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CHARACTERIZATION AND OCCURRENCE OF EARLY SOFTENING DISORDER IN 'GOLDEN' PAPAYA FRUITS[1]

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ABSTRACT- The occurrence of green skin and soft pulp in 'Golden' papaya fruit during certain seasons has been reported by farmers in the northern of the state of Espirito Santo, Brazil. The objective of this study was to characterize and determine the occurrence of this disorder, which was referred as "early softening disorder". Fruits were harvested weekly for 11 months (from September to July). The fruits were stored at 10°C, and then fruit flesh firmness and skin color were analyzed. The results of the firmness test were submitted to regression analysis assuming a linear trendline. The slope of the curve was called the 'softening index' (SI). Fruits with early softening are characterized by a loss of firmness in less than 10 days, even when stored under refrigeration. Although softened, the skin of the fruit remains partially green. Fruits with the disorder occurred more frequently from mid-summer to mid-autumn (February to May). It is not possible to distinguish early softening disorder fruits from those without the disorder by skin color and flesh firmness analysis at the time of the harvest.

Index terms: Physiological disorder, flesh softening, softening index, *Carica papaya* L.

CARACTERIZAÇÃO E OCORRÊNCIA DO DISTÚRBIO DO AMOLECIMENTO PRECOCE EM MAMÕES 'GOLDEN'

RESUMO- Tem sido relatado por produtores da região norte do Espírito Santo a ocorrência de mamões 'Golden' com casca verde e polpa mole, em determinadas épocas do ano. O objetivo deste trabalho foi caracterizar e determinar a ocorrência deste distúrbio denominado de amolecimento precoce. Foram realizadas coletas semanais durante 11 meses (período de setembro a julho). Os frutos foram armazenados a 10°C e analisados quanto à firmeza da polpa e à cor da casca. Os resultados de firmeza da polpa foram submetidos à análise de regressão, assumindo-se que a equação é do tipo linear, e o ângulo de inclinação da curva foi chamado Índice de Amolecimento (IA). Frutos com o distúrbio caracterizaram-se pela perda da firmeza em menos de 10 dias, mesmo quando armazenados sob refrigeração. Embora amolecidos, a coloração da casca manteve-se parcialmente verde. A maior frequência de frutos com o distúrbio ocorreu de meados de verão a meados de outono (fevereiro a maio). Não é possível distinguir frutos com o distúrbio do amolecimento precoce daqueles normais pela análise da cor da casca e da firmeza da polpa, no momento da colheita.

Termos para indexação: Distúrbio fisiológico, amolecimento da polpa, indice de amolecimento, *Carica papaya* L.

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Brazil is the third largest fruit producer in the world and is presently the world's largest papaya producer. Its production is about of 1.900.000 tons per year. Of this total, 32.000 tons are exported. The papaya yield is done almost in the entire Brazilian territory, concentrated in Bahia (48,2%) and Espírito Santo (36,7%) (AGRIANUAL, 2010). The largest Brazilian papaya yields are situated in Espírito Santo (66 $t.ha^{-1}$), Bahia (53 $t.ha^{-1}$) and Ceará (42 $t.ha^{-1}$) (SOUZA, 2007). The fruits are harvested from the stage 0 (zero) (green skin) to the stage 2 (16% to 25% of the fruit with yellow skin). The 'Golden' papaya is exported to markets in North America and Europe in refrigerated containers. Since they are shipped by sea, the papayas will not be consumed until at least 20 days after harvest. Papaya is also subject to a series of factors that affect its quality after harvesting, many of which can be determined before harvesting. Some factors, like skin freckles and gellification, are under current study, and their causes have been partially determined (REYES; PAULL, 1994; CAMPOSTRINI et al., 2005).

Skin freckles in papaya were first reported by Ishii & Holzmann (1963) in Hawaii. Climatic factors like the quantity of rain and incident radiation are associated with characteristics of the plant such as transpiration capacity and the developmental stage of the fruits. Together, these are determining factors in the occurrence of skin freckles anomaly (REYES; PAULL, 1994). These factors can also be associated to a physiological anomaly called gellification, which affects the physical integrity of the cellular membrane. Gellification occurs mainly in 'Golden' papaya and is characterized by a translucent mesocarp with a drenched aspect (OLIVEIRA et al., 2002). These authors suggest that a possible dysfunction in the cellular membranes alters the osmotic gradient of the tonoplast.

Other sporadic disorders that affect the fruit quality have not yet been studied, such as the early softening of the fruit flesh. Producers and workers in the northern of the Espirito Santo have reported that, at certain times of the year, it is common to find fruits with green skin and soft pulp. Such fruits are found more often between mid-summer and mid-autumn. In extreme situations, the fruits soften while still on the tree, before they are harvested. These fruits are discarded during the packaging process. In other situations, the fruits seem normal during harvesting but soften during maritime shipping. Variation in firmness is not desirable for commercialization of any fruit, because it can cause considerable postharvest losses if the fruit is ready for consumption before it arrives at the market place.

