

The effect of storage on the quality attributes of ultraviolet-irradiated and thermally pasteurised pineapple juices

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Abstract: The effect of storage time on the quality of ultraviolet-irradiated and thermally pasteurised pineapple juice was evaluated. The juices were irradiated with ultraviolet light (UV-C) at wavelength 254 nm (53.42 mJ/cm², 4.918 s), thermally pasteurised at 80°C for 10 minutes and stored at 4°C for 13 weeks. There were significant changes in the total soluble solids, pH, titratable acidity and turbidity of UV-irradiated juice during storage, whereas for the same quality attributes of thermally pasteurised juice remained stable throughout the storage time. There were no significant changes in total phenolics for both treatments throughout the storage period. Other quality parameters (ascorbic acid, colour L, hue angle and chroma) were significantly affected by the storage time. Regarding the microbiological analysis, the total plate counts and yeast and mould counts of the UV-irradiated juice increased gradually throughout the 13 weeks of storage while these parameters remained unchanged in the thermally pasteurised juice with almost no microorganism growth. UV-irradiated pineapple juice preserved better quality attributes (TSS, pH, titratable acidity, ascorbic acid, turbidity, total phenolic, L (lightness), hue angle and chroma) than the thermal pasteurised juice during the storage time. Hence, UV irradiation has great potential as an alternative technology to thermal pasteurisation in producing products of high nutritive values.

Keywords: Juice quality, ultraviolet irradiation, thermal pasteurisation, pineapple juice, storage stability, microbial

Introduction

Fruit juices are important trade commodities in most countries (Vasavada, 2003). Fruit juices provide nutrients that are beneficial for human health and are in high and continually increasing demand (Ashurst, 2005). Pineapple juice is consumed by people around the world, mainly in single-strength, reconstituted or concentrated form; in blends for new flavour; and in beverages as well as other products (Carvalho *et al.*, 2008). Generally, the shelf life of fresh pineapple juice is restricted by enzyme and microorganism activity. Spoilage of fruit and vegetable juices is mainly due to the presence of osmophilic microflora (Tahiri *et al.*, 2006). These microflora (yeasts) causes fermentation and produce a buttermilk-like off-flavour and moulds (Tournas *et al.*, 2006).

Presently, thermal pasteurisation is considered the most effective technology in inactivating microorganisms and enzymes to extend product shelf life (Noci *et al.*, 2008). However, its high processing temperature can affect the overall quality of juice by changing its nutritional and biochemical properties

(Sanchez-Vega *et al.*, 2009). In response to this limitation, ultraviolet (UV) irradiation, which is a nonthermal technology was introduced. Nonthermal technologies can minimise the impact on flavour, colour and nutritional values (Mertens and Knorr, 1992), thereby producing a product that has similar quality attributes to the fresh juice..

UV technology has been utilised in the food industry for decades to disinfect water and effectively destroy microorganisms on surfaces and packaging (Bintsis *et al.*, 2000). UV irradiation induces the crosslinking of neighbouring pyrimidine nucleoside bases in the same DNA strand, blocking DNA transcription and replication and eventually causing cell death (Guerrero-Beltran and Barbosa-Canovas, 2004).

Most of the published studies have investigated the effect of UV irradiation on the quality of fruit juice and the efficiency of this emerging nonthermal technology in reducing microbes. These studies were reported by Keyser *et al.* (2008), Noci *et al.* (2008), Flaguera *et al.* (2011), Oteiza *et al.* (2010), Koutchma *et al.* (2004), Gabriel and Nakano (2009)

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and Walking-Ribeiro *et al.* (2008). However, little is known about the storage quality of UV treated fruit juice. Storage studies were reported by Donahue *et al.* (2004), Tran and Farid (2004), Guerrero-Beltran and Barbosa-Canovas (2006) and Tandon *et al.* (2003). Donahue *et al.* (2004) reported that UV (at 254.7 nm, 35.1 mJ/cm², 8.12 s) treated apple cider stored at 4 °C had a shelf life 7 days longer than untreated apple cider. Tran and Farid (2004) exposed orange juice to a limited UV dose (73.8 mJ/cm² at wavelength 254 nm) and succeeded in extending its shelf life from 2 days to more than 5 days. In the paper by Guerrero-Beltran and Barbosa-Canovas (2006), UV (at 254 nm, 450 kJ/m², 30 min) treated mango nectar maintained its yellow and yellow-orange colour after 26 days of storage, and its shelf life was extended to 20 days with no microbe growth. Tandon *et al.* (2003) observed significant changes in the pH, titratable acidity, soluble solids and turbidity of UV-irradiated (14 mJ/cm² at wavelength 254 nm) apple cider during storage and obtained an acceptable reduction in microbial loads. No studies have evaluated the storage quality of UV-irradiated pineapple juice. Therefore, the objective of this study was to investigate the effect of storage time on the quality of UV-irradiated pineapple juice compared with thermal pasteurisation which is the conventional technology.

