{A}	5.78 ± 0.01^{A}	5.76 ± 0.01^{A}	0.080
	Mango juice	3.63 ± 0.01^{B}	3.59 ± 0.07^{B}	3.64 ± 0.01^{B}	3.65 ± 0.04^{B}	3.62 ± 0.02^{B}	3.66 ± 0.04^{B}	0.092
Total soluble solids (°Brix)	Watermelon juice	5.50 ± 0.01^{B}	5.33 ± 0.25^{B}	5.25 ± 0.35^{B}	5.30 ± 0.42^{B}	5.55 ± 0.21^{B}	5.65 ± 0.07^{B}	0.622
	Mango juice	15.0 ± 0.01^{A}	15.5 ± 0.71^{A}	16.1 ± 1.56^{A}	15.8 ± 1.77^{A}	15.3 ± 0.99^{A}	15.5 ± 1.63^{A}	0.962
Vitamin C (mg AAE/100 mL)								
	Watermelon juice	0.59 ± 0.01^{aB}	0.59 ± 0.01^{aB}	0.53 ± 0.04^{aB}	0.21 ± 0.02^{bB}	n.d	n.d	<0.001

	Mango juice	61.1 ± 0.31^{aA}	63.1 ± 3.47^{aA}	60.1± 0.97^{aA}	61.3 ± 1.80^{aA}	44.6 ± 1.36^{b}	39.2± 1.28^{b}	<0.001
Color								
L*	Watermelon juice	22.6 ± 0.20^{bcB}	22.1 ± 0.06^{cB}	23.6± 0.39^{aB}	22.3 ± 0.04^{cB}	23.5 ± 0.26^{baB}	22.7±0.20^{bcB}	0.003
	Mango juice	52.5 ± 0.44^{A}	50.5 ± 0.46^{A}	52.5 ± 0.62^{A}	51.9 ± 0.11^{A}	51.5 ± 1.58^{A}	52.4 ± 0.60^{A}	0.205
a*	Watermelon juice	7.71± 0.20^{a}	6.12 ± 0.01^{bB}	6.77± 0.31^{aB}	6.28 ± 0.51^{bB}	6.15 ± 0.55^{b}	5.85 ± 0.18^{bB}	0.015
	Mango juice	8.81 ± 0.50	8.73 ± 0.74^{A}	10.1 ± 0.39^{A}	9.54 ± 0.04^{A}	9.39 ± 1.65	10.3 ± 0.64^{A}	0.397
b*	Watermelon juice	2.02 ± 0.04^{bB}	7.81 ± 0.07^{aB}	8.47± 1.00^{aB}	7.88 ± 0.26^{aB}	8.48 ± 0.67^{aB}	8.70 ± 0.93^{aB}	<0.001
	Mango juice	51.9 ± 0.81^{A}	52.9 ± 0.44^{A}	55.6 ± 0.72^{A}	55.0 ± 0.48^{A}	54.2 ± 2.88^{A}	55.3 ± 0.91^{A}	0.167
h°	Watermelon juice	14.7 ± 0.62^{bB}	51.9 ± 0.23^{aB}	51.3± 2.03^{aB}	51.5 ± 1.36^{aB}	54.0 ± 0.28^{aB}	55.9 ± 3.73^{aB}	<0.001
	Mango juice	80.4 ± 0.39^{A}	80.6 ± 0.71^{A}	79.7 ± 0.26^{A}	80.2 ± 0.13^{A}	80.2 ± 1.18^{A}	79.4 ± 0.82^{A}	0.563
C	Watermelon juice	7.97 ± 0.18^{bB}	9.92 ± 0.06^{abB}	10.9± 0.97^{aB}	10.1 ± 0.52^{abB}	10.5 ± 0.86^{abB}	10.5 ± 0.66^{abB}	0.034
	Mango juice	52.7 ± 0.88^{A}	53.6 ± 0.56^{A}	56.5 ± 0.78^{A}	55.8 ± 0.46^{A}	55.0 ± 3.12^{A}	56.3 ± 0.78^{A}	0.173
ΔE	Watermelon juice	-	6.03 ± 0.01^{A}	6.60 ± 0.01	6.07 ± 0.05^{A}	6.73 ± 0.44	6.93 ± 0.86^{A}	0.541
	Mango juice	-	2.61 ± 0.26^{B}	3.82 ± 0.12	3.19 ± 0.38^{B}	2.96 ± 1.42	3.78 ± 0.38^{B}	0.429
Enzymes (U/mL)								
PPO	Watermelon juice	0.10 ± 0.03^{a}	0.08 ± 0.00^{a}	0.03 ± 0.00^{b}	0.02 ± 0.00^{b}	0.02 ± 0.00^{b}	0.01 ± 0.00^{b}	0.001

