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Physiological maturation and postharvest resting of papaya fruits and seeds in agroecological transition

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Abstract

This study aimed to characterize the maturation stages of the papaya fruits and to evaluate the physiological quality of papaya seeds produced in an agroforestry system as a function of postharvest maturation. Papaya fruits were used (*Carica papaya* L.) from two groups, Formosa Tainung 1 and Solo Sunrise Solo, harvested at maturation stage I (up to 15% of the yellow bark). The seeds were obtained, without sarcotesta: soon after harvest (T_1); 14 days after standing at room temperature (T_2); and 14 days after standing at 10 °C (T_3). The variables analyzed included: germination, first count, speed, and mean germination time and length of seedlings. The experimental design was completely randomized, in a 2 × 3 factorial scheme (2 groups and 3 rest periods), with 4 replicates of 50 seeds for each treatment. The papaya fruits produced maximum germinating seed in a less average time at room temperature and maturation stage V and the final stage (76%–100% of the yellow bark), allowing maximum number of seedlings with greater vigor. Fruits in stage I impaired the physiological quality of the seeds. The agroecological production presented a systemic approach in the management of papaya.

Keywords: Agroforestry system; *Carica papaya* L; Germinability; Vigor.
Abbreviations: G_germination; PC_first count; IVG_germination speed index; TMG_average germination time; VMG_average speed of germination; CP_length of seedlings.

Introduction

The papaya (*Carica papaya* L.) is widely cultivated in tropical America. Among the main exporting countries, Brazil is the second largest producer of papaya for the European market. The plant can be propagated by means of seeds, cutting, and grafting. However, seed propagation is widely preferred by the farmers, because it is more practical and economical (Mengarda et al., 2015). In general, this method enhances continuous production, allowing the harvesting of fruits in several stages of development and maturation (Lima et al., 2018). Therefore, this influences the physiological quality of the seeds, because those that are harvested immature reveal low vigor and less germinative power.

Early harvesting and proper post-harvesting can reduce the time of fruit permanence in the matrix plant, avoiding possible unfavorable conditions during production (Dias et al., 2015). This is particularly necessary while trying to improve the yield of seeds, knowing that their germination is slow and irregular and that the mechanisms responsible for such behavior remain unclear. According to Melo et al. (2015), the production of papaya seedlings at the commercial scale is affected by the seed issues due to the presence of sarcotesta (a mucilaginous envelope that externally surrounds the seed and contains phenolic compounds that prevent or hinder germination) and postharvest dormancy.

Alternatively, the potential of agroforestry systems (SAFs) is recognized for small producers in poor or marginal areas of the tropics and subtropics (Altieri, 2012), indicated for a wide range of property sizes and socioeconomic conditions. Therefore, according to Figueira et al. (2017), SAFs are productive systems for the environmental restoration that can be based on ecological succession. They are also considered as analogous to the natural ecosystems, according to a pre-established spatial and temporal arrangement, due high species diversity and interactions. In general, the seed or seedlings are planted in SAFs. The resources and the return of the production are generated permanently and in several strata, considering that papaya is one of the majorly cultivated and consumed fruits in the tropical and subtropical regions of the world.

Thus, in order to provide important subsidies to the fruit–seed producers, this study aimed to evaluate the influence of the postharvest period at different temperatures during the maturation stage of the fruits and the germination and vigor of papaya seeds produced in a recently implanted agroforestry system.

Results and discussion

Fruit maturation

It was verified that the color of the papaya fruits varied according to the place and temperature (Fig. 2) with visible changes in relation to the fruits without rest. Fruit of

Formosa papaya cv. Tainung nº 1, reached the maturation II stage, i.e up to 25% of the yellow surface after 14 days of rest in a controlled environment at 10 °C (Fig. 2A). It also acquired degree of complete maturation or stage V, i.e. 76%–100% of the yellow surface, at room temperature after 14 days of rest in the laboratory environment (Fig. 2B). Alternatively, fruit Solo cv. Sunrise Solo, reached maturation stage III, i.e up to 50% of the yellow surface, after storing at 10 °C, for 14 days (Fig. 2C). Fruit Solo, presented maturation stage V after stored at room temperature for 14 days. It showed visible symptoms of fungal deterioration (Fig. 2D).

Papaya is a climacteric fruit that transformation is occurred immediately after harvesting. This transformation results from ripening. The mature fruit produce ethylene that stimulates increased respiratory rate, which causes considerably perishable fruits during the postharvest period (Souza et al., 2014). According to Sanches et al. (2017), ethylene is associated with the acceleration of ripening and senescence of climacteric fruits. At a certain stage of maturation, ethylene binds to its receptor in the cell. A protein–enzymatic complex triggers a series of events that culminate in fruit ripening and senescence. With low temperature, the ethylene production decreases, followed by reduced maturation. Notably, the conservation of papaya at room temperature is desirable, since almost all the fruit marketed at the retail level in Brazil is non-refrigerated.

