

Ripening and quality of 'Golden' papaya fruit harvested at different maturity stages

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The objective of this study was to determine how ripening physiology and quality of 'Golden' papaya are affected by maturity stages at harvest. Papayas were harvested at four maturity stages (Stage 0: totally green; Stage 1: up to 15% of yellow skin; Stage 2: 16-25% of yellow skin; Stage 3: 26-50% of yellow skin) and evaluated during ripening at 23°C. Physical and physico-chemical (skin color, pulp firmness, soluble solids, titratable acidity, and ascorbic acid), physiological (respiratory activity and ethylene production), and sensorial (flavor, odor, firmness, and appearance) characteristics were evaluated. Regardless of maturity stages, fruit showed similar variation in respiration rate, exhibiting constant values after the 2nd day of storage at 23°C (~31 mL CO₂ kg⁻¹ h⁻¹ for stages 0, 1, and 2, and ~37 mL CO₂ kg⁻¹ h⁻¹ for stage 3). Typical climacteric behavior was not observed for any maturity stage. Only fruit harvested at stage 0 and 1 showed a well defined ethylene production peak of 2.1 µL C₂H₄ kg⁻¹ h⁻¹ after 7 d of storage and 1.3 µL C₂H₄ kg⁻¹ h⁻¹ after 6 d, respectively. Fruit harvested at stages 0, 1, 2 and 3 reached the edible condition (pulp firmness ≤ 20 N) after 7, 6, 4, and 3 d at 23°C, respectively. The ascorbic acid concentration increased 20-30% during ripening, while skin hue angle and titratable acidity was reduced. Independent of the maturity stages at which papayas were harvested, soluble solids did not alter during ripening. Fruit harvested at stages 2 and 3 had superior scores for sensorial evaluation, mainly for flavor and appearance. Harvest at different maturity stages altered fruit postharvest physiology and when effectuated at early stages, it reduced fruit quality but did not make its consumption unacceptable.

Key words: *Carica papaya*, ethylene, harvest time, postharvest, respiration

Amadurecimento e qualidade do mamão 'Golden' colhido em diferentes estádios de maturação: O trabalho objetivou estudar como a fisiologia do amadurecimento e a qualidade do mamão 'Golden' são afetadas pelo estágio de maturação no momento da colheita. Foram colhidos mamões em quatro estádios de maturação (Estádio 0: totalmente verde; Estádio 1: até 15% da casca amarela; Estádio 2: 16-25% da casca amarela; Estádio 3: 26-50% da casca amarela) e, durante o amadurecimento, a 23°C, foram avaliadas características físicas e físico-químicas (cor da casca, firmeza da polpa, sólidos solúveis, acidez titulável e ácido ascórbico), fisiológicas (atividade respiratória e produção de etileno) e sensoriais (sabor, odor, firmeza e aparência). Desconsiderando-se o estágio de colheita, os frutos apresentaram variação similar na respiração, exibindo valores constantes após o 2º dia de armazenamento a 23°C: ao redor de 31 mL CO₂ kg⁻¹ h⁻¹ para os estádios 0, 1 e 2, e de 37 mL CO₂ kg⁻¹ h⁻¹ para o estágio 3. Não foi observado comportamento climatérico típico em nenhum dos estádios de maturação. Somente frutos colhidos nos estádios 0 e 1 apresentaram pico bastante definido na produção de etileno, de 2,1 µL C₂H₄ kg⁻¹ h⁻¹ aos 7 d de armazenamento, e 1,3 µL C₂H₄ kg⁻¹ h⁻¹, aos 6 d, respectivamente. Frutos colhidos nos estádios 0, 1, 2 e 3 atingiram condição de consumo (firmeza da polpa ≤ 20 N) após 7, 6, 4 e 3 d, a 23°C, respectivamente. A concentração de ácido ascórbico aumentou de 20 a 30% durante o amadurecimento, enquanto o ângulo de cor da casca e a acidez titulável tiveram seus valores reduzidos. Independentemente do estágio de maturação em que os mamões foram colhidos, não houve alteração nos sólidos solúveis durante o amadurecimento. Frutos colhidos nos estádios 2 e 3 tiveram notas superiores na avaliação sensorial, principalmente quanto ao sabor e aparência. A colheita em diferentes estádios de maturação alterou a fisiologia pós-colheita dos frutos, sendo que, quando efetuada em estádios menos avançados, resultou em diminuição da qualidade do fruto, mas não impossibilitou o seu consumo.