	Mango juice	0.08 ± 0.00	n.d	n.d	n.d	n.d	n.d	
POD	Watermelon juice	11.7 ± 0.61^{aA}	7.37 ± 0.61^{bA}	3.47 ± 0.00^{cA}	2.17 ± 0.61^{cA}	0.82 ± 0.06^{dA}	0.65 ± 0.06^{dA}	<0.001
	Mango juice	0.22 ± 0.06^{aB}	0.13 ± 0.06^{bB}	0.07 ± 0.01^{bB}	0.03 ± 0.01^{bB}	0.02 ± 0.01^{bB}	0.02 ± 0.00^{bB}	0.008
TPC (mg GAE/100mL)								
	Watermelon juice	13.2 ± 3.28^{B}	11.0 ± 3.28^{B}	9.07 ± 0.17^{B}	9.95 ± 0.86^{B}	11.5 ± 1.26^{B}	11.8 ± 1.61^{B}	0.521
	Mango juice	74.8 ± 0.19^{A}	68.5 ± 14.4^{A}	66.4 ± 14.1^{A}	65.7 ± 2.38^{A}	62.5 ± 8.34^{A}	63.5 ± 3.86^{A}	0.789
Antioxidant capacity								
ABTS	Watermelon juice	4.72 ± 0.37^{B}	10.5 ± 4.73^{B}	11.1 ± 6.42^{B}	8.53 ± 1.29^{B}	10.1 ± 4.43^{B}	13.2 ± 8.26^{B}	0.676
µmol TE/100mL)	Mango juice	125 ± 34.7^{A}	157 ± 23.2^{A}	134 ± 35^{A}	134 ± 20.6^{A}	131 ± 37.4^{A}	131 ± 15.6^{A}	0.892
DPPH	Watermelon juice	3.76 ± 0.70^{B}	3.86 ± 0.73^{B}	4.79 ± 0.30^{B}	4.29 ± 0.86^{B}	3.73 ± 0.59^{B}	4.16 ± 0.52^{B}	0.584
(mg TE/100mL)	Mango juice	105 ± 14.2^{A}	107 ± 22.9^{A}	106 ± 11.0^{A}	106 ± 10.0^{A}	105 ± 16.7^{A}	102 ± 10.2^{A}	0.999

Values expressed as means ± standard deviations within a row with different lowercase letters (a-d) indicate a significant difference (p < 0.05) across the pasteurization time according to Turkey's post hoc test and along a column (A-B) indicate a significant difference ($p < 0.05$) in the fruit juices according to Student's t-test. L***** - lightness and luminosity, a***** - green-red, b***** - blue-yellow, H° - hue angle, C - chroma, ΔE - color difference, n.d not detected, $n = 2$. Control is unpasteurized watermelon / mango juice

Table 3. Microbial quality, physicochemical properties and bioactive compounds of pasteurized and unpasteurized watermelon and mango juice during cold storage