Materials and Methods

Preparation of pineapple juice

Commercially mature Yankee variety pineapples were purchased from a commercial farm in Selangor, Malaysia. After the fruit was washed, the skins were removed using a meat slicer (300SL, DEUGI, Italy). The flesh of the fruit was cut into smaller pieces using a food slicer (ECA-201, EMURA, Japan). The juice was then produced using a supermass colloidier (ZA10-20J, MASAKO, Japan), an ultra-fine friction grinder, followed by filtering through a bean grinder (MH-280, Taiwan). The juice was filtered again using a 500 micro aperture stainless steel sieve screen (BS410-1, ALPHA, England) prior to treatment.

Ultraviolet treatment

The filtered pineapple juice was treated using a CiderSure 3500-B laboratory unit (Macedon, New York). This laboratory unit consists of electronic controls and a process tube, through which the fluid flows. The process tube is composed of two concentric tubes (an outer stainless steel Grade 304 tube and an inner, vertically stacked quartz tube) and sensors. The UV irradiation comes from eight low-pressure lamps that emit 90% UV light at 254 nm.

The lamps are enclosed by the quartz tube. The juice was pumped through a 0.762 mm thin film that is the annular space between the stainless steel tube and the quartz tube. Sensors were placed in the bottom and top portions of the process tube such that a gap of 0.483 mm was maintained between the ends of the rod sensor and the inner quartz tube. The sensors provided the information for UV dosage calculations. The touch screen of the laboratory unit was used to adjust the process parameters and monitor the status of the operational sensors, such as the lamps and drive. Juice was pumped into the UV laboratory unit at a flow rate of 2.587 L/min, which exposed the juice to a UV irradiation dose of 53.42 mJ/cm². The UV dosage, defined as the total radiant energy passing through an infinitesimally small sphere of cross-sectional area (Sastry *et al.*, 2000), was calculated using the following equation:

$$UV\ dosage\ (mJ/cm^2) = irradiance\ (mJ/cm^2s) \times exposure\ time\ (s) \quad (1)$$

where irradiance was determined by the sensor device and exposure time was obtained by dividing the dimension of the processing tube by the flow rate. The method for calculating UV dosage was reported in detail by Canitez (2002).

Cleaning of the UV machine

The UV machine was cleaned and disinfected with a 2% alkaline solution prior to processing and after each juice treatment. The alkaline solution was pumped into the UV device and circulated for 15 min. The device was then rinsed and washed with distilled water for another 15 min to ensure that the UV machine was sanitised.

Thermal pasteurisation treatment

For the thermal pasteurisation treatment, the filtered juices were poured into an electric jacketed kettle (Sul Supplies (M) Sdn Bhd, Malaysia) and heated to 80°C and held for 10 min. According to Azam Ali (2008), fruit juices are pasteurised at temperatures between 80-95°C for 1-10 min. The temperature of the juice during the heating process was monitored using a type K-thermocouple (1319A, TES Electrical Electronic Corp, Taiwan) with an accuracy of ±1°C. The pasteurised juice was then poured into sterilised glass bottles and capped with sterilised caps.

Storage of pineapple juice

Untreated (fresh), UV-irradiated and thermally pasteurised pineapple juices were stored at refrigerated temperature 4±1°C for 13 weeks after processing.

Sample of juice was taken at two weeks interval for analysis.

Physico-chemical analysis

Total soluble solids (TSS) were determined by a digital refractometer (AR-2008, Kruss, Germany), and the measured value was expressed as °Brix. Titratable acidity and pH were measured using a digital autotitrator (785 DMP Titrino, Metrohm, Switzerland). The pH was shown automatically on the screen, and the titratable acidity of the juice was obtained by titration with 0.1 mol/L NaOH to the endpoint of pH=8.5. The titratable acidity results were expressed as the percentage of a citric acid reference.

The ascorbic acid content was also measured using the digital autotitrator. The titrator operates using the Bi-voltametric titration method with 2, 6-dichlorophenol indophenol as the titrant. Ten millilitres of distilled water, 15 ml of oxalic acid and 1 ml of sodium acetate solution (10%) were pipetted into a beaker. Then, 10 ml of juice was added to the mixture and titrated with 0.001 mol/L of 2, 6-dichlorophenol indophenol. The results are expressed as mg/ml.