Palavras-chave: *Carica papaya*, etileno, ponto de colheita, pós-colheita, respiração

INTRODUCTION

Many studies have been conducted in order to understand the postharvest factors that influence papaya quality. However, information is scarce on the preharvest aspects that influence fruit postharvest physiology. Postharvest physiology can be affected by cultivar, environmental condition and also by harvest time. Harvest time is fundamental to obtain a high quality fruit with storage potential. Pratt and Goeschl (1969) reported that in melons both maximum respiratory activity and ethylene production were dependent on fruit maturity at harvest. According to Lalel et al. (2003), only melons harvested at early maturity stages exhibit the climacteric pattern.

Harvest time also has influence on fruit sensorial quality. Bananas harvested at more advanced maturity stages had better consumer acceptance (Ahmad et al., 2001). Knee and Smith (1989) verified that apples harvested at precocious maturity stages showed good conservation but presented an unsatisfactory flavor and color when ripe. Maturity stages at harvest also affect the biosynthesis of volatile compounds in mangoes, responsible for fruit flavor (Lalel et al., 2003). According to Johnston et al. (2002) and MacRae et al. (1989) firmness loss in apples and kiwi is also affected by harvest time.

The Golden cultivar represents a major proportion of exported papayas; nevertheless, there are few studies considering its postharvest physiology. The poor quality of fruit is one of the limiting factors for expanding the papaya market. Therefore, knowledge of factors that influence ripening physiology is essential to elaborate adequate techniques to preserve fruit quality.

The aim of this investigation was to study how ripening physiology and quality of 'Golden' papaya are affected by maturity stages at harvest.

MATERIAL AND METHODS

Papaya fruit (*Carica papaya* L. 'Golden') (a genotype resulting from mass selection of 'Sunrise Solo' plants; Costa and Pacova, 2003) were harvested in February 2004 from a commercial orchard in Linhares (Espírito Santo State, southeastern Brazil) at maturity stages 0, 1, 2 and 3. Fruits were then transported in a refrigerated truck at 10°C to Piracicaba (São Paulo State, southeastern Brazil). The maturity stages were visually defined according to the skin color as: Stage 0 - totally green; Stage 1 - yellow color that does not

cover more than 15% of skin surface; Stage 2 - fruit with 16-25% of yellow skin; Stage 3 - fruit with 26-50% of yellow skin. Fruits were stored in chambers with controlled temperature (23°C) and 80-90% relative humidity until fully ripe, i.e. fruit with pulp firmness ≤ 20 N. Measurements of skin color, pulp firmness, soluble solids, titratable acidity, ascorbic acid, respiration rate, and ethylene production were made after harvest and daily during the storage period, whereas those of sensorial characteristics were performed when fruits reached full ripening.

Fruit firmness was manually measured using a digital penetrometer (model 53200, Tr Turoni, Forli, Italy) fitted with an 8 mm diameter probe tip. The skin was previously removed with a peeler. Fruit skin color was measured as hue angle (H°) with a colorimeter (Minolta Chromameter 300, Minolta Camera Co., Japan). These measurements were taken from four opposite points within the largest diameter area. For soluble solids measurements, rectangular samples of fruit pulp were removed from two opposite sides within the largest diameter portion and pressed for the evaluation of the juice in a digital refractometer (Atago PR-101, Atago, Japan). The data were expressed as °Brix. Eight single fruit replicates were used for pulp firmness, skin color, and soluble solids evaluations.

Ascorbic acid and titratable acidity were determined according to Carvalho et al. (1990) and the results expressed as % citric acid and g kg^{-1} FW, respectively. Four replicates were used, each composed of two fruits.