The objective of this study was to determine the characteristics of early softening in 'Golden' papaya and to investigate the occurrence in commercial orchards over 11 months.

'Golden' papaya fruits were harvested weekly in several commercial orchards in the northern of the Espirito Santo, Brazil (latitude 19º23'28" south and longitude 40º04'20" west), from September 2004 to July 2005. Eight orchards in full production were selected; the orchards had distinct characteristics such as age, microclimate and soil. These orchards were subject to quality control for export. Papaya fruit were harvested at the following stages: stage 1 (up to 15% of the skin with a yellow color) and stage 2 (16% to 25% of the skin with a yellow color). Approximately 100 fruits in stage 1 and 100 fruits in stage 2 were harvested weekly and subjected to the same procedures as fruits for export, i.e., storage at 10±1°C and 85±5% UR for 12 days. The skin color was determined every two days, and visually defined as: 0 means totally green, 1 means up to 15% of the skin with a yellow color, 2 means up to 25% of the skin with a yellow color, 3 means up to 50% of the skin with a yellow color, 4 means from 50% to 70% of the skin with a yellow color and 5 means from 76% to 100% of the skin with a yellow color (BRASIL, 2000).

The flesh firmness was determined every two days in each sampled orchard for each maturation stage by an 8 mm digital diameter penetrometer (53200-Samar, Tr-Turoni, Forli, Italy). Four measurements were taken for each fruit at points equally distant from the middle of the fruit after the skin was removed. The results were expressed in Newton. Approximately 70.000 fruits sampled in total, from 8 to 10 orchards that were studied over the course of 44 weeks. Only firmness values equal to or greater than 20 N were used, since values lower than 20 N indicate that the pulp is completely soft (Bron; Jacomino, 2006).

The softening index (SI) methodology was intended as a way to characterize the slope of softening. This method is based in the flesh firmness plotted as a function of time (days after harvest), and submitted to regression analysis assuming a linear trendline. The slope of the regression represented by "a" value in the equation "$y = ax + b$" was designated the softening index (SI). Fruits that had a softening index ≥ -10 were considered to be "hard" and have not firmness decrease during storage period at 10°C. In other hand, fruits that had a softening index < -10 were considered to be "soft". In some cases, SI was strongly negative, less than -20 or -30, and those fruits achieved the firmness for consumption ($\leq 20N$) before the end of the storage period at 10°C.

The measurements were arranged in a com-

pletely randomized design. The data were analyzed by analysis of variance (ANOVA). Statistical analyses were carried out using the SAS software (SAS Institute, Inc., Cary, NC).

The softening index (SI) observed by fruits stored at 10°C was illustrated on Figure 1. "Hard" fruit showed a softening index of -2.62 while "soft" fruit was -19.79. This shows the difference in the softening pattern in 'Golden' papaya fruit.

The average values of firmness obtained from the 8 orchards over the 44–week time span show that both "soft" fruits and "hard" fruits lost firmness during storage, however "soft" fruits were subject to more intense softening (Table 1). The "soft" fruits could be distinguished from the "hard" ones after the fourth day of storage at 10ºC. The loss of firmness in both "soft" and "hard" fruits occurred in a similar way in two maturation stages (Table 1). In fact, maturation stage at harvest does not affect the occurrence of disorder, since fruits harvested at stage 1 and fruits harvested at stage 2 lost firmness in the same manner.

One of the difficulties in identifying the presence of early softening disorder in green fruit, at harvest time, is that the fruit shows skin color characteristic of the ripe stage, independently of being "soft" or "hard". Visually, it would be impossible to differentiate the two types of fruits due to the small difference between them and due to the high variability of the fruits within each lot. There was no significant difference in skin color between "soft" and "hard" fruits of either stage 1 or stage 2 at the time of harvest (day 0) (Table 2). Only after the sixth day of storage is it possible to observe a change in skin color in the "soft" fruits, while the firmness of these fruits decreases significantly after the fourth day (Tables 1 and 2). As a result, the yellowing of the skin occurs less rapidly than the softening, resulting in fruits that are still partially green when the pulp is ready for consumption.