Fruit juice	Storage time (days)	Control	Pasteurization time (min)				
			P1	P2.5	P5	P10	P15
Microbial quality (log CFU/mL)							
Total plate count							
Watermelon juice	0	5.45 ± 0.07^{d}	< 1	< 1	< 1	< 1	< 1
	2	5.76 ± 0.04^{d}	< 1	< 1	< 1	< 1	< 1
	5	6.09 ± 0.15^{c}	< 1	< 1	< 1	< 1	< 1
	9	7.65 ± 0.21^{b}	< 1	< 1	< 1	< 1	< 1
	14	8.33 ± 0.05^{a}	< 1	< 1	< 1	< 1	< 1
	P value	<0.001	-	-	-	-	-
Mango juice	0	5.02 ± 1.08	< 1	< 1	< 1	< 1	< 1
	2	4.44 ± 0.27	< 1	< 1	< 1	< 1	< 1
	5	4.34 ± 0.57	< 1	< 1	< 1	< 1	< 1
	9	5.18 ± 1.30	< 1	< 1	< 1	< 1	< 1
	14	5.31 ± 1.14	< 1	< 1	< 1	< 1	< 1
	P value	0.782	-	-	-	-	-
Yeasts and molds							
Watermelon juice	0	4.10 ± 0.02^{c}	< 1	< 1	< 1	< 1	< 1
	2	5.92 ± 0.01^{b}	< 1	< 1	< 1	< 1	< 1
	5	6.20 ± 0.14^{b}	< 1	< 1	< 1	< 1	< 1
	9	6.99 ± 0.16^{a}	< 1	< 1	< 1	< 1	< 1

	14	5.96 ± 0.17[c]	< 1	< 1	< 1	< 1	< 1
	P value	<0.001	-	-	-	-	-
Mango juice	0	3.57 ± 0.70	< 1	< 1	< 1	< 1	< 1
	2	2.87 ± 0.24	< 1	< 1	< 1	< 1	< 1
	5	3.78 ± 0.94	< 1	< 1	< 1	< 1	< 1
	9	4.90 ± 1.38	< 1	< 1	< 1	< 1	< 1
	14	5.09 ± 1.47	< 1	< 1	< 1	< 1	< 1
	P value	0.318	-	-	-	-	-
pH							
Watermelon juice	0	5.75 ± 0.01	5.73 ± 0.01	5.74 ± 0.03	5.76 ± 0.01	5.78 ± 0.01	5.76 ± 0.01
	2	5.74 ± 0.02	5.72 ± 0.01	5.73 ± 0.03	5.73 ± 0.03	5.74 ± 0.01	5.75 ± 0.02
	5	5.73 ± 0.01	5.73 ± 0.03	5.73 ± 0.03	5.69 ± 0.01	5.73 ± 0.03	5.70 ± 0.02
	9	5.53 ± 0.19	5.72 ± 0.02	5.73 ± 0.04	5.74 ± 0.02	5.75 ± 0.01	5.74 ± 0.02
	14	5.43 ± 0.14	5.75 ± 0.01	5.76 ± 0.01	5.70 ± 0.01	5.74 ± 0.02	5.73 ± 0.01
	P value	0.205	0.626	0.589	0.112	0.539	0.167
Mango juice	0	3.63 ± 0.01	3.59 ± 0.07	3.64 ± 0.01	3.65 ± 0.04	3.62 ± 0.02	3.66 ± 0.04
	2	3.61 ± 0.01	3.64 ± 0.01	3.65 ± 0.02	3.66 ± 0.04	3.66 ± 0.04	3.66 ± 0.02
	5	3.65 ± 0.08	3.68 ± 0.06	3.66 ± 0.04	3.66 ± 0.03	3.66 ± 0.06	3.67 ± 0.04
	9	3.62 ± 0.06	3.67 ± 0.06	3.68 ± 0.05	3.66 ± 0.04	3.65 ± 0.03	3.66 ± 0.04
	14	3.60 ± 0.04	3.69 ± 0.05	3.69 ± 0.04	3.68 ± 0.06	3.66 ± 0.04	3.66 ± 0.02
	P value	0.868	0.521	0.614	0.957	0.754	0.987
Titratable acidity (%)							
Watermelon juice	0	0.10 ± 0.05[b]	0.12 ± 0.02	0.13 ± 0.01	0.10 ± 0.04	0.12 ± 0.02	0.15 ± 0.02
	2	0.13 ± 0.01[b]	0.13 ± 0.01	0.13 ± 0.01	0.13 ± 0.05	0.18 ± 0.02	0.15 ± 0.02
	5	0.15 ± 0.02[b]	0.13 ± 0.01	0.15 ± 0.02	0.17 ± 0.05	0.13 ± 0.01	0.18 ± 0.02

