Ripening Stage Affects the Quality of Fresh and Dehydrated Pineapples (*Ananas comosus* (L.) Merr.) cv. Mauritius in Sri Lanka

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Abstract. Pineapple (*Ananas comosus* (L.) Merr.) being a non climacteric fruit, its flavor and sugar content does not increase after harvesting. Thus, the maturity stage at harvesting affects the quality of pineapples after harvesting. This study was conducted to compare the quality parameters at four different ripening stages of pineapple (cultivar Mauritius-Queen type) and their effect on sensory properties after dehydration. Pineapples were harvested at dark green, 50% yellow, 75% yellow and 100% yellow color stages. Total Soluble Solid (TSS) content, Titratable Acidity (TA), TSS/TA ratio, pH, Fruit firmness, L*,a*,b* and hue angle were quantified in fresh samples and the appearance, texture, taste, odor, color and overall acceptability were evaluated in dehydrated samples at each ripening stage. The ripening stage had a significant ($P<0.05$) effect on selected quality parameters of fresh pineapples. Highest TSS content of 17.75 ± 0.67 was observed in 100% yellow stage whereas the lowest was observed in dark green stage (15.75 ± 0.48). In contrast, the highest firmness was observed in dark green stage (27.47 ± 6.4 N) while the lowest was in 100% yellow stage (12.01 ± 1.17 N). Lowest pH and highest TA were observed in dark green stage while the highest pH and lowest TA were observed in 100% yellow stage with values of 3.49 ± 0.06 , 0.82 ± 0.02 , 3.74 ± 0.01 and 0.78 ± 0.02 , respectively. Sensory evaluation revealed that 75% yellow stage is the optimum ripening stage for dehydration of pineapple (cultivar Mauritius-Queen type) with significantly greater sensory evaluation ranks compared to other stages.

Abbreviations: TA, titratable acidity; TSS, total soluble solids; TSS/TA, total soluble solid/titratable acidity

Introduction

Pineapple (*Ananas comosus* (L.) Merr) is a delicious fruit crop belonging to the family bromeliaceae cultivated mainly in tropical regions including Sri Lanka. It has long been one of the most popular non-citrus tropical and subtropical fruits, largely because of its attractive flavor and refreshing sugar-acid balance [1]. Pineapple is the third most important fruit in world production after banana and citrus [2]. There are 4-5 groups of pineapple cultivar types including Cayenne, Queen, Pernambuco, and Spanish. Cultivated pineapple types are called 'clones', since they are vegetatively propagated [3]. In Sri Lanka, the pineapple varieties Mauritius which is a queen type and Kew which is a smooth cayenne type are mainly cultivated. Nearly 95% of the cultivated extent is occupied by Mauritius [4] mainly due to their better inherent flesh quality, flavor and color.

Pineapple is consumed worldwide because of their attractive sensory properties such as sweetness and color and inherent acidic flavor with unique odor due to volatile compounds. It is known to have several minerals such as potassium, calcium, manganese, copper and zinc as well as vitamins like vitamin C and vitamin B complex [3]. Furthermore, they contain bioactive compounds which have positive effects on human health [5]. Their positive health effects are mainly attributed to their potent antioxidant properties and free radical scavenging ability [6]. As bioactive compounds they contain carotenoids, phenolic compounds, ascorbic acid, bromelain, antioxidants and dietary fibers [7].

Pineapple is mainly consumed in fresh form worldwide. In addition, various value-added products are available including dehydrated products, frozen products, canned products, jam, jelly, salads, minimal processed products, juice and nectar. Value added products are used mainly either to preserve the perishables and reduce postharvest losses or to diversify fruit-based products in the market. Among these products, dehydrated pineapple is most commonly used as a preservation method. Sensory properties of dehydrated products are mainly decided by the ripening or harvesting stage of fruits because physico-chemical properties are highly dependent on the ripening stage [8]. However, the quality of pineapple including physico-chemical attributes vary with the cropping season as well [9]. Nevertheless, there is no high seasonal variation in Sri Lanka, especially in pineapple cultivating areas.

Therefore, this experiment was carried out to identify the effects of ripening stage on sensory properties of dehydrated pineapple and to discover the variation of quality parameters with ripening stage of the cultivar Mauritius which is the most cultivated variety in Sri Lanka.

Materials and Methods

Experimental location. Pineapple fruits were harvested from a selected commercial cultivation (7.312770° N, 80.130701° E) in Gampaha district, Sri Lanka. Fruits were harvested at four different maturity stages as dark green, 50% yellow, 75% yellow and 100% yellow (Figure 1.).

Figure 1. Mauritius pineapple (Queen type) at four different maturity stages.