In a similar way, other studies revealed that the production in the organic system is viable and postharvest rest of the fruits improves the physiological potential of the seeds in *Capsicum baccatum* L. (Pereira et al., 2014) and *Capsicum annum* L. (Nogueira et al., 2017). The papaya cannot be matured properly if harvested at the immature stage.

The consortium of papaya with corn, beans, sweet potatoes, and legumes for green manure is very popular. Moreover, the organic soil management is important, when plant reaches the adult stage. The agroforestry system observed in this study entails a low cost for maintenance of fruit and wood species, since quick commercialization is possible.

Physiological seed quality

The seed performance and interaction between fruits and different treatments of postharvest rest can be observed in Tables 1 and 2. In these tables, the values of germination, first count, speed, and mean germination time and seedling length are described. Statistical difference was observed for the analyzed variables ($p < 0.05$), with higher values for fruits at final maturation stage, indicating that the changes in the fruit color during maturation correspond to the physiological and biochemical changes inside the fruits that favor the seed quality.

Despite the removal of the sarcotesta, seeds harvested immediately after harvesting the fruits of Formosa and Solo, at the maturation stage I, revealed low and uneven germination (Tables 1 and 2). The location of the seed inside the fruit may influence its internal morphology, thereby affecting the physical and physiological quality. According to Jesus et al. (2016), at this stage, the removal of the sarcotesta may simultaneously promote the removal of compounds that could be used at the later stages by seeds for structuring the cell walls and/or the germ-promoting substances in sarcotesta, endosperm and embryo during the germination.

We found that the resting in the laboratory environment at room temperature induced the maximum seed germinability (Tables 1 and 2), which would presumably be associated with a change between the promoters and inhibitors of germination caused by presence of seeds inside the fruit during the ripening phase. Therefore, the seed did not reach the physiological maturity during the fruit harvesting (Silva et al., 2015). This results show existence of postharvest dormancy. Development and resting time of fruits can overcome dormancy. However, the information about dormancy is still scarce. In practice, the dormancy intensity of the seeds may vary depends on the maturation/harvest season of the fruits. The seeds obtained from mature fruits during the winter often reveals marked dormancy, unlike the seeds that develop during the summer, under higher temperatures, which germinate satisfactorily soon after the harvest.

The papaya fruits reached the maturation stage V at room temperature. They defined to be used for the subsequent experiments, since it provided a higher percentage of germination in a lower average time (higher germination speed), without harming the development of seedlings (Tables 1 and 2). It is an interesting strategy to reduce the occurrence of dormant seeds in a batch to allow the translocation of nutrients from the fruit to the seeds. Similar results were found by Rocha et al. (2018), on *Lycopersicon esculentum* Mill. in agroecological transition. We observed a significant increase in emergence speed with physiological maturation and postharvest storage of fruits and seeds. Sanches et al. (2017) reported an increase in the germinative vigor of *Cucurbita pepo* L. seeds with the advancement of the fruit maturation process.

In papaya, the seed maturation after the removal of the plant fruit becomes an advantage by reducing the number of harvests. The early withdrawal of fruits has as another advantage in reduction of fruits exposure to the climatic intemperate and the attacks of pests and diseases in the field, leading to the reduction of seed quality. Few studies have been conducted on papaya fruit, relating the maturation of the fruits with the maturation of the seeds.

Materials and methods

The study was conducted during July–December 2015 at the Plant Propagation Laboratory, Center of Agricultural Sciences, Federal University of Alagoas, Rio Largo, AL, Brazil.

The agroforestry system of this study was characterized as agroforestry quintal in 4–6 years, which established after the elimination of secondary vegetation (without burning), planting of seeds and seedlings, management of natural regeneration, and plants preserved from the original vegetation. Considering the papaya cultivation, the main advantages include the better quality of fruits using the seeds of selected plants and by the shading other species, greater fruit production and fruit production throughout the year. According to Gliessman (2016), quintals constitute agroecological alternatives that seek to maintain the ecological balance of natural ecosystems, being configured as an improvement of food security and additional income for traditional agriculture.

