Rev. FCA UNCUYO. 2013. 45(2): 299-310. ISSN impreso 0370-4661. ISSN (en línea) 1853-8665.

Fruit yield and growth parameters of several *Carica papaya* L. genotypes in a temperate climate

Rendimiento en fruto y parámetros de crecimiento en diferentes genotipos de *Carica papaya* L. bajo clima templado

Gabriel Céccoli [1, 2, 3], Elisa Soledad Panigo [1, 2, 3], Norberto Gariglio [1], Juan Carlos Favaro [1], Carlos Alberto Bouzo [1]

Originales: Recepción: 15/02/2013 - Aceptación: 02/09/2013

ABSTRACT

The aim of this work was to evaluate changes in growth and productivity parameters of different precocious hybrids and a naturalized variety of papaya under both greenhouse and field cultivation in a temperate climate (the center of the province of Santa Fe, Argentina). In view of the aforesaid, the purpose of our research was to identify further genotypes better suited for the cultivation of this species in temperate climates and demonstrate the need for the use of semi-controlled systems to make possible the cultivation of these promising genotypes in middle latitudes. The average yield was 291% higher in greenhouse than in the field. The average productivity for hybrid genotypes compared with the naturalized variety more than doubled in both environments. Considering behavior in height, leaf area index and yield parameters, hybrids H2 (principally), and H4 showed a great adaptation for use in semi-forced systems. The use of greenhouse and short stature papaya hybrids allows its feasible and surely profitable cultivation in non- tropical climates.

RESUMEN

El objetivo de este trabajo fue evaluar el crecimiento y los parámetros de productividad en diferentes híbridos precoces de papaya y en una variedad naturalizada bajo dos condiciones ambientales en una zona de clima templado (Centro de la Provincia de Santa Fe, Argentina): al aire libre y en invernadero. A partir de lo anterior, el propósito de la investigación fue identificar, además, los genotipos mejor adaptados al cultivo de esta especie en clima templado y demostrar la necesidad de la utilización de sistemas semicontrolados para hacer factible el cultivo de estos genotipos promisorios en latitudes medias. El rendimiento promedio fue un 291% superior en invernadero que al aire libre. La productividad promedio de los híbridos, comparados con una variedad naturalizada de la zona, aumentó más del doble en ambas condiciones ambientales. Considerando las variables altura, índice de área foliar y rendimiento en fruto, se concluye que los híbridos H2 (principalmente) y H4 presentaron muy buena adaptación para su uso en sistemas semi-forzados. El uso de invernaderos y de genotipos de menor estatura brinda mejores condiciones medioambientales para el crecimiento y la producción. Esto permite que el cultivo de papaya sea factible en zonas no tropicales.

1 Facultad de Ciencias Agrarias. Universidad Nacional del Litoral. Kreder 2805. Esperanza. Santa Fe, Argentina. (S3080HOF). gabrielcnbj@yahoo.com.ar; gceccoli@conicet.gov.ar
2 Instituto de Agrobiotecnología del Litoral (IAL, UNL-CONICET). Santa Fe, Argentina.
3 Consejo Nacional de Investigaciones Científicas y Técnicas (CONICET).

Keywords
semi-forced systems • tropical crop • frosts • leaf area index

Palabras clave
sistemas semi-forzados • cultivo tropical • heladas • índice de área foliar

INTRODUCTION

Papaya (*Carica papaya* L.) is a crop grown in tropical and subtropical regions (4, 27, 28), cultivated for its fruit and for the production of papain, a proteolytic enzyme of elevated commercial value (13, 18). The stem, fruit, leaves and roots of papaya are used in a wide range of medical applications (7, 15).

The genetic improvement of this species started with the first domestications carried out in the early 20th century (20, 31, 32). Between 1900 and 1960, at least 56 open pollinated varieties of papaya (20, 31, 32) were selected. In the 1990s, hybrid cultivars began to be commercialized; their main selection features were fruit size, taste, a high pulp/seed ratio, resistance to pests and diseases, early obtention of crops and dwarf plants for greenhouse use (12, 32, 34). It is precisely this latter feature that makes these genotypes interesting in the production strategies of semi-forced crops, in annual production cycles, underutilised crop regions or in areas where the climatic limitations at certain times of the year do not allow production, *e.g.*, the windy season in Guam (23).