Harvested fruits were packed in plastic crates and transported to the laboratory at Institute of Postharvest Technology, Anuradhapura. Fruits free from any visible defects were selected and subdivided into five replicates in each maturity stage. Physico-chemical attributes were evaluated, and dehydration was conducted following sensory analysis.

Peel color. Peel color was measured using Hunter lab color difference meter (CR 400, Konica Minolta) and the values of L^* , a^* and b^* were recorded [10]. Color values from bottom, middle and upper part of each fruit were taken, and the average was calculated for each replicate. Hue angle was calculated using a^* and b^* values [11].

Fruit firmness. Fruit firmness was measured using bench top type digital fruit firmness tester (53205, Turoi). Firmness from bottom, middle and upper part of each fruit was taken and the average was calculated for each replicate and expressed in Newton (N).

Total soluble solid (TSS), pH and Titratable Acidity (TA). Pineapple juice was extracted representing all parts of the fruit to measure Total Soluble Solid (TSS), pH and Titratable Acidity (TA). Vertical slices of pineapple flesh were obtained from top to bottom in each replicate. Then the slices were chopped using mortar and pestle separately after removing the core parts. The juice was extracted separately using a muslin cloth.

TSS of extracted juice samples were measured by a temperature compensated digital refractometer (3810, Atago PAL-1) and expressed as a percentage. Juice pH was measured by a pH meter (230 A+, Thermoorion). Titratable acidity was separately measured by titrating juice samples against 0.1N NaOH until the pH reached an end point of 8.2 as indicted by phenolphthalein. Titratable acidity was expressed as a percent citric acid equivalent.

$$\text{TA} = \text{ml NaOH added} \times 0.1 \text{ (conc. of NaOH)} \times 0.064 \times 100 \div \text{ml of juice titrated}$$

Sensory evaluation. Pineapple fruits from each ripening stage were washed thoroughly, peeled, core removed and cut into small pieces (3-4 mm thickness). These samples were subjected to hot air oven drying at 65°C for 16 hours [12]. Sensory evaluation was conducted for dehydrated samples (samples with different ripening stages) to identify optimum ripening stage for dehydration. Nine-point hedonic scale [13,14] was used to evaluate sensory properties such as appearance, color, taste, texture, odor and overall acceptability using a semi trained 30-member panel.

Experimental design and data analysis. Experiment was conducted as a completely randomized design. Continuous data were analyzed using analysis of variance (ANOVA) and, sensory data using friedman test. Means were separated using LSD test at $p < 0.05$ level with statistical software SPSS version 16.0.

Results and Discussion

Fleshy fruits undergo a ripening process in which the biochemistry, physiology and structure of the organ are developmentally altered to influence appearance, texture, flavor, and aroma in ways to attract seed-dispersing organisms [15]. Changes of physical and chemical properties differ among different maturity or ripening stages (Table 1).

Table 1. Total soluble solids (TSS), Firmness, pH and Titratable Acidity of Mauritius pineapple (Queen type) in different ripening stages.

Ripening Stage	TSS (°Brix)	Firmness (N)	pH	TA (% citric acid)
Dark Green	15.75±0.48 ^a	27.47±6.4 ^a	3.49±0.06 ^a	0.82±0.02 ^a
50% Yellow	16.16±0.5 ^{ab}	17.46±0.8 ^b	3.61±0.03 ^b	0.81±0.03 ^{ab}
75% Yellow	17.10±0.76 ^{bc}	13.27±1.13 ^c	3.67±0.05 ^{bc}	0.80±0.03 ^{ab}
100% Yellow	17.75±0.67 ^c	12.01±1.17 ^c	3.74±0.01 ^c	0.78±0.02 ^b

*TSS= Total Soluble Solids, TA= Titratable Acidity. Values in the same column with different superscript letters differ significantly ($P < 0.05$). Each value represents mean $\pm$ S.D. of five replicates.

Total soluble solid (TSS) content was significantly different ($P < 0.05$) between dark green stage with 75% and 100% yellow color stages while 50% yellow color stage showed significant difference ($P < 0.05$) with 100% yellow color stage. TSS showed continuous increasements with ripening (Figure 2) of the fruit where 12.69% higher in 100% yellow color stage than dark green stage. The TSS value of the pineapples increases due to the conversion of starch by ADP-glucose pyrophosphorylase, β -amylases and sucrose phosphate synthase to sugars, such as glucose, sucrose and fructose during ripening [16].

Increment of TSS content with ripening stages from dark green to yellow have been observed [17] in previous studies and TSS changed with the propagation method as well [18]. Pineapple varieties of Moris, N36 and MD2 cultivated in Malaysia showed similar pattern of increment [19] as Mauritius pineapple in Sri Lanka. However, pineapples obtained from different varieties and stages of maturity possess different compositions and are of varying eating quality [19] along with above factors.