Colour was measured using an UltrascanPro spectrophotometer (D65, Hunter Lab, USA) to obtain L*, a* and b*. The a* and b* values are used to calculate the following parameters of colour appearance: hue angle ($h = \tan^{-1} b^*/a^*$) and chroma ($\sqrt{a^{*2} + b^{*2}}$) (Bernalte et al., 2003). Turbidity was determined using a turbidimeter (TN-100, Eutech, Singapore) and expressed as nephelos turbidity units (NTU).

The total phenolic content of the juices was determined with the Folin-Ciocalteu method, as reported by Lukanin et al. (2003), with some modifications, i.e. the juices were centrifuged at 5000 rpm for 5 min at 4 °C. The assay mixtures were allowed to stand for 1 hour at room temperature in the dark. Absorbance was determined using a UV spectrophotometer (Ultraspec3100 pro, AmershamBiosciences, UK) at 765 nm. Total phenolic content data were obtained from the calibration curve prepared with gallic acid at concentrations of 0, 50, 100, 150, 250 and 500 mg/L and are expressed as gallic acid equivalents (mg GAE/L).

Microbiological analysis

For the microbiological analysis, total plate counts (TPC) were determined using the plate count agar (PCA) (Merck, Germany) and dichloran rose bengal chloramphenicol (DRBC) agar (Condalab, Spain) was used for yeast and mould counts. For both

tests, a 0.1 ml of sample from each serial dilution (10^{-1} to 10^{-5}) was spread onto the solidified agar. The PCA plate was incubated for 2 days at 37 °C while the plate for the yeast and mould counts was incubated for 5 days at 30 °C. Colonies of TPC and yeasts and moulds were counted using a colony counter. The results are expressed as log CFU/ml.

Statistical analysis

Three replications of the treatments were conducted. For each replication, triplicate measurements were conducted. Two replications of the entire study were performed. The correlations between each parameter and storage time were assessed using regression analysis, with a significance level of 95% ($p < 0.05$). The statistical analyses were conducted using SPSS Version 13.0 software (SPSS Inc., USA).

Result and Discussions

Total Soluble Solids

Figure 1 shows the effects of storage time on the total soluble solids (°Brix) of UV-irradiated and thermally pasteurised pineapple juices. The total soluble solids of the UV-irradiated juice was lower than the thermally pasteurised juice throughout the 13 weeks of storage time. According to Tandon *et al.* (2003), the higher soluble solids of pasteurised juice are due to water evaporation during thermal pasteurising in the steam kettle. Untreated and UV-irradiated pineapple juice exhibited a significant decreasing trend in the total soluble solids at the significance level of 95% ($p < 0.05$) during the storage period. The total soluble solids of the UV-irradiated pineapple juice remained almost constant in the initial weeks, but started to decrease after 7 weeks storage time. Rivas *et al.* (2006) stated that the change in total soluble solids is due to the presence of the microorganisms that cause the fruit juice to deteriorate as a result of sugar fermentation. Fermentation caused by microorganisms is the process of breaking down glucose through the biochemical pathway (Rosen and Gothard, 2010). Such phenomena may have taken place in the untreated juice around the third week of storage, as the researchers noticed that the untreated juice began to present a fermented smell the moment the bottles were uncapped. It is also possible that a similar fermentation process occurred in the UV-irradiated juices. This was shown by the significant reduction of TSS values after 7 weeks of storage. Microorganisms that cause fermentation can utilise the soluble solids present in juice and change its Brix

value (Yeom *et al.*, 2000). In contrast, the thermally pasteurised pineapple juices did not show significant changes in total soluble solids during the storage period. Similarly, Tandon *et al.* (2003) reported no significant change in the Brix of hot-fill pasteurised apple cider and indicated the biological stability of the samples throughout their storage period. These authors also stated that UV-treated cider was less stable than hot-fill pasteurised cider, which presented a minor change in soluble solids over time. Bull *et al.* (2004) also reported that the Brix of thermally processed Valencia and Navel orange juice did not change significantly during storage time at 4°C and 10°C.