Table 1. Germination (G), first count (PC) and germination speed index (IVG) of papaya seeds produced in an agroforestry system, submitted to postharvest conditions.

cv. (G)	Postharvest fruit repose (R) G (%)		
	Resting 14 days at 25 °C	Resting 14 days at 10 °C	Without rest
Tainung nº 1	100 aA	93 aA	43 aB
Sunrise Solo	97 aA	68 bB	30 bC
F interaction G X R	5.32*		
DMS G within R	2.51		
DMS R within G	3.05		
CV (%)	9.40		
cv. (G)	Postharvest fruit repose (R) PC (%)		
	Resting 14 days at 25 °C	Resting 14 days at 10 °C	Without rest
Tainung nº 1	43 aA	17 aB	1 aC
Sunrise Solo	36 bA	5 bB	0 aB
F interaction G X R	6.21**		
DMS G within R	1.16		
DMS R within G	1.41		
CV (%)	18.38		
cv. (G)	Postharvest fruit repose (R) IVG		
	Resting 14 days at 25 °C	Resting 14 days at 10 °C	Without rest
Tainung nº 1	5.100 aA	3.260 aB	1.170 aC
Sunrise Solo	4.800 aA	1.950 bB	0.780 bC
F interaction G X R	12.20**		
DMS G within R	0.33		
DMS R within G	0.40		
CV (%)	7.87		

Means followed by the same lowercase letter in the column and upper case in the row do not differ from each other to a 5% probability by the Tukey test.
*Significant at the 5% probability level.
**Significant at the 1% probability level.

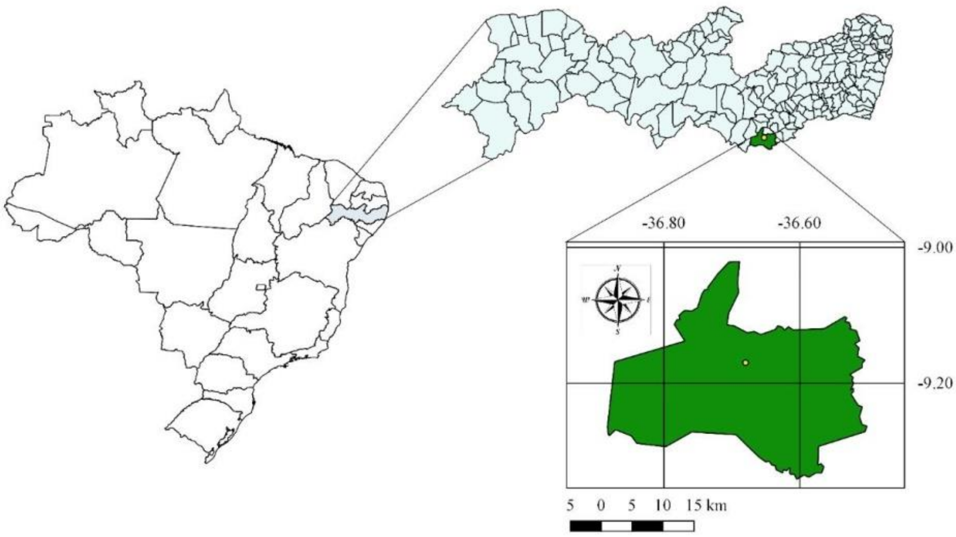

Fig 1. Geographic location of the fruit collection region.

Table 2. Average germination time (TMG) and average speed of germination (VMG) of seed, and length of seedlings (CP) of papaya produced in an agroforestry system, submitted to postharvest conditions.

cv. (G)	Postharvest fruit repose (R) TMG (days)		
	Resting 14 days at 25 °C	Resting 14 days at 10 °C	Without rest
Tainung nº 1	16.3 aA	18.1 aB	20.3 aC
Sunrise Solo	17.5 bA	20.0 bB	23.6 bC
F interaction G X R	7.43**		
DMS G within R	0.83		
DMS R within G	1.01		
CV (%)	2.89		
cv. (G)	Postharvest fruit repose (R) VMG ($days^{-1}$)		
	Resting 14 days at 25 °C	Resting 14 days at 10 °C	Without rest
Tainung nº 1	0.069 aA	0.060 aB	0.040 aC
Sunrise Solo	0.067 aA	0.057 bB	0.034 bC
F interaction G X R	722.45**		
DMS G within R	0.003		
DMS R within G	0.003		
CV (%)	4.16		
cv. (G)	Postharvest fruit repose (R) CP (mm)		
	Resting 14 days at 25 °C	Resting 14 days at 10 °C	Without rest
Tainung nº 1	80.5 aA	65.0 aB	25.2 aC
Sunrise Solo	72.7 bA	44.2 bB	4.5 bC
F interaction G X R	8.07**		
DMS G within R	0.55		
DMS R within G	0.67		
CV (%)	7.68		

Means followed by the same lowercase letter in the column and upper case in the row do not differ from each other to a 5% probability by the Tukey test. ** Significant at the 1% probability level.