Papaya is a polygamous species exhibiting three sex types: male (staminate), female (pistillate) and bisexual (hermaphrodite) (9, 14). In most cases, plants with hermaphrodite flowers are desired for commercial production (10, 29). Fruits from hermaphrodite flowers are usually heavier than those from female flowers, probably due to the fact that the self-pollination of the former is more effective than the cross- pollination of the latter (33). Female papaya trees are not grown commercially as a result of the reduced seed content resulting in a large air space in the seed cavity due to an ineffective cross pollination (24). In addition, the round shape of the female fruits requires greater container volume for shipping than the more slender pyriform- shaped fruit of the hermaphrodite plants (9, 14).

Papaya displays considerable phenotypic variation for many morphological and horticultural traits (28, 29). However, there are few precise data on morphological diversity in papaya in the literature (28, 29). Moreover, since this species yields high-quality products under high radiation and temperatures between 16°C and 25°C (3, 7), in Argentina it grows mainly in the Northern part of the country (1). At higher latitudes, this species encounters certain difficulties for its growth and production mainly related to the incidence of frosts, which may reduce production and cause total loss of plants (4). Even temperatures lower than 11°C adversely affect papaya growth (4, 5).

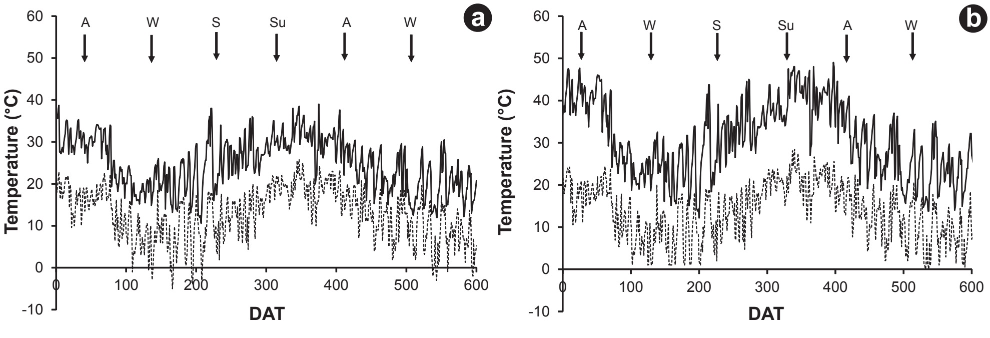
In the East central region of the province of Santa Fe, the expansion of this crop is principally limited by the occurrence of frost, but it is possible to find large samples of naturalized varieties in urban plantations with a lower incidence of frosts. The generation and subsequent use of precocious hybrids with smaller plants would facilitate the inclusion of this species both in semi-forced greenhouse systems (15) and frost-free fields (4).

The aim of this work was to evaluate changes in growth and productivity parameters of different precocious hybrids and a naturalized variety of papaya under both greenhouse and field cultivation in a temperate climate (the center of the province of Santa Fe, Argentina), as well as to identify materials best adapted to semi-forced systems in non tropical climates.

MATERIALS AND METHODS

Plant materials and cultivation conditions

The study was performed at the Experimental Field of Intensive and Forest Farming (Campo Experimental de Cultivos Intensivos y Forestales, Facultad de Ciencias Agrarias, Universidad Nacional del Litoral) (32°30' S, 62°15' W), Esperanza, Santa Fe, Argentina. Mean annual precipitation total is about 1,000 mm. Eight experimental precocious hybrids of papaya (*Carica papaya* L.) were used, supplied by Western Seed Co. Spain S. A. (Las Palmas, Islas de Gran Canaria, Spain) here described by an alpha-numeric code: H1, H2, H3, H4, H5, H7, H8, and H9. A naturalized variety (T) of the region was also included. Two environmental conditions were established: field (F) and greenhouse cultivation (GC). Multi-span greenhouses were used with vertical walls of 3.5 m and total height of 5.5 m, 30 m length and 9 m width. Each greenhouse had a floor surface covered of 270 m^2. They were heated to maintain a minimum temperature above 0°C and ventilation was natural and automatic; windows opened when the air temperature was higher than 23°C. In F, average maximum and minimum temperatures were lower than in GC, with absolute minimum temperatures of -5°C during the first year and- 3°C in the second year (figure 1a) and absolute maximum temperature of 40°C. In GC, absolute minimum temperatures were always above 1°C (figure 1b), and absolute maximum temperature of 47°C in the first year and 49°C in the second one.



The upper arrows indicate season beginning: A: Autumn; W: Winter; S: Spring and Su: Summer. DAT: Days after transplant.