For respiratory activity and ethylene production, fruits of known mass were individually placed into 1700 mL hermetic flasks for 1 h. After this time, gas samples (1 mL) were taken through a silicone septum with a syringe (Hamilton, Gastight, USA). Gas samples were analyzed by a gas chromatograph (Thermo Finnigan Trace 2000GC, Italy) equipped with a capillary Poropak column (2 m) set at 100°C, with hydrogen as carrier gas at a pressure of 100 kPa. After measurements, the flasks were opened and fruits removed. The respiration rate and ethylene production were determined by the difference between the initial (when flasks were closed) and final (after 1 h) gas concentration, and expressed as $\text{mL CO}_2 \text{ kg}^{-1} \text{ h}^{-1}$ and $\mu\text{L C}_2\text{H}_4 \text{ kg}^{-1} \text{ h}^{-1}$, respectively. Seven single fruit replicates were used. The same fruits were used during the whole experimental period.

For sensorial evaluation, portions containing two pieces of papaya were placed in a plastic recipient and offered to 40 untrained panelists. Fruits were evaluated for flavor, odor,

firmness and appearance on a five points scale (corresponding to excellent, good, regular, bad, and very bad) (Ferreira, 2000).

The experimental design was completely randomized and data were analyzed using the ANOVA procedure and the Tukey test ($P < 0.05$) to compare means.

RESULTS AND DISCUSSION

Papaya fruit harvested at all maturity stages presented normal ripening, evidenced by changes in quality attributes, mainly in skin color and pulp firmness. However, typical climacteric respiration was not observed (Figure 1A). Regardless of maturity stages, fruit showed a similar variation in respiration rate (Figure 1A). The respiratory activity decreased during the first days of storage at 23°C, but after the 3rd day a trend for an increase ($P > 0.05$) in respiration rate was observed, mainly for fruits harvested at stages 0 and 1. During ripening respiratory activity was $\sim 31 \text{ mL CO}_2 \text{ kg}^{-1} \text{ h}^{-1}$ for fruits harvested at stages 0, 1, and 2, and averaged $37 \text{ mL CO}_2 \text{ kg}^{-1} \text{ h}^{-1}$ for fruits harvested at stage 3 (Figure 1A).

Fruit harvested at stage 0 showed two increases in ethylene production. The first increase occurred after 1 d of storage, reaching constant values up to the 5th day, and the second increase was characterized by a well defined peak ($P < 0.05$) of $2 \mu\text{L C}_2\text{H}_4 \text{ kg}^{-1} \text{ h}^{-1}$, after 7 d of storage at 23°C (Figure 1B). Fruit harvested at stages 1 and 0 showed a similar variation in ethylene production. However, the second increase in ethylene production for fruit harvested at stage 1 occurred at 6 d and, although significant ($P < 0.05$), it was less intense, reaching $1.3 \mu\text{L C}_2\text{H}_4 \text{ kg}^{-1} \text{ h}^{-1}$ (Figure 1B). Fruit harvested at stages 2 and 3 showed the lowest ethylene production, with a mean value of $0.57 \mu\text{L C}_2\text{H}_4 \text{ kg}^{-1} \text{ h}^{-1}$, without any significant increase during the storage period (Figure 1B).

Previous studies with other papaya cultivars have demonstrated a respiration peak. Wills and Widjanarko (1995) found a respiration rate of $36 \text{ mL CO}_2 \text{ kg}^{-1} \text{ h}^{-1}$ in papayas (harvested at mature green stage), 5 d after harvest, while maximum ethylene production ($5 \mu\text{L C}_2\text{H}_4 \text{ kg}^{-1} \text{ h}^{-1}$) was achieved on the 6th day. Selvaraj et al. (1982) found that the climacteric peak in papayas occurred 140 d after anthesis, when fruits were already ripe, with yellow skin and soft pulp.

Various interrelated processes are involved in the physiology of ripening in a complex way, and for that reason fruit behavior during this period might not correspond to