The occurrence of the disorder throughout the year is shown in Figure 2. Each point represents an average SI value across the eight papaya orchards that were surveyed. In some weeks, some orchards yielded "soft" fruits while others yielded "hard" fruits, resulting in high standard deviation values. During some periods of the year, the resulting SI exhibited low values (i.e., the fruits remained firm throughout the 12-day storage period at 10ºC). However, in other periods of the year, SI values were more negative, indicating that the fruits were soft at the end of the storage period. From February to May 2005, SI values were predominantly low (i.e., the fruit pulp softened considerably). This period corresponds to the end of the summer and autumn (March to May), and papaya producers report that this is the period when the fruits are more prone to pulp softening. However, pulp softening may occur at other times as well. Orchards in which fruits show early softening disorder may yield normal fruits after a few weeks; the contrary is also true. In winter and spring, "hard" fruit was predominant, except for some weeks in November and December 2004. It is possible that the beginning of the rainy season may have stimulated this behavior. Moreover, the occurrence of this disorder may also be related to nutritional unbalance, which is then aggravated by the occurrence of intense rain.

Little information is available about the behavior of enzymes in the modification of the papaya cell wall and nothing is know about how these enzymes are altered in fruits with early softening disorder. When there is a decrease in firmness, the enzymes that are involved in the disassembly of the cell wall may play a role, especially those that are dependent on ethylene, such as polygalacturonase, pectin methylesterase and galactosidase (ALI et al., 2004). The cohesion in cell wall components is an important factor in determining the firmness of the fruit. Hence, the modifications of the primary cell wall contribute to the fruit softening (CROOKES; GRIERSON, 1983). According to Giovannoni (2001), ethylene is necessary to coordinate and complete maturation in climacteric fruits. The visual aspect of the skin is the first characteristic observed during the maturation phase; changes in color indicate the degradation of chlorophyll due to changes in pH, increase in acids, and in oxidation process, action of chlorophyllase and synthesis of carotene and anthocyanin, which make the fruit yellow after harvesting (SEYMOUR et al., 1993). In papayas with the early softening disorder, the change in skin color does not follow the decrease in flesh firmness. It is possible that skin yellowing may be less dependent than the firmness by ethylene. Besides that, physiological and biochemical differences between "hard" and "soft" fruits may be related to the availability of ethylene biosynthesis precursors, to the sensitivity of the tissue to hormonal alteration, or either to the cell wall metabolism modification.

This work showed that early softening in 'Golden' papaya fruit is a disorder that occurs more frequently from March to May. Furthermore, the softening index (SI) is a promise methodology to identify the "hard" and the "soft" fruit.

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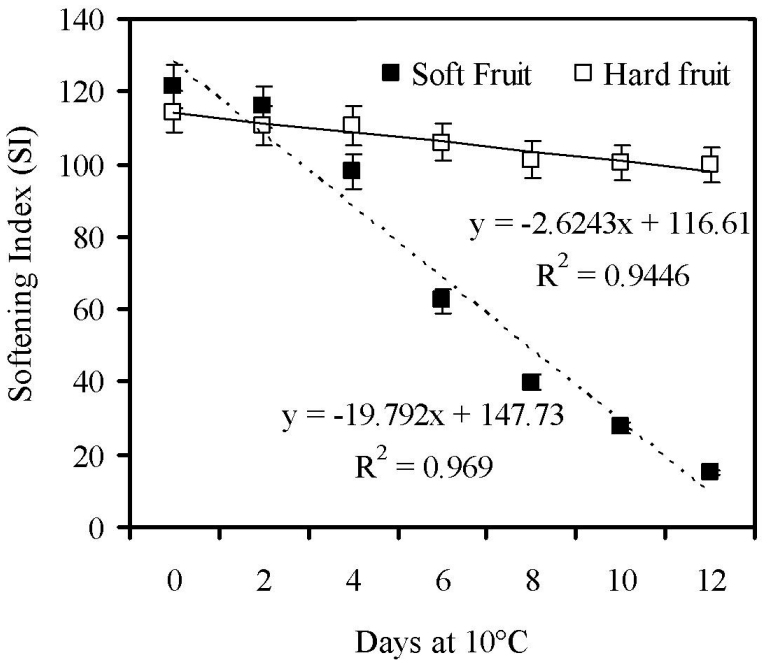

FIGURE 1- Softening index (SI) of 'Golden' papaya fruit harvested in stage 1 of maturation and stored during 12 days at 10°C. Hard fruit: SI ≥ -10; Soft fruit: SI < -10.