Las flechas en la parte superior indican el comienzo de las estaciones del año: A: Otoño; W: invierno; S: Primavera y Su: Verano. DAT: días luego del trasplante.

Figure 1. Maximum and minimum temperature values (°C) in field (a) and in the greenhouse experiments (b).

Figura 1. Valores de temperaturas máximas y mínimas (°C) en el experimento al aire libre (a) y en invernadero (b).

Seeds were sown at warm temperatures (30°C) as described by Yahiro (38), without removing the sarcotesta (36), in pots of 1,500 cm^3. Transplantation was performed after 5 months of sowing. At this time, plants had an average height of 0.50 m and 550°Cd of thermal time accumulation (37). Plants density was 2,380.95 plants ha^{-1} obtained by a planting distance of 1.4 m between rows and 3.0 m between plants in F and 2,222.22 plants ha^{-1} obtained by a planting distance of 1.5 m between rows and 3.0 m between plants in GC. As shown, differences in plant densities between field and greenhouse conditions were due to the distance of the drip lines installed. Silt loam Molisolls (Aquic Argiudoll in both conditions) were used as growing medium. In order to prevent the possible accumulation of water and the risk of plant loss, the soil was prepared by building 0.20 m high and 0.60 m wide domes to avoid water logging (16). The drip irrigation system was accomplished by means of surface pipelines. A fertirrigation with N, P_2O_4 and K_2O was also performed according to what was recommended by Crane (9, 14).

Air temperature was measured hourly during 650 days after transplant (DAT) by means of two Davis Weather Wizard III® automatic meteorological stations, one in F and the other in GC. Mean annual radiation values were 18.1 MJ m^{-2} d^{-1} for F and 14.2 MJ m^{-2} d^{-1} for GC.

Growth and productivity variables

The experiment ended at 650 DAT. The following variables were measured: leaf area (LA) (cm^2), plant total height (cm), number of flowers at anthesis, fruits per plant (N° $plant^{-1}$), fruit weight (g $fruit^{-1}$) and variety total yield (kg $plant^{-1}$).

Leaf area was estimated, by the authors, from the following allometric equation, previously obtained for the naturalized variety:

$$\mathbf{LA\ (cm^2) = 0.89 \times (length \times width) - 49.41 \qquad (R^2 = 0.97)}$$

Then, the LA expression in m^2 $plant^{-1}$ and considering plant density (plants m^{-2}) allowed estimating the Leaf Area Index (LAI) (m^2 m^2). Plant height was taken with a graduated tape measure.

Time to flowering was recorded once plants presented first flowers at anthesis. The number of flowers at anthesis was counted, every 40 days, on 13 samplings from 19 DAT up to 544 DAT. Following Parés *et al*. (30), measurements were performed during daytime.

At the end of the experiment, productivity was quantified as the individual weight and fruit number per plant and variety total yield (in fruits with an equatorial diameter above 100 mm) as described by Pomper *et al*. (32). Five plants were randomly selected from each hybrid and repeated, the selected fruit having a diameter above 50 mm at the time of the first extraction.

Statistical design and analysis

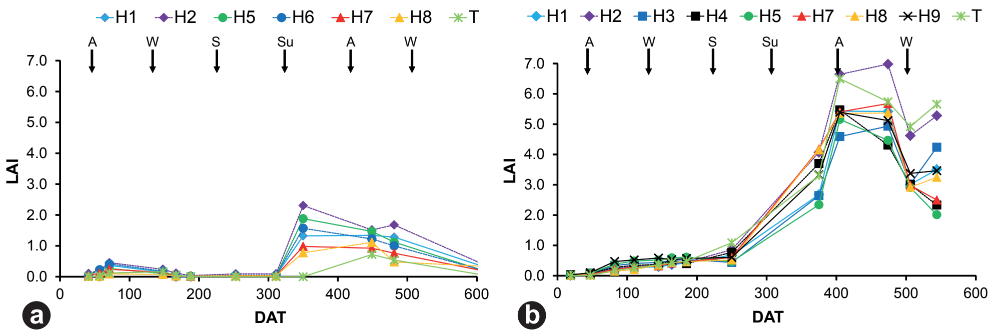
The experimental design used was randomized blocks with three blocks per treatment and 5 plants per block. In this way, 18 treatments were obtained, from a combination of 9 genotypes and 2 environments (F and GC). The statistical analysis was performed through ANOVA; the means between treatments were compared by Duncan's test, with a significance level of 5% and 1% in certain cases. The Statgraphics Plus 5.0® computer statistical program was used to perform the statistical analyses and graphs (21). ANOVA assumptions were met in all analyses.