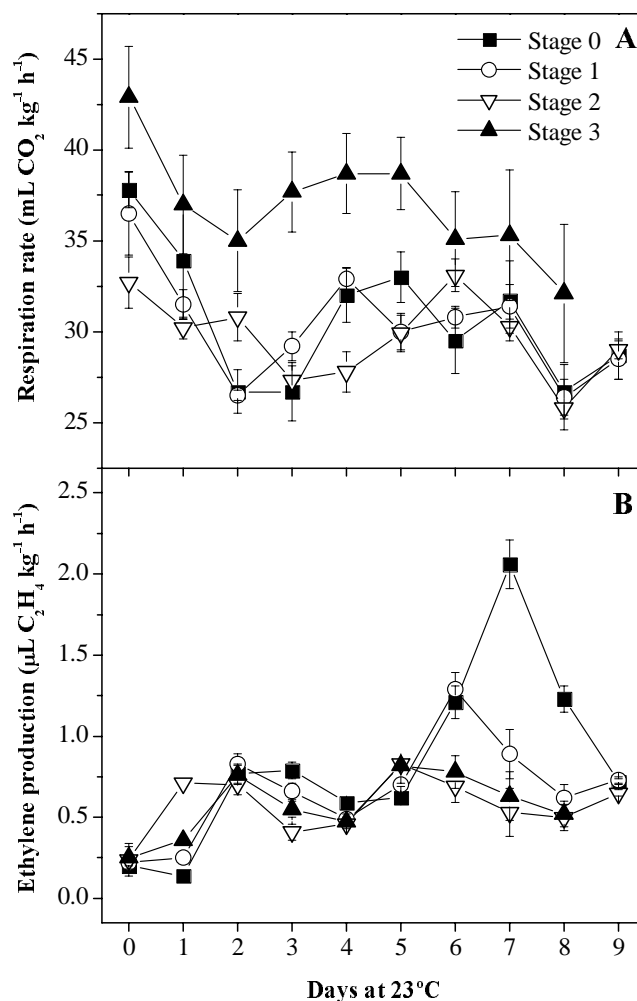


Figure 1. Respiration rate (A) and ethylene production (B) of 'Golden' papaya fruits harvested at four maturity stages and stored at 23°C. Symbols represent the mean values \pm SE ($n = 7$). Stage 0: totally green; Stage 1: up to 15% of yellow skin; Stage 2: 16-25% of yellow skin; Stage 3: 26-50% of yellow skin.

previous established patterns. Azzolini et al. (2005) demonstrated that 'Pedro Sato' guavas exhibited a gradual increase in respiration rate and ethylene production. Abdi et al. (1998) showed that plums also produced ethylene up to the end of ripening.

The interference of harvest time on climacteric manifestation was studied by Lalel et al. (2003) who noticed that only mangoes harvested at early stages showed an ethylene peak with a significant increase of respiration. This led them to affirm that only fruit harvested at early stages were in a pre-climacteric phase. Possibly, this also occurred

in our study, with fruits harvested at stages 2 and 3 showing maximum ethylene production while attached to the plant. In a study conducted by Johnston et al. (2002), apples harvested at a less advanced maturity stage showed higher ethylene production than those harvested at more advanced stages. According to Trewavas (1982), in fruits at more advanced maturity stages the quantity of ethylene receptors is higher, leading to a lower need for ethylene production. Consequently, we may argue that the need of ethylene for ripening is greater in fruits harvested precociously.

The function, interaction and meaning of the climacteric and increase of ethylene production are still not completely understood. Since the energy generated by basal metabolism may be sufficient to support biochemical changes during ripening (Solomos, 1977) and some of these changes occur without any respiratory increase (Romani et al., 1983), the climacteric may be considered as a maximum homeostatic response of mitochondria to compensate the degradation effects caused by cellular senescence (Romani, 1984), with ethylene production being a stress response. Consistent with this idea, Selvaraj and Pal (1982) did not find expressive changes in fruit contents after maximum climacteric respiration in papayas. In the present study, there is evidence that the basal level of ethylene and respiration activity were sufficient to stimulate biochemical changes associated with fruit ripening.

Fruits harvested at more advanced maturity stages had lower pulp firmness when compared to those harvested at earlier stages (Table 1). Because of high firmness variation (CV = 25%), statistical differences among maturity stages were not detectable (Table 1).

The rate of firmness loss was also affected by maturity stage at harvest (Table 2, Figure 2A). At the 2nd day of storage, fruits harvested at stage 0 lost approximately 39% of initial firmness, and more than 60% when harvested at stages 2 and 3 (Figure 2A). Johnston et al. (2002) and MacRae et al. (1989) also observed the slower initial softening in apples and kiwis harvested at early maturity stages. Possibly, in early maturity stages the enzymes related to softening were still not completely synthesized and activated. In addition, the quantity of ethylene receptors is reduced in fruits harvested when still green (Trewavas, 1982) and, for this reason, the ethylene-dependent processes can be delayed.