	9	0.14 ± 0.04[b]	0.12 ± 0.06	0.15 ± 0.02	0.15 ± 0.02	0.17 ± 0.05	0.17 ± 0.05
	14	0.27 ± 0.01[a]	0.13 ± 0.01	0.13 ± 0.01	0.20 ± 0.01	0.13 ± 0.01	0.15 ± 0.02
	P value	0.018	0.989	0.640	0.288	0.190	0.765
Mango juice	0	1.07 ± 0.06	1.02 ± 0.08	0.83 ± 0.09	0.89 ± 0.08	1.02 ± 0.03	1.00 ± 0.06
	2	1.02 ± 0.08	0.85 ± 0.12	0.72 ± 0.12	0.80 ± 0.14	0.92 ± 0.12	1.02 ± 0.08
	5	1.02 ± 0.01	0.76 ± 0.16	0.87 ± 0.14	0.87 ± 0.14	0.92 ± 0.12	0.87 ± 0.14
	9	0.95 ± 0.02	1.00 ± 0.01	0.87 ± 0.01	0.75 ± 0.02	0.75 ± 0.02	1.03 ± 0.01
	14	0.81 ± 0.19	0.79 ± 0.07	0.95 ± 0.08	0.91 ± 0.16	1.00 ± 0.06	0.84 ± 0.19
	P value	0.200	0.147	0.347	0.677	0.121	0.404
Total soluble solids (°Brix)							
Watermelon juice	0	5.50 ± 0.00	5.53 ± 0.25	5.25 ± 0.35	5.30 ± 0.42	5.55 ± 0.21[ab]	5.65 ± 0.07[b]
	2	5.45 ± 0.07	5.40 ± 0.01	5.25 ± 0.35	5.65 ± 0.07	5.55 ± 0.07[ab]	5.50 ± 0.14[b]
	5	5.45 ± 0.07	5.40 ± 0.14	5.55 ± 0.07	5.65 ± 0.21	5.50 ± 0.14[b]	5.65 ± 0.07[b]
	9	5.75 ± 0.35	5.85 ± 0.07	5.95 ± 0.07	6.00 ± 0.01	6.00 ± 001[a]	6.15 ± 0.07[a]
	14	5.65 ± 0.07	5.95 ± 0.21	5.50 ± 0.71	5.95 ± 0.07	5.98 ± 0.04[ab]	6.00 ± 0.01[a]
	P value	0.387	0.234	0.453	0.107	0.018	0.003
Mango juice	0	15.0 ± 0.00[a]	15.5 ± 0.71	16.1 ± 1.56	15.8 ± 1.77	15.3 ± 0.99	15.5 ± 1.63
	2	15.0 ± 0.00[a]	15.8 ± 0.35	15.2 ± 0.28	15.3 ± 0.35	15.0 ± 0.71	15.2 ± 0.57
	5	14.7 ± 0.14[ab]	15.5 ± 0.71	15.3 ± 0.35	15.3 ± 0.49	15.3 ± 0.35	15.1 ± 0.14
	9	14.6± 0.49a[b]	15.2 ± 0.21	15.3 ± 0.64	14.9 ± 0.21	15.0 ± 0.21	15.3 ± 0.85
	14	14.1 ± 0.07[b]	14.6 ± 0.14	15.3 ± 0.64	15.1 ± 0.14	15.0 ± 0.01	15.0 ± 0.04
	P value	0.042	0.291	0.780	0.862	0.950	0.984
Vitamin C (mg/100 mL)							
Watermelon juice	0	0.59 ± 0.01	0.59 ± 0.01	0.53 ± 0.04	0.21 ± 0.02	n.d	n.d