RESULTS AND DISCUSSION

Leaf area index (LAI)

LAI was greater in GC than in F (figures 2a-2b). In F, the lower values of LAI (figure 2b) resulted in a slower growth of the plants after winter. In GC, since there were no frosts and day temperatures were higher than in F, ambient conditions in GC resembled those of tropical regions, where higher growth rates are reached. With temperatures below 15°C, this crop grows more slowly, which finally occurs at the end of autumn and beginnings of spring (22, 26, 27).

Even temperatures lower than 11°C adversely affect papaya growth (3, 4, 5, 7, 26). Given the fact that in GC temperatures were similar to those of tropical regions, but not equal, even in winter, genotypes also decreased their LAI. These low values of LAI could not only be the result of low temperatures (as in F) but also a consequence of the lower radiation received in this season of the year (winter) (figure 2a).



The upper arrows indicate season beginning. A: Autumn; W: Winter; S: Spring and Su: Summer. Some hybrids, as H8, are not shown because almost all of them were similar in leaf area index parameter.

Las flechas superiores indican el comienzo de cada estación. A: Otoño; W: Invierno; S: Primavera; Su: Verano. Algunos híbridos, como H8, no se muestran ya que casi todos los híbridos fueron similares en el parámetro índice de área foliar. Los mismos se diferenciaron claramente de la variedad naturalizada (T).

Figure 2. Evolution of the leaf area index of the cultivars in field (a) and greenhouse cultivation (b) as a function of the days after transplant (DAT).

Figura 2. Evolución del índice de área foliar de los genotipos utilizados al aire libre (F) (a) y en invernadero (GC) (b) en función de los días luego del trasplante (DAT).

When the older leaves are in a low light-intensity environment, the photosynthesis rate is reduced as the stomatic conductance dramatically decreases (3, 8). If this situation persists, with light intensities below the light compensation point, leaf abscission occurs (6).

Damage or death caused by frost starts at temperatures below -0.6°C (9, 14, 26, 27). In F, frost severity during the first year resulted in total defoliation (figure 2b, page 303) and in some cultivars, such as H3, H4 and H9, even in plant death or null yield, such as in H3, H4, H8 and H9 (table 1).

Table 1. Effect of two environmental conditions, greenhouse cultivation (GC) and field (F), upon the final accumulated yield values (kg plant^{-1}), number of fruits (N° plant^{-1}), individual weight (g fruit^{-1}) and latex production (cm^3 fruit^{-1}).
Tabla 1. Efecto de dos condiciones ambientales, cultivo en invernadero (GC) y al aire libre (FC), sobre el rendimiento en fruto por planta (kg planta^{-1}), el número de frutos (N° planta^{-1}), el peso individual de los mismos (g fruto^{-1}) y sobre la producción de látex (cm^3 fruto^{-1}).

Variety	Yield^z kg plant^{-1}		Fruits^z N° plant^{-1}		Weight^z g fruit^{-1}	
	GC**	F**	GC*	F*	GC**	F**
H1	64.4 abc	16.9 b	87 a	20 a	770.8 cd	845 c
H2	91.8 a	24.3 a	60 bc	19 a	1531.1 ab	1289 ab
H3	60.8 bc	n/d	52 bcd	n/d	1169.2 abc	n/d
H4	87.1 ab	n/d	64 b	n/d	1371.9 abc	n/d
H5	48.4 cd	21.4 a	37 cd	18 a	1341.3 abc	1189 ab
H7	44.3 cd	7.4 c	42 bcd	5 b	1052.8 bc	1480 a
H8	56.4 c	n/d	35 d	n/d	1718.9 a	n/d
H9	68.9 abc	n/d	55 bcd	n/d	1248.3 abc	n/d
T	22.3 d	7.4 c	99 a	7 b	242.1 d	1057 bc

z Means in columns followed by the same letter are not significantly different according to Duncan's test.
*, ** Significant at P< 0.05 or 0.01, respectively.
n/d no data.

z Los valores promedios en cada columna seguidos de la misma letra no presentan diferencias estadísticamente significativas de acuerdo con el Test de Duncan.
*, ** Valores con diferencias estadísticamente significativas con P< 0,05 o 0,01, respectivamente.
n/d sin datos.