In climacteric fruits the ethylene production peak commonly precedes major changes in fruit quality attributes. In the present work, increases in ethylene production in fruit harvested at stages 0 and 1 occurred when fruits had already achieved pulp firmness below 20 N (Figures 1B and 2A) and major quality changes had occurred. Accordingly, Blankenship and Unrath (1988) observed decreases in firmness before any increase in internal ethylene concentration during apple ripening. Paull et al. (1983) proposed that ethylene only speeds or coordinates the firmness changes during soursop ripening, where increases in production only occurred at more advanced stages of ripening.

The ripening processes, including firmness loss, can be the result of an increase in ethylene sensitivity of the fruit tissue and not necessarily dependent on increases in ethylene production. Besides, a low quantity of this hormone can be sufficient for beginning the ripening processes. Flores et al. (2001) concluded that melon softening depends only

Table 1. Physical and physico-chemical attributes of 'Golden' papaya fruits harvested at different maturity stages. Mean values followed by the same letter within rows do not differ by the Tukey test ($P > 0.05$). Stage 0: totally green; Stage 1: up to 15% of yellow skin; Stage 2: 16-25% of yellow skin; Stage 3: 26-50% of yellow skin

Attribute	Stage 0	Stage 1	Stage 2	Stage 3
Soluble solids (°Brix)	11.5 a	11.6 a	12.0 a	12.7 a
Titrateable acidity (%)	0.12 a	0.13 a	0.13 a	0.12 a
Ascorbic acid (g kg ⁻¹ FW)	0.74 a	0.74 a	0.85 a	0.83 a
Pulp firmness (N)	106.5 a	99.4 ab	84.3 ab	73.8 b
Skin color (H°)	110.8 a	108.3 b	105.3 c	101.5 d