pH

Figure 2 shows the effects of storage time on the pH of UV-irradiated and thermally pasteurised pineapple juice. pH is one of the important quality characteristics that describes the stability of bioactive compounds in fruit juice (Sanchez-Moreno *et al.*, 2006). The pH of UV-irradiated juice was higher than that of thermally pasteurised juice throughout the storage time. Untreated and UV-irradiated pineapple juice presented a statistically significant pH increase ($p < 0.05$) during 13 weeks of storage. The pH increase can be related to the TSS decrease illustrated in Figure 1. The decrease in TSS was due to the microorganisms that cause juice spoilage. Cortes *et al.* (2008) similarly found that pH increased significantly in the fresh, high-pressurised and pasteurised orange juice during 7 weeks of storage at 2°C and 10°C. These researchers stated that the increased pH values in these juices were caused by the microorganisms that caused juice spoilage. Del Caro *et al.* (2004) also found a pH increase in citrus segments and juices stored at 4°C. In contrast, there was no significant change in the pH value of thermally pasteurised pineapple juice during storage. These results are consistent with those of Rivas *et al.* (2006), who reported no pH variations in thermally treated juice (blended orange and carrot juice) during refrigerated storage at 2°C and 12°C. Yeom *et al.* (2000) also did not observe significant changes in heated orange juice during storage at 4°C and 22°C. A similar study that described the pH of thermally processed Valencia and Navel orange juice found no significant modifications during storage at 4°C and 10°C (Bull *et al.*, 2004).

Titrateable acidity

Figure 3 shows the effects of storage time on the titrateable acidity of UV-irradiated and thermally pasteurised pineapple juice. The titrateable acidity of the UV-irradiated juice was lower than that of the

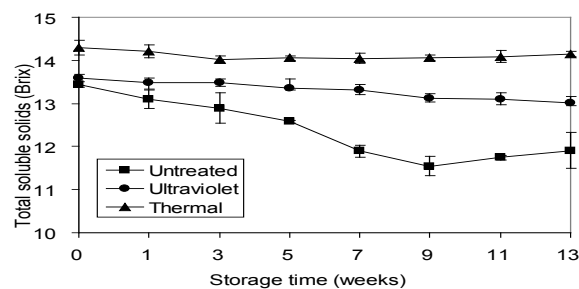


Figure 1. Changes in the total soluble solids of untreated, ultraviolet-irradiated and thermally pasteurised pineapple juice during storage at 4°C for 13 weeks

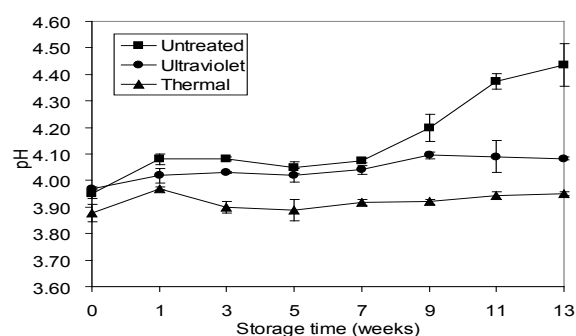


Figure 2. Changes in the pH of untreated, ultraviolet-irradiated and thermally pasteurised pineapple juice during storage at 4°C for 13 weeks

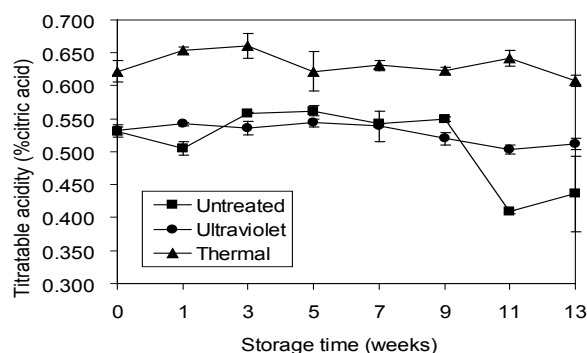


Figure 3. Changes in the titrateable acidity of untreated, ultraviolet-irradiated and thermally pasteurised pineapple juice during storage at 4°C for 13 weeks

pasteurised juice throughout the 13 weeks storage period. Significant decrease ($p < 0.05$) were found in the titrateable acidity of the untreated and UV-irradiated pineapple juice throughout the storage time. The UV-irradiated juice remained stable for the first seven weeks, then decreased. Sodeko *et al.* (1987) reported that microorganisms reduce acidity and cause the fermentation of organic acid, which leads to spoilage. For the thermally pasteurised juice, titrateable acidity was not affected by the storage time and no significant changes were observed.