TSS/TA ratio showed a similar trend as in TSS (Figure 2). Highest TSS (Brix) and TSS/TA ratio was observed in 100% yellow stage where 17.75 ± 0.67 and 21.54 ± 1.29 respectively, while lowest was in dark green stage with 15.75 ± 0.48 of brix and 19.49 ± 1.40 TSS/TA ratio. Reason for the highest TSS/TA ratio in 100% yellow stage is the reduction of TA and increment of TSS when the pineapples ripe. There was no significant difference ($P > 0.05$) of TSS (Brix) between 75% and 100% yellow stages indicating that no considerable increment of TSS (Brix) after 75% yellow stage.

Figure 2. Variation of Brix value (TSS) and TSS/TA variation of “Mauritius” pineapple (Queen type) at four different ripening stages.

pH of a fruit indicates the strength of the acidity while titratable acidity (TA) indicates the amount of acid present as a percentage of the most abundant acid. With ripening, pH value increases while TA reduces because of depleting acids due to metabolic reactions of the ripening fruit. Consumption of pineapple is favored by their sugar: acid balance which influences the flavor of the flesh. Low pH content, high TA with low sugar content leads to higher sourness while high pH, low TA with higher sugar content leads to characteristic consumer acceptable flavor in pineapple. Our results revealed that pH was increased from dark green to yellow stage (Figure 3.) and the difference was significant ($P < 0.05$) among ripening stages. In contrary pH of Josapine Pineapple juice decrease gradually from 4.10 to 3.81 over the maturation period [20] whereas gradual increment was observed in Moris pineapple from 3.92 to 4.23 over the maturation period [19] confirming the results of the present study for Mauritius pineapples. These findings revealed that the different pineapple varieties behave differently when they ripe.

Titratable acidity was continuously decreased from dark green (0.82 ± 0.02) to yellow stage (0.78 ± 0.02) while the greatest value was observed in dark green stage and the lowest in fully yellow color stage (Table 1). Similarly a study conducted in Vietnam found the reduction of acid percentage from dark green to yellow color stage [21] and Dhar *et al.* (2008) [22] confirmed decreasing TA after maturity and ripening of pineapple. Lower TA than Mauritius pineapple with the similar pattern of change was observed in 3 different pineapple varieties grown in Malaysia in a previous study [19] confirming the results of present study. However, on contrary it was proved that the TA of the pineapple increased as the fruits developed [23]. Therefore it can be concluded that the TA of the fruit increases when the fruit develops and reduces when the fruit ripe after maturation.

Figure 3. Variation of pH and Titratable acidity of “Mauritius” pineapple (Queen type) at four different ripening stages.

Firmness of the fruit indicates how hard or soft the flesh is. Firmness of pineapple fruit was highest at dark green stage while was lowest in full yellow color stage showing the pattern of gradual reduction over maturation (Table 1) where the same results were observed for Josapine pineapple in Malaysia as well [24]. Reduction of fruit hardness during maturation is related to the activation of enzymes such as polygalacturonase (PG) and cellulose [21]. With ethylene production during ripening, these enzymes become active leading to cell wall pectin and cellulose to hydrolyze causing cell wall softening.

Peel color changes in pineapple fruits when they ripe is considered as a major visual observation to determine correct maturity stage for harvesting. The L^* , a^* and b^* values indicate color directions. Negative a^* values indicate the greenness whereas positive values indicate redness. Negative b^* values indicate the blueness and positive values indicate the yellowness. Hue angle indicate the degree of greenness and yellowness in “Mauritius” pineapple (Queen type).

Results revealed that peel color values of L^* , a^* and b^* were increased continuously from dark green stage to full yellow stage while hue angle was decreased continuously (figure 4). Increment of a^* value indicate that the reduction of green color of the peel and increment of b^* value indicate the increment of yellowness of the fruit peel while L^* value shows the increment of lightness from dark green color. Increment of L^* value was observed for MD-2 variety in Malaysia in previous studies where supports the results of the present study [25]. Contradictory results were observed for pineapple juice in N36 variety and flesh of MD-2 variety where L^* value gradually decreased over the ripening period [19, 25] where same results were observed for Josapine variety [20]. Results indicated that the peel color gets lighter and flesh color gets darker over the maturation period. Accumulation of sugar resulting from starch synthesis upon fruit ripening might be related to the darker color of the pineapple flesh [19] leading to the gradual reduction of L^* value during the growth and development period [23].