	2	0.47 ± 0.08	0.41 ± 0.12	0.35 ± 0.17	n.d	n.d	n.d
	5	0.59 ± 0.01	0.59 ± 0.01	0.20 ± 0.06	n.d	n.d	n.d
	9	0.60 ± 0.01	0.59 ± 0.00	0.23 ± 0.08	n.d	n.d	n.d
	14	0.59 ± 0.00	0.54 ± 0.04	n.d	n.d	n.d	n.d
	P value	0.467	0.487	0.185	< 0.001		
Mango juice	0	61.1 ± 0.31[a]	63.1 ± 3.47	60.1 ± 0.97	61.3 ± 1.80	44.6 ± 1.36	39.2 ± 1.28
	2	64.9 ± 0.79[a]	46.4 ± 0.31	42.4 ± 9.3	50.6 ± 9.07	46.1 ± 2.65	43.6 ± 7.56
	5	58.7 ± 9.62[ac]	52.3 ± 3.62	50.8 ± 3.22	58.4 ± 1.55	48.4 ± 9.19	39.2 ± 2.98
	9	42.0 ± 1.87[b]	56.1 ± 0.06	52.9 ± 10.7	55.5 ± 2.57	57.9 ± 0.79	40.8 ± 8.55
	14	33.9 ± 2.82[c]	46.7 ± 9.01	49.6 ± 7.63	47.9 ± 5.15	53.5 ± 3.01	42.0 ± 3.13
	P value	0.004	0.063	0.170	0.170	0.133	0.904
TPC (GAE/100mL)							
Watermelon juice	0	13.2 ± 3.28	11.0 ± 3.28	9.07 ± 0.17	9.95 ± 0.17	11.5 ± 1.26	11.8 ± 1.61[a]
	2	8.39 ± 0.24	7.11 ± 0.23	9.12 ± 0.04	7.01 ± 1.06	5.59 ± 0.09	6.91 ± 0.19[b]
	5	8.42 ± 0.85	9.67 ± 0.03	11.2 ± 0.95	11.1 ± 2.54	12.8 ± 4.25	8.78 ± 1.33[ab]
	9	9.20 ± 0.10	8.12 ± 0.35	9.10 ± 0.53	9.53 ± 0.71	8.94 ± 0.78	8.18 ± 0.09[ab]
	14	9.75 ± 0.10	9.79 ± 0.41	9.89 ± 3.96	8.69 ± 1.36	8.68 ± 0.74	7.58 ± 1.47[ab]
	P value	0.108	0.225	0.741	0.213	0.093	0.046
Mango juice	0	74.8 ± 0.19	68.5 ± 14.4	66.4 ± 14.1	65.7 ± 2.38	62.5 ± 8.34[b]	63.5 ± 3.86
	2	77.1 ± 8.62	75.0 ± 11.5	83.4 ± 19.1	68.6 ± 8.66	75.3 ± 7.07[ab]	80.9 ± 8.49
	5	73.5 ± 2.98	74.2 ± 7.60	85.0 ± 8.84	86.2 ± 12.7	108.2 ± 15.2[a]	83.1 ± 11.2
	9	68.9 ± 9.25	80.2 ± 6.28	80.2 ± 4.76	72.4 ± 11.3	73.2 ± 7.02[ab]	67.4 ± 6.03
	14	77.2 ± 11.4	79.3 ± 12.9	86.2 ± 3.83	87.4 ± 14.2	80.7 ± 2.27[ab]	89.3 ± 4.91
	P value	0.809	0.827	0.506	0.270	0.026	0.069