Ascorbic acid

Figure 4 shows the effect of storage time on the ascorbic acid in UV-irradiated and thermally

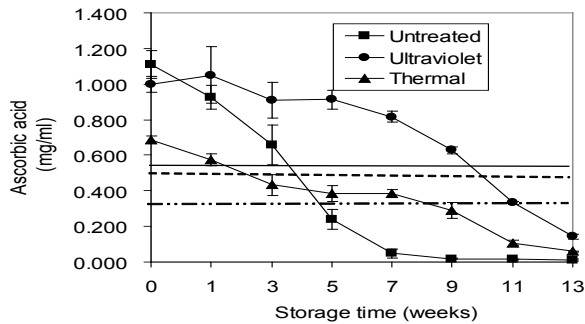


Figure 4. Changes in ascorbic acid level of untreated, ultraviolet-irradiated and thermally pasteurised pineapple juice during storage at 4 C for 13 weeks indicates 50% retention of ascorbic acid in untreated, ultraviolet-irradiated and thermally pasteurised pineapple juice respectively

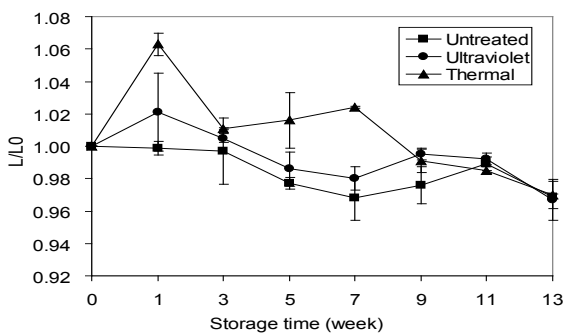


Figure 5. Changes in the lightness (L/L_0) in untreated, ultraviolet-irradiated and thermally pasteurised pineapple juice during storage at 4°C for 13 weeks

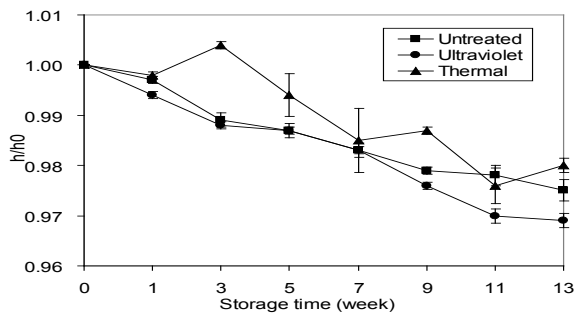


Figure 6. Changes in the hue angle (H/H_0) of untreated, ultraviolet-irradiated and thermally pasteurised pineapple juice during storage at 4°C for 13 weeks

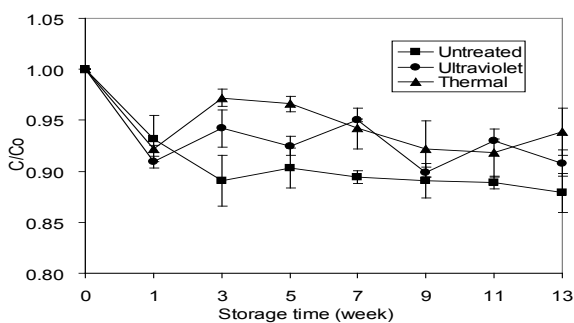


Figure 7. Changes in the chroma (C/C_0) of untreated, ultraviolet-irradiated and thermally pasteurised pineapple juice during storage at 4°C for 13 weeks

pasteurised pineapple juice. Ascorbic acid is an important nutrient that possesses antioxidant ability

and provides the protection against free radicals (Esteve *et al.*, 2005). It is also considered an indicator of the nutritional quality of juices (Bull *et al.*, 2004). Juice exposed to ultraviolet irradiation retained a higher ascorbic acid content than thermally pasteurised juice throughout the storage period. The statistical analysis showed that the ascorbic acid content of untreated, ultraviolet irradiated and thermally pasteurised juices decreased significantly ($p < 0.05$) throughout the storage time. Plaza *et al.* (2006) stated that ascorbic acid reduction during storage could be used as a quality and shelf life indicator for products like citrus juice. As shown in Figure 4, untreated juice retained 50% of its initial ascorbic acid at Week 3. By the seventh week, ascorbic acid was no longer detected in the untreated juice. UV-irradiated and thermally pasteurised retained 50% of their initial ascorbic acid at Week 10 and Week 8 respectively. Juices with 50% retention of their initial Vitamin C are considered as the end of their shelf life (Shaw, 1992). The degradation of Vitamin C during long term storage is due to atmospheric oxygen (Odriozola-Serrano *et al.*, 2008). In addition, ascorbic acid loss is caused by the oxidative mechanism resulting from the presence of not just oxygen, but also exposure to light, heat peroxides and enzymes such as ascorbate oxidase and peroxidase (Davey *et al.*, 2000). Storage temperature, type of processing and packaging materials affect the rate of ascorbic acid degradation during storage (Ayhan *et al.*, 2001). Nevertheless, as illustrated in Figure 4, UV-irradiated pineapple juice retained a higher ascorbic acid content than the thermally pasteurised juice during storage. Heating greatly affects the loss of ascorbic acid through the aerobic pathway because ascorbic acid is a heat sensitive bioactive compound (Odriozola-Serrano *et al.*, 2008).