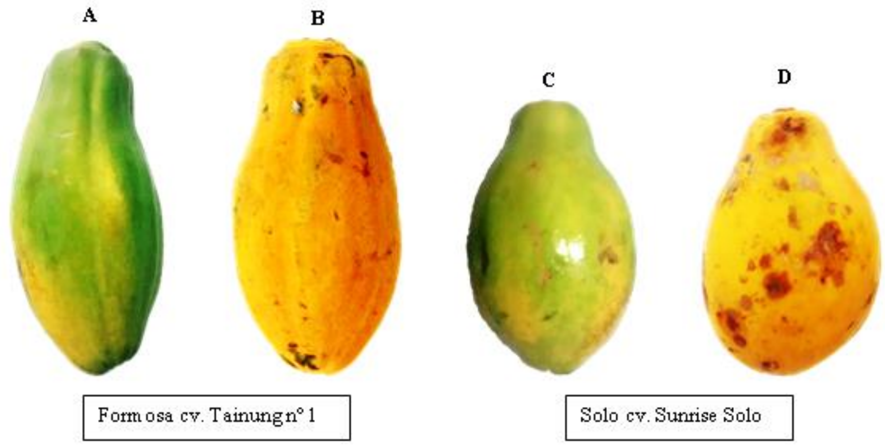

Fig. 2. Postharvest recovery of papaya fruits. A – B: Fruit Formosa stored at 10 °C and room temperature for 14 days, respectively. C – D: Fruit Solo stored at 10 ° C and room temperature for 14 days, respectively.

Plant materials

Papaya fruits, from the group Formosa, cv. Tainung nº 1 and Solo cv. Sunrise Solo, were self-fertilized and harvested as usual in the same production area during maturation stage I (up to 15% of the yellow surface), produced under an agroforestry system located in the municipality of Garanhuns, PE, at 09º 53´ 25´´ S, 36º 29´ 34´´ W, and at 896 m of altitude. According to the climatic classification of Köppen, the climate is type Aw, tropical climate with dry winter season. The geographical location of this region is presented in Figure 1.

Seeds were extracted immediately after harvesting the fruits (T_1), after 14 days of rest in a laboratory environment at room temperature (T_2), and after 14 days of rest in a controlled environment at 10 °C (T_3). The fruits were split in half and the seeds were extracted manually, and were washed with tap water to remove the pulp residues. The seeds were subjected to friction in a wire sieve using a brush of plastic bristles under running water to remove the sarcotesta, and were then placed to dry on paper towels until they reached a water content of approximately 12%; procedure adapted from Tokuhisa et al. (2008).

Germination test

For standardization of the germination test, the seed asepsis was initially performed by immersing in 70% alcohol for 1 min (Melo Jr et al., 2018), followed by washing in running water for 24 h. Thereafter, the seeds were placed to germinate between two sheets of paper towel, previously moistened with water volume equivalent to 2.5 times the weight of the dry paper, wrapped in roll form. Then, they were placed in a vertical position in a germination chamber of *biochemical oxygen demand* (B.O.D.), regulated at an alternating temperature of 20–30 °C, with an 8-h photoperiod, simulated by four 20-W daylight fluorescent lamps (Brasil, 2009).

The normal seeds were germinatedto produce seedlings. The daily germinated seed counts were performed at the same time, for 30 days, with the substrate being rewetted when necessary (Brasil, 2009).

Variables analyzed

(a) Germinability (Carvalho et al., 2005):

gi = (Σki=1ni/N) x 100, where ni is the number of seeds germinated during time i and N is the total number of seeds placed to germinate.

(b) First germination count:

This count was performed together with the germination test, computing the percentage of normal seedlings obtained on the seventh day after the test installation.

(c) Index of germination speed: (Maguire, 1962):

IVG = $G_1/N_1 + G_2/N_2 + ... + G_n/N_n$, where G_1, G_2 and G_n are the numbers of seeds germinated in the first, second, and last counts; and N_1, N_2, and N_n are the numbers of days of sowing at the first, second, and last counts.

(d) Average germination time:

t = Σki=1(niti)/Σki=1ni, where ti is the time from the beginning of the experiment to the i nth observation (days or hours); ni is the number of seeds germinated at time i (corresponding number i nth observation); and k is the last day of germination.

(e) Average speed of germination (Ranal and Santana, 2006):

$v = 1/t$, where t is mean germination time.

(f) Length of seedlings:

At the end of the germination test, the length of normal seedlings of the experimental unit was measured, using graded ruler.

Statistical procedure

The experimental design was completely randomized, in a 2 × 3 factorial scheme, 2 groups and 3 resting periods with 4 replicates of 50 seeds for each treatment. The data were subjected to analysis of variance (ANOVA), then means compared by the Tukey test at 5% probability. The analyzes were performed using Sisvar software version 5.6 (Ferreira, 2011). It was necessary to transform the percentage values in sine arc √%, but in the table the original results are presented.

Conclusions

Greater germination and vigor occured in the seeds of Formosa and Solo papaya extracted from fruits in stages V and final maturation. Harvesting fruits at stage I impaired the physiological quality of the seeds. System of agroecological production presents a systemic approach in the management of papaya.

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