Antioxidant capacity

DPPH (mg TE/100mL)							
Watermelon juice	0	3.76 ± 0.70	3.86 ± 0.73	4.79 ± 0.30[a]	4.29 ± 0.86	3.73 ± 0.59	4.16 ± 0.52[ab]
	2	3.93 ± 0.40	4.91 ± 0.48	4.17 ± 0.13[ab]	3.40 ± 0.54	3.89 ± 0.04	4.50 ± 0.18[a]
	5	3.03 ± 0.40	4.18 ± 1.88	3.21 ± 0.69[b]	2.93 ± 0.04	2.57 ± 0.19	2.72 ± 0.32[b]
	9	3.13 ± 1.00	2.68 ± 0.43	2.73 ± 0.18[b]	3.24 ± 0.42	2.86 ± 0.52	2.88 ± 0.67[ab]
	14	3.60 ± 0.49	3.53 ± 0.21	3.64 ± 0.31[ab]	3.27 ± 0.78	3.85 ± 1.39	3.32 ± 0.18[ab]
	P value	0.597	0.438	0.016	0.337	0.338	0.028
Mango juice	0	105 ± 14.2	107 ± 22.9	106 ± 11.0	106 ± 10.0	105 ± 16.7	102 ± 10.2
	2	104 ± 8.86	122 ± 23.9	125 ± 38.5	108 ± 12.3	115 ± 1.37	111 ± 18.7
	5	93.3 ± 7.28	106 ± 11.3	103 ± 11.7	105 ± 10.5	118 ± 30.5	103 ± 8.50
	9	95.1 ± 0.62	105 ± 9.99	107 ± 3.57	105 ± 3.69	108 ± 7.86	104 ± 1.85
	14	105 ± 6.23	99.2 ± 19.5	107 ± 14.4	105 ± 13.9	102 ± 14.7	105 ± 11.6
	P value	0.548	0.793	0.823	0.997	0.866	0.924
ABTS (µmol TE/100mL)							
Watermelon juice	0	4.71 ± 0.37	10.5 ± 4.73	11.1 ± 6.42	8.53 ± 1.29	10.1 ± 4.43	13.2 ± 8.26
	2	6.69 ± 3.72	9.02 ± 0.36	7.79 ± 0.84	9.30 ± 1.17	11.5 ± 0.07	10.4 ± 2.32
	5	4.63 ± 0.32	6.40 ± 0.52	7.92 ± 2.04	7.19 ± 1.68	8.57 ± 1.08	6.72 ± 2.27
	9	5.08 ± 0.01	8.09 ± 1.55	5.10 ± 1.36	7.61 ± 1.00	10.5 ± 3.28	16.2 ± 0.98
	14	8.26 ± 1.98	12.1 ± 2.79	13.4 ± 4.80	6.33 ± 0.80	6.78 ± 0.56	7.02 ± 1.30
	P value	0.149	0.344	0.335	0.289	0.467	0.230
Mango juice	0	125 ± 34.7	157 ± 23.2	135 ± 35.3	134 ± 20.6	131 ± 37.4	131 ± 15.6
	2	120 ± 29.8	155 ± 19.9	163 ± 19.4	156 ± 15.3	152 ± 24.6	156 ± 25.1
	5	129 ± 2.41	153 ± 11.4	141 ± 1.01	150 ± 18.5	169 ± 25.6	144 ± 3.67

9	127 ± 0.92	150 ± 11.6	144 ± 20.0	149 ± 6.81	152 ± 8.32	142 ± 3.69
14	154 ± 7.18	143 ± 18.6	141 ± 32.8	146 ± 23.3	153 ± 13.5	150 ± 30.4
P value	0.567	0.928	0.816	0.797	0.658	0.744

Values are expressed as means ± standard deviations. [a,b,c] Different small letters along a column denote a significant difference ($p < 0.05$). $n = 2$. Control is unpasteurized watermelon / mango juice. n.d., not detected