Colour

Figure 5 shows the effect of storage time on the L value (lightness) of UV-irradiated and thermally pasteurised pineapple juice. The L value of UV-irradiated juice was higher than that of the thermally pasteurised juice throughout the storage time. This showed that UV irradiation was more efficient than thermal pasteurisation in maintaining lightness of pineapple juice during storage. According to the statistical analysis, the L values of untreated, UV-irradiated and thermally pasteurised juice decreased significantly ($p < 0.05$) throughout the storage period. According to Genovese *et al.* (1997), the unstable and suspended particles that cause partial precipitation in juice may lead to the depletion of L values. Aguilo-Aguayo *et al.* (2009) found that strawberry juice subjected to heat treatment exhibited decreased L

values during storage at 4°C. Heating caused the accumulation of dark colour compounds in the juice and consequently decreased the L value (Klim and Nagy, 1988). According to Rivas *et al.* (2006), the L values of thermally pasteurised blended orange and carrot juice decreased significantly during storage at 12°C. Yeom *et al.* (2000) also described the decrease in lightness in heated orange juice during storage at 22°C.

Hue angle and chroma are the parameters associated with a* and b* values. According to Patras *et al.* (2009), hunter L, a* and b* or some combinations of a* and b* are the physical characteristics used to indicate the visual colour. Figure 6 shows the effect of storage time on the hue angle of UV-irradiated and thermally pasteurised pineapple juice. The hue angle of the UV-irradiated juice was higher than that of the thermally pasteurized juice throughout the 13 weeks storage period. As illustrated in Figure 6, the hue angle of untreated, UV-irradiated and thermally pasteurised juices decreased significantly ($p < 0.05$) throughout the storage time. Juice becomes redder and less yellow when the hue decreases (Esteve and Frigola, 2007). Rivas *et al.* (2006) reported that the hue angle of thermally pasteurised mixed orange and carrot juice diminished significantly during storage at 12°C. Yeom *et al.* (2000) presented similar results, in which the hue angle of heated orange juice decreased significantly during storage at 22°C.

Figure 7 shows the effect of storage time on the chroma of UV-irradiated and thermally pasteurised pineapple juice. The UV-irradiated juice retained a higher chroma value than the thermally pasteurised juice throughout the storage time. The chroma was significantly ($p < 0.05$) decreased in all pineapple juices during the storage period. This indicates that the juices' colour became significantly less saturated with increasing of storage time. A similar observation was obtained by Cortes *et al.* (2008), who found that the chroma of thermally pasteurised orange juice decreased during refrigerated storage at 2 to 10°C. A similar study was reported by Choi *et al.* (2002), who found that the chroma of thermally pasteurised blood orange juice decreased during storage at 4.5°C for 7 weeks.

Colour degradation in juice may due to nonenzymatic Maillard browning, which is the reaction between sugars, amino acids and organic acids (Moyer and Aitken, 1980). Nonenzymatic browning has a severe impact on colour and thus reduces the appeal of citrus juices to consumers (Klim and Nagy, 1988). In addition, the colour of juice may change due to heating, air and light, which cause carotenoids to undergo oxidation, cis/trans

changes and alterations in epoxide rings as a function of storage (Esteve and Frigola, 2007).

Turbidity

Figure 8 shows the effects of storage time on the turbidity of UV-irradiated and thermally pasteurised pineapple juice. The UV-irradiated juice had lower turbidity than the thermally pasteurised juice throughout the storage period. As can be observed, the untreated and UV-irradiated samples exhibited a significant increase ($p < 0.05$) in turbidity during storage time. Spoilage by yeast and bacteria has been shown to induce visible sediment and turbidity in soft drinks that contain juice (DiGiacomo and Gallagher, 2001). Luthi (1959) also stated that yeasts contributed biologically to the turbidity of fruit juices. The increasing of yeast and bacteria, which contribute to the turbidity of pineapple juices throughout the storage can be observed from Figure 10 and Figure 11. In contrast, the experimental data did not produce any significant variation in the turbidity of the thermally pasteurised pineapple juice during the storage period. This finding agreed with the study published by Tandon *et al.* (2003). These authors reported that the moderate temperature/time combination during hot-fill processing did not change the turbidity of apple cider and was able to maintain cloud stability during storage time. However, thermal treatment resulting in increased turbidity produced a quality quite different from the untreated juice, compared with the UV-irradiated juice.