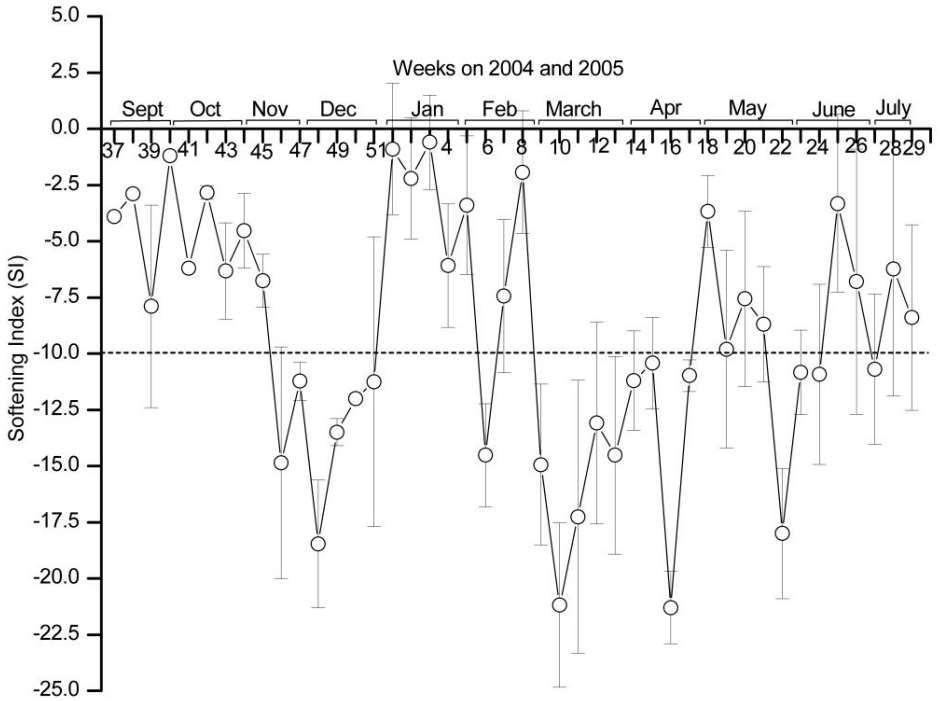

FIGURE 2- Softening index of 'Golden' papaya fruits during a 44-week time span, from September 2004 to July 2005. Dotted lines indicate that SI ≥ -10 is referred to "Hard" fruit and SI < -10 are "Soft" fruit.

TABLE 1 - Pulp firmness (N) of 'Golden' papaya fruits of two maturation stages at harvest, stored for 12 days at 10ºC.

Days at 10°C	Stage 1			Stage 2		
	"Hard"	"Soft"	LSD*	"Hard"	"Soft"	LSD*
0	116.7 Aa	112.4 Aa	11.7	112.9 Aa	117.0 Aa	12.3
2	114.6 Aa	111.0 Aa	11.7	115.7 Aa	106.6 Aa	12.3
4	117.3 Aa	90.8 Bb	11.9	108.6 Aa	85.7 Bb	12.3
6	110.0 ABa	62.3 Cb	11.7	95.7 ABa	53.0 Cb	12.3
8	101.7 ABCa	53.2 CDb	11.9	85.7 Ba	43.9 Cb	12.3
10	97.5 BCa	48.1 CDb	12.1	85.1 Ba	42.9 Cb	12.3
12	91.1 Ca	42.2 Db	12.4	83.7 Ba	38.0 Cb	12.3
LSD*	16.1	19.7		20.8	15.9	
CV (%)	20.2			23.2		

Means followed by the same small letters within rows and by the same capital letters within columns are not significantly different at $P \leq 0.05$ using the Tukey Multiple Range Test. LSD* = Least Significant Difference at $P \leq 0.05$

TABLE 2 - Skin color of "soft" and "hard" 'Golden' papaya fruits of two maturation stages at harvest, stored for 12 days at 10ºC.

Days at 10°C	Stage 1			Stage 2		
	"Hard"	"Soft"	LSD*	"Hard"	"Soft"	LSD*
0	1.00 Aa	1.04 Aa	0.24	1.93 Aa	2.00 Aa	0.24
2	1.15 Aa	1.33 Aa	0.24	1.98 Ab	2.23 ABa	0.24
4	1.16 Aa	1.39 Aa	0.24	2.17 ABa	2.31 ABCa	0.24
6	1.28 ABb	1.96 Ba	0.24	2.23 ABCb	2.62Ca	0.24
8	1.48 Bb	2.16 BCa	0.24	2.48 BCb	3.05 Da	0.24
10	1.92 Cb	2.35 CDa	0.20	2.62 Cb	3.09 Da	0.24
12	2.01 Cb	2.74 Da	0.24	2.65 Cb	3.32 Da	0.24
LSD*	0.32	0.39		0.42	0.32	
CV (%)	23.5			14.69		

Means followed by the same small letters within rows and by the same capital letters within columns are not significantly different at $P \leq 0.05$ using the Tukey Multiple Range Test. Values refer to a range of color grades, where 1 = up to 15% of the skin with a yellow color, 2 = up to 25% of the skin with a yellow color, 3 = up to 50% of the skin with a yellow color, 4 = from 50% to 75% of the skin with a yellow color and 5 = from 76% to 100% of the skin with a yellow color. LSD* = Least Significant Difference at $P \leq 0.05$

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