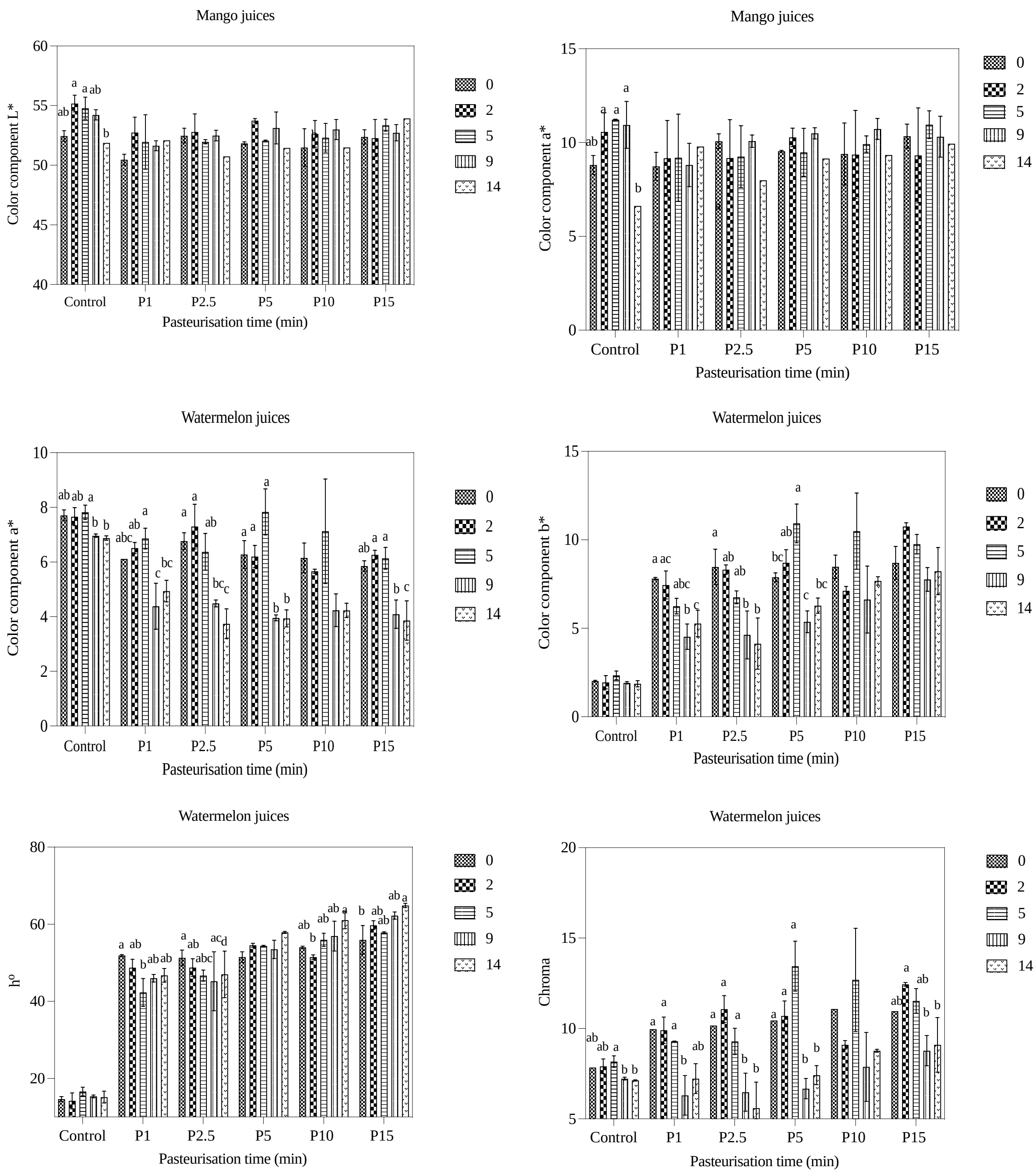

Figure.1 Color change of pasteurized and unpasteurized watermelon and mango juices during cold storage (days)

Values expressed as means and error bars represent standard deviations. [a,b,c,d] Different small letters denote a significant difference ($p < 0.05$), n=2. Control is unpasteurized watermelon / mango juice.