Total phenolic

Figure 9 shows the effect of storage time on the total phenolic of UV-irradiated and thermally pasteurised pineapple juice. Phenolic compounds provide antioxidant potential and health-promoting properties and contribute to the flavour and colour attributes of fruits and vegetables (Kaur and Kapoor, 2001). The levels of phenolic compounds also used to gauge the physical stages and potential loss in the quality of fruit products due to browning, formation of hazes and sediments (Macheix *et al.*, 1990). Throughout the 13 weeks of storage, the total phenolic content of UV-irradiated juice was maintained above those achieved in thermally pasteurised juice. No significant ($p > 0.05$) changes were observed in the total phenolic content of any of the treated juices during the storage period. The phenolic compounds in the juices were maintained during storage because peroxidase, the enzyme that degrades phenolic compounds was inactivated (Odriozola-Serrano *et al.*, 2008). Peroxidase has been reported to cause the loss of quality in tomato juices (Odriozola-Serrano

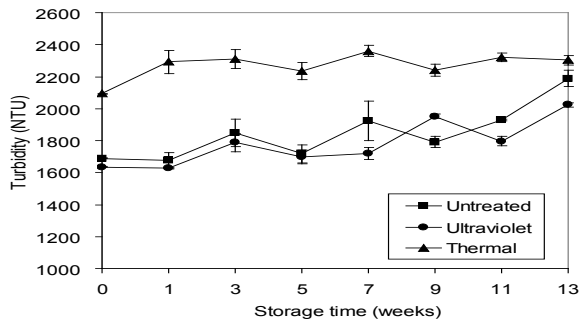


Figure 8. Changes in the turbidity of untreated, ultraviolet-irradiated and thermally pasteurised pineapple juice during storage at 4°C for 13 weeks

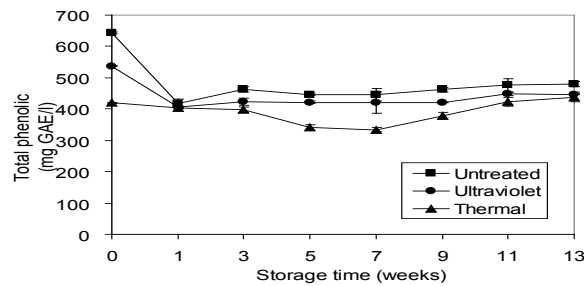


Figure 9. Changes in the total phenolics of untreated, ultraviolet-irradiated and thermally pasteurised pineapple juice during storage at 4°C for 13 weeks

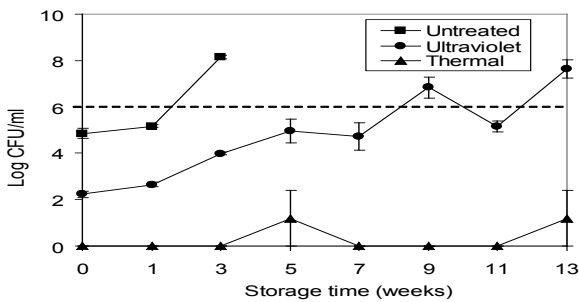


Figure 10. Changes in the total plate counts of untreated, ultraviolet-irradiated and thermally pasteurised pineapple juice during storage at 4°C for 13 weeks. The dashed line indicates the limit of microbial shelf life.

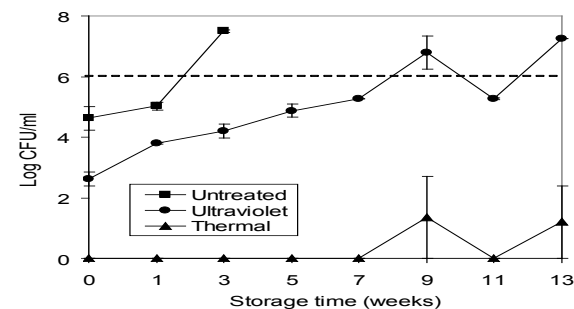


Figure 11. Changes in the yeast and mould counts of untreated, ultraviolet-irradiated and thermally pasteurised pineapple juice during storage at 4°C for 13 weeks. The dashed line indicates the limit of microbial shelf life.