Hue angle is the basic unit of color and interpreted as 0° red and 90° yellow. Results showed that hue angle was decreased towards dark yellow color through yellowness from greenness (Table 2). Same results were observed for the Smooth cayenne pineapples in Thailand where carotenoid content was increased at harvest [9] resulting more yellow color towards the ripening. Hence increment of carotenoid content may be the reason for the reduction of hue angle over maturation period.

Figure 4. Variation of L*, a*, b* values and hue angle of peel in “Mauritius” pineapple (Queen type) at four different ripening stages.

Table 2. Peel color values of “Mauritius” pineapple (Queen type) in different ripening stages.

Ripening Stage	Color values			
	L*	a*	b*	hue
Dark Green	23±1.38 ^a	-4.56±0.84 ^a	13.02±1.69 ^a	109.38±3.66 ^a
50% Yellow	38±1.86 ^b	-2.12±1.48 ^b	29.84±3.78 ^b	94.11±2.74 ^b
75% Yellow	40±2.23 ^b	0.71±1.72 ^c	34.30±4.8b ^c	89±2.68 ^c
100% Yellow	49±1.45 ^c	6.48±0.79 ^d	38.37±4.93 ^c	80.29±1.73 ^d

Values in the same column with different superscript letters differ significantly ($P < 0.05$) L = 0: black, 100: white; a* = (-): greenness, (+): redness; b* = (-) blueness, (+): yellowness. Each value represents mean $\pm$ S.D. of five replicates.

Sensory evaluation was conducted to identify optimum maturity of “Mauritius” pineapple (Queen type) for dehydration. Quality parameters of fresh fruits vary with their maturity (Ripening) stages. Therefore, the stages at which they subjected to dehydration are affecting to the quality of final product. Nine-point hedonic scale was used to evaluate the quality parameters of appearance, color, odor, texture, taste and overall acceptability.

Figure 5. Organoleptic properties of Mauritius pineapple (Queen type) with different ripening stages. Each point shows the mean values of sensory evaluation for different parameters.

Considering sensory evaluation, lowest ranks for appearance, color and overall acceptability were observed in dehydrated samples of 100% yellow color stage. Major compound governing the color of the ripe pineapples may be the carotenoid which was increased considerably at later stages of ripening [9, 25] resulting lowest hue angle at 100% yellow stage (Table 2). According to the color rankings of the sensory evaluation, it can be concluded that the people may not prefer dark yellow color pineapple flesh when they search for dehydrated ones. Lowest ranks for texture and taste were observed in dehydrated samples at 50% yellow color stage while lowest rank for odor was observed in samples dehydrated at dark green stage (Table 3). Volatile compounds are the major governing factor for the odor development of ripe fruits. Therefore, the lowest amount of volatile compounds may be present at dark green stage resulting lowest rank was given for odor in sensory evaluation. Even though a highest rank for odor was expected for the pineapples which were dehydrated at 100% yellow stage, the inherent odor was masked by the sugary smell resulting lower rank.

Results revealed that, 75% yellow color stage obtained highest ranks which were significantly greater ($P < 0.05$) compared to other stages for all the tested quality parameters (Figure 5). Highest rank for taste may have had assigned during sensory evaluation due to people's accepted flavor and sugar acid ratio acquired and retained by this stage of ripening after dehydration. Higher content of nutritional compounds retained in the 50% and 75% yellow color stages than other stages [25]. Therefore, the results of previous and present study indicate that the 75% yellow color stage acquires higher sensorial properties as well as higher nutritional attributes.

Table 3. Mean rank values of tested quality parameters in sensory evaluation for "Mauritius" pineapple (Queen type) with different ripening stages.

Quality parameter	Dark green	50% Yellow	75 % Yellow	100% Yellow
Appearance	6.00	5.58	6.77	5.19
Color	6.00	5.65	6.81	5.27
Odor	5.62	5.88	6.73	5.85
Texture	5.92	5.77	6.69	5.85
Taste	6.23	6.15	7.15	6.38
Overall acceptability	5.96	5.92	7.35	5.88

Conclusions

Ripening stage affected the physicochemical attributes of fresh pineapples thus the dehydrated products as well. However, Pineapple dehydration is practiced in Sri Lankan food processing industry without considering about the proper ripening/harvesting stage. Nevertheless, more importantly the results of present study revealed that the consumer acceptability was varying with ripening stage. Sensory evaluation emphasized that the 100% yellow color stage was the least acceptable for dehydration whereas 75% yellow color stage was the optimum for pineapple cultivar Mauritius (Queen type) ($P < 0.05$). Therefore, the pineapple cultivar “Mauritius” should be harvested at 75% yellow color stage for dehydration.

Conflict of Interest

The authors declare that there is no conflict of interest.

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