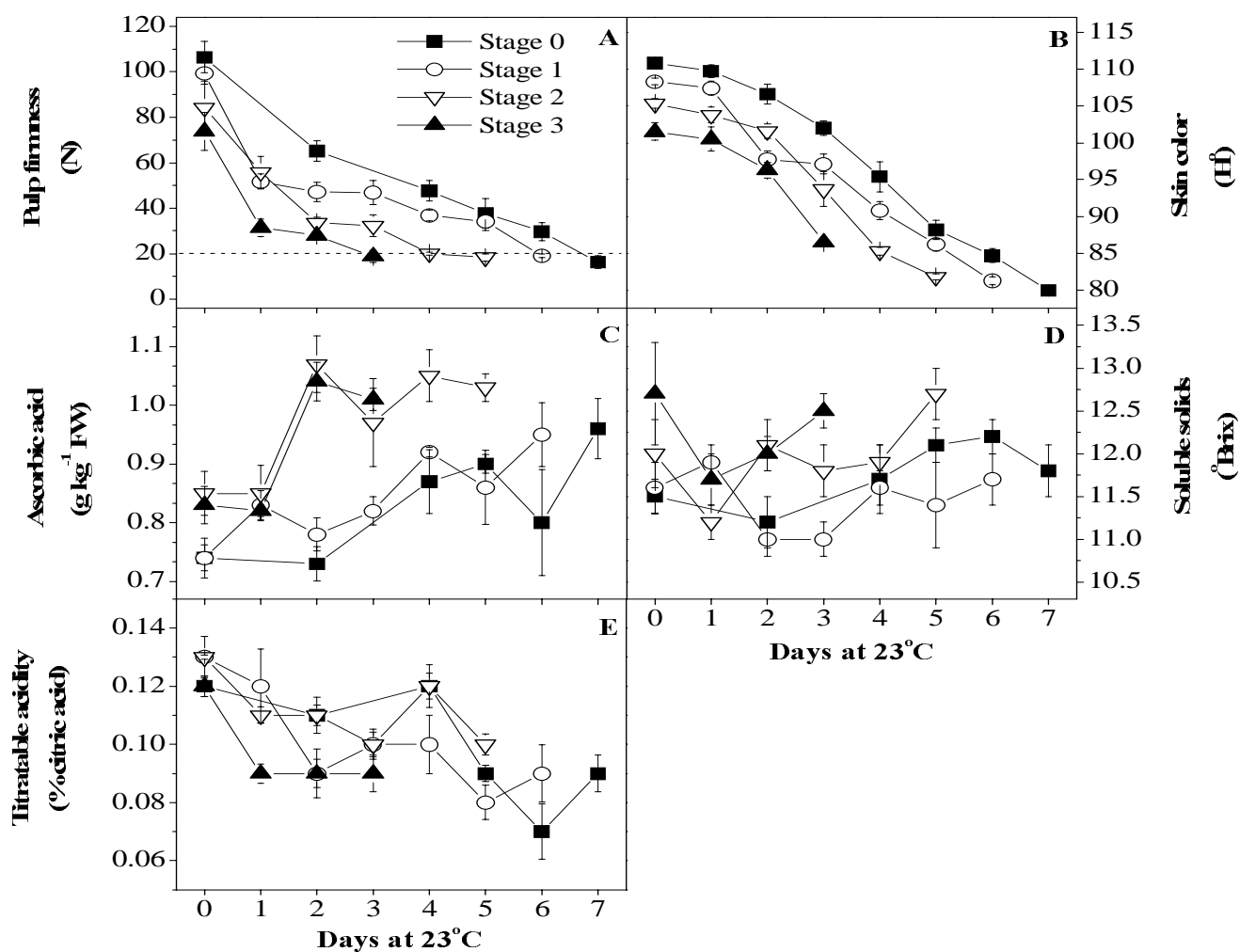


Figure 2. Physical and physico-chemical characteristics of 'Golden' papaya fruits harvested at four maturity stages and stored at 23°C. Symbols represent the mean values \pm SE ($n=8$). Stage 0: totally green; Stage 1: up to 15% of yellow skin; Stage 2: 16-25% of yellow skin; Stage 3: 26-50% of yellow skin. Dotted line indicates the edible firmness (20 N).

partially on ethylene, since firmness loss of genotypes that express the antisense 1-aminocyclopropane-1-carboxylic acid oxidase was about 50% lower than in normal fruit. Therefore, it is reasonable to assume that other ethylene-independent processes are involved in fruit ripening. In fact, firmness loss has a close relationship with activity of pectic enzymes, which are related to ethylene but at different dependence levels (Jeong et al., 2002).

During ripening, fruits harvested at all maturity stages showed decreases in H° , or yellow color development, mainly after the 2nd day of storage (Figure 2B).

As observed for firmness, the increase in ethylene production found at stages 0 and 1 occurred when

papayas had already achieved $H^{\circ} = 80^{\circ}$, i.e. a completely yellow skin. Also, in this case, it is reasonable to assume that skin color changes cannot be only dependent of high ethylene concentrations, but that ethylene simply coordinates the events that have already been initiated during ripening.

Fruits harvested at stages 2 and 3 showed higher ascorbic acid concentration than those harvested at other maturity stages (Table 1). During ripening, ascorbic acid increased 20-30% independent of the maturity stage at harvest (Figure 2C). When completely ripe, fruit harvested at all maturity stages had ~ 1.0 g ascorbic acid kg^{-1} FW (Table 2). These data are quite similar to those of Pal et al. (1980), who found a maximum ascorbic acid concentration of around 1.0 g kg^{-1} FW in ripe papayas.

Table 2. Physical and physico-chemical attributes of 'Golden' papaya harvested at different maturity stages after fruit achieved the edible condition (pulp firmness < 20 N). Statistics and other details as in Table 1

Attribute	Stage 0	Stage 1	Stage 2	Stage 3
Days at 23°C to reach edible firmness	7	6	4	3
Soluble solids (°Brix)	11.9 a	11.7 a	12.7 a	12.5 a
Titrateable acidity (%)	0.09 a	0.09 a	0.10 a	0.09 a
Ascorbic acid (g kg ⁻¹ FW)	0.96 a	0.95 a	1.03 a	1.01 a
Pulp firmness (N)	16.3 a	19.0 a	18.3 a	18.8 a
Skin color (H°)	80.0 b	81.3 b	81.8 b	86.5 a