et al., 2008). Nevertheless, as shown in Figure 9, the phenolic compounds in untreated and UV-irradiated juice sharply decreased during the first week, remained stable from Week 3 to Week 9 and then increased slightly ($p>0.05$) at the end of the storage

period (Weeks 11 and 13). The thermally pasteurised samples behaved similarly; total phenolic decreased sharply during Week 5, remained almost stable from Week 7 to Week 9 and increased slightly ($p>0.05$) at Weeks 11 and 13. This observation is supported by the findings of Klimczak *et al.* (2007), who reported that the total phenols of orange juice decreased after 4 months of storage and increased significantly at the end of 6 months' storage time. These authors stated that some compounds may form during storage and react with the Folin-Ciocalteu reagent to increase the phenolic content. Another similar finding was reported by Tavarini *et al.* (2008), who found that the phenols in kiwifruits remained stable during the initial 2 months of storage at 0°C and increased significantly after 6 months of storage.

Microbiological properties

Figures 10 and 11 show the effect of storage time on the total plate counts and total yeasts and mould counts for UV-irradiated and thermally pasteurised pineapple juice. According to Vasavada and Heperkan (2002), juices produced from healthy fruit have yeast loads between 1000 ($3 \log_{10}$) to 100000 ($5 \log_{10}$) per ml. The limit of microbial shelf life for juice is 6 log cfu/ml (Mirrazavi, 2011). Untreated pineapple juice has a shelf life of 1 to 2 weeks, as can be seen in Figures 10 and 11. In contrast, the total plate counts and yeast and mould counts of UV-irradiated juice slowly increased ($p<0.05$) throughout the 14 weeks of storage time. The UV-irradiated pineapple juice achieved a shelf life up to 7 to 8 weeks below the microbial load limit (6 log cfu/ml). Some mesophilic bacteria that suffered from chilling injury caused a sudden decrease in microorganism loads at Week 11 (Tran and Farid, 2004). As a result of UV treatment, shelf life of pineapple juice which stored at 4°C was extended at least 6 weeks longer than fresh or untreated juice. The thermally pasteurised juice remained virtually unchanged with almost no microorganism growth during the storage time. This shows that thermally pasteurised juice had a shelf life more than 13 weeks. As can be observed, the thermal treatment killed the microbes more effectively than UV irradiation. A similar finding for apple cider was reported by Tandon *et al.* (2003). These authors stated that the UV treatment increased the total plate counts and yeast and mould counts, while hot-fill pasteurised cider had minimal or no microorganism growth during the storage time. Tran and Farid (2004) reported that the shelf life of orange juice extended from 2 days to 5 days after UV treatment. Most of the spoilage in refrigerated citrus juices is due to the presence of fermentative yeast, *Saccharomyces*

cerevisiae (Alwazeer *et al.*, 2002). The emergence of moulds that caused juice spoilage affects flavour and results in the production of filamentous structures and enzymes such as amylases, proteases and pectinases (Swanson, 1989).

Conclusion

Ultraviolet treatment was associated with less biological stability than thermally pasteurisation treatment. Most of the physicochemical characteristics (total soluble solids, pH, titratable acidity, turbidity, ascorbic acid, L (lightness), hue angle and chroma) of the UV-irradiated juice changed with increasing storage time, in contrast with the thermally pasteurised juice, which changed in ascorbic acid, L (lightness), hue angle and chroma. UV irradiated pineapple juice which stored at 4°C extended at least 6 weeks longer shelf life than the fresh or untreated pineapple juice. This result suggests that a juice manufacturer or retailer can keep the UV treated pineapple juice at the refrigerated temperature 4°C for 7 weeks. The thermal pasteurisation treatment achieved a higher reduction of total plate counts and yeast and mould counts during storage than UV irradiation, thus providing an improved shelf life. However, quality attributes of pineapple juice (TSS, pH, titratable acidity, ascorbic acid, turbidity, total phenolic, L (lightness), hue angle and chroma) were better maintained in UV irradiation than in thermal pasteurisation during storage. This indicates that UV irradiation preserved the valuable attributes of the juice better than thermal pasteurisation. The quality attributes of the thermally pasteurised juice were more adversely affected, although the application of heat gave the juice a longer shelf life.

Acknowledgements

This project is funded by Fundamental Research Grant Scheme (FGRS), project no: 03-04-10-802FR. Thanks to the Federal Agriculture Marketing Authority (FAMA) for providing the fruit samples.

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