Table S1. Proportion of fruit parts

Fruit part	**Watermelon**		**Pineapple**		**Mango**	
	Weight (g)	% (w/w)	Weight (g)	% (w/w)	Weight (g)	% (w/w)
Juice yield	2072 ± 182	52.2 ± 2.14	932 ± 44.6	48.4 ± 0.67	2383 ± 23.3	70.3 ± 0.17
Peels	1655 ± 307	41.3 ± 2.21	825 ± 20.5	43.3 ± 0.41	551 ± 1.39	16.2 ± 0.16
Seeds + pomace	213 ± 2.56	5.83 ± 1.24	-	-	-	-
Seeds	-	-	-	-	473 ± 9.85	13.9 ± 0.19
Crown	-	-	147 ± 0.87	7.70 ± 0.31	-	-

Values are expressed as mean ± standard deviations, $n = 2$

Table S2. Pasteurization conditions of watermelon and mango juices

Pasteurization process	Variable	Watermelon juice	Mango juice	P value
Heating	Initial temperature (°C)	16.5 ± 0.8[b]	19.5 ± 0.9[a]	<0.001
	Heat transfer time (s)	237 ± 26.8[b]	486 ± 39.1[a]	0.001
	Heating rate (°C/s)	0.55 ± 0.09[a]	0.31 ± 0.03[b]	<0.001
Holding	Holding temperature (°C)	79.5 ± 0.2	79.2 ± 0.2	0.092
	External temp (°C)	95.1 ± 0.30	94.8 ± 0.50	0.3022
Cooling	Cooling medium temperature (°C)	0.1 ± 0.00	0.1 ± 0.00	> 1.00
	Cooling medium	ice bath	ice bath	

Values expressed as means ± standard deviations. [a, b] Different small letters within a row denote a significant difference ($p < 0.05$). $n = 2$

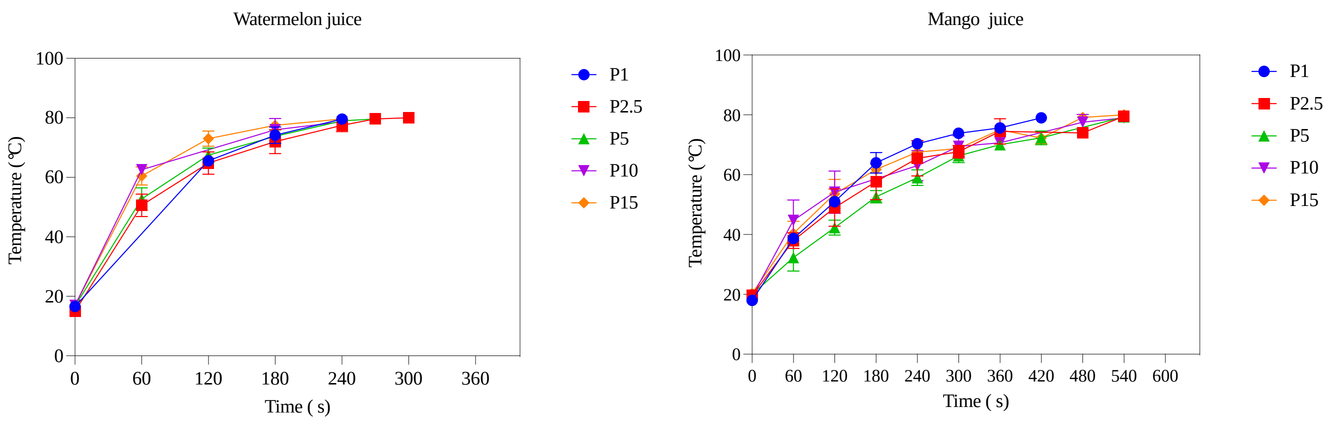

Figure.1 Temperature profiles of watermelon and mango juices during pasteurization

Values expressed as means and error bars represent standard deviations, *n* = 2