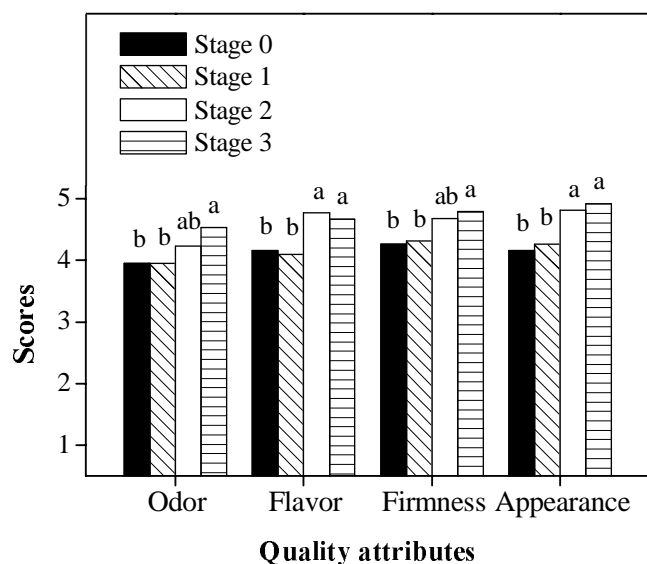


Figure 3. Sensorial evaluation of ripe (firmness < 20 N) 'Golden' papaya fruits harvested at four maturity stages and stored at 23°C. Symbols represent the mean values ($n = 40$). Stage 0: totally green; Stage 1: up to 15% of yellow skin; Stage 2: 16-25% of yellow skin; Stage 3: 26-50% of yellow skin. Scores: 1 = very bad, 2 = bad, 3 = regular, 4 = good, 5 = excellent. Mean values followed by the same letter do not differ by the Tukey test ($P > 0.05$).

Mannose and L-galactose are key substrates for ascorbic acid synthesis in plants (Conklin, 2001). Therefore, cell wall degradation during ripening may provide substrates for ascorbic acid synthesis, explaining the ascorbic acid increase in 'Golden' papayas.

Independent of the maturity stages at which papayas were harvested, soluble solids did not differ during

ripening ($P > 0.05$) (Figure 2D). Papaya has a low starch content (around 0.5-0.1%; Selvaraj et al. 1982). Therefore, the fruit does not have significant amounts of starch to be hydrolyzed during ripening, which results in little, if any, change in soluble contents during the postharvest period.

According to Selvaraj et al. (1982), sucrose content increases up to five times at 110-130 d after anthesis in papayas attached to the tree, when skin color begins to change. Therefore, it is important to consider that a higher sink demand occurs when fruit begins to turn yellow, and it is reasonable to assume that fruit harvested at maturity stages 0 and 1 did not have sufficient time to accumulate soluble sugar before harvest. According to Zhou and Paull (2001), the papaya sugar content remains constant during postharvest ripening, suggesting that sugar accumulation in pulp is related to continued sugar translocation from plant to fruit.

The titrateable acidity in ripe fruit was 0.09% (Table 2), with values similar to those reported for other 'Solo' papayas (Pal et al., 1980), and very low compared to other fruits. During the postharvest period, Wills and Widjanarko (1995) observed maximum titrateable acidity when fruits had already achieved a completely yellow skin. In the present work, the acidity in papayas was reduced during ripening, mainly in fruit harvested at maturity stages 0 and 1 (Figure 2E). Chan et al. (1971) reported that the malic acid content decreases during papaya ripening, as also observed by Selvaraj et al. (1982). However, Lazan et al. (1989) concluded that the titrateable acidity increases with fruit ripening until approximately 75% of yellow skin, decreasing thereafter.

In sensorial analysis, the highest scores were attributed to fruit harvested at advanced maturity stages, when the edible condition was reached (Figure 3). In general, two groups were segregated ($P < 0.05$) according to sensorial analysis: fruits harvested at stages 2 and 3, and those harvested at stages 0 and 1. Since papaya has low acidity, flavor is attributed mainly to sugar content. Comparing the results obtained in sensorial analysis (Figure 3) with soluble solid values (Table 2), it is noticeable that the panelists detected the differences found in soluble solids. Harvesting at early stages does decrease fruit quality but did not make the fruit unacceptable for consumption.

CONCLUSIONS

Typical climacteric behavior was not verified for 'Golden' papaya fruit harvested at different maturity stages. Fruit harvested at a more advanced maturity stage showed reduced ethylene production during postharvest. Fruits harvested at early stages had acceptable but lower sensory quality for consumption. The maturity stage at harvest affected the respiratory activity and ethylene production during postharvest of 'Golden' papayas.

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