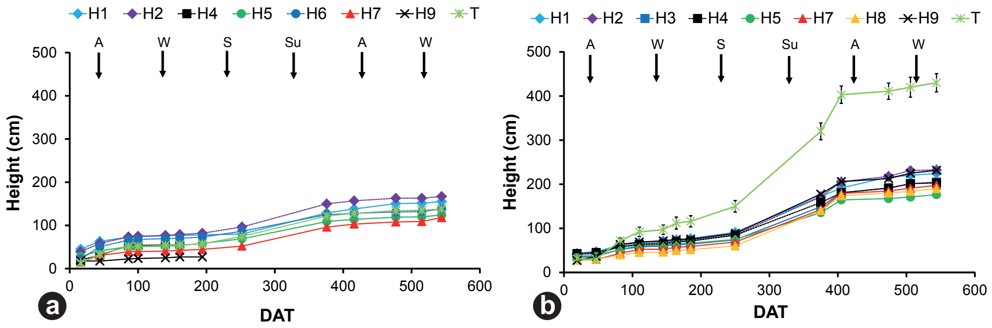
The plants in GC never presented total defoliation, different from those in F, in which the LAI was zero in winter (figure 2b, page 303). Hybrid H2 had the highest LAI both in F (in Summer) and in GC (Autumn-Winter), possibly being a genotype with good adaptation to cool conditions given its tolerance to frost and rapid regrowth with increasing temperatures, these variables being well correlated with high fruit yields (table 1).

The source/sink balance in papaya is critical for the establishment and development of fruit (6). In general, each mature leaf is able to provide photoassimilates for about three fruits (19, 35, 39). This ratio would mostly explain the yield difference obtained in GC compared to the production in F (table 1, page 304).

Height

In GC, the naturalized cultivar (T) was the tallest one, reaching 4.30 m (figure 3a) at the end of the experiment. This meant a difference above 2.00 m with respect to hybrid cultivars, among which the tallest one was H9 (2.31 m) and the smallest one, H5 (1.76 m) (figure 3a).

On the contrary, in F there were no statistically significant differences between T and hybrid cultivars (figure 3b). The behavior observed in T, which occurred in the GC microclimate explained above, also resembled the heights that plants can reach in tropical regions (9 m) (9, 11, 19, 23). The difference in height between environments could be caused by the low temperatures in F. Besides, the action of the wind could be another determining factor of this variable, since it is known that it decreases the production of leaf and stem dry matter (6, 23, 25). Therefore, the use of greenhouse would encourage vegetative growth.



The upper arrows indicate season beginning. A: Autumn; W: Winter; S: Spring; Su: Summer. The magnitude of standard deviation is indicated through bars in the T variety only.

Las flechas en la parte superior indica el comienzo de cada estación. A: Otoño; W: Invierno; S: Primavera; Su: Verano. El valor del desvío estándar se indica con las barras verticales para la variedad naturalizada T.

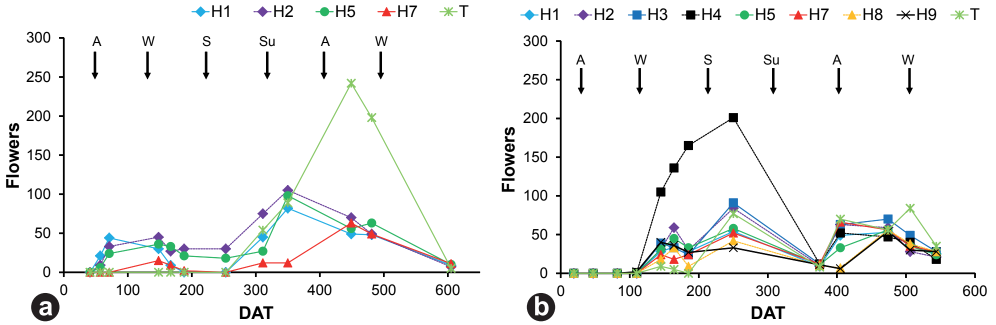
Figure 3. Changes in the average height of plants (cm) of the field (a) and greenhouse cultivation (b) conditions as a function of the days after transplant (DAT).
Figura 3. Cambios en la altura promedio de las plantas (cm) al aire libre (F) (a) en invernadero (GC) (b) en función de los días luego del trasplante (DAT).

In this trial, sensitivity differences between hybrids could be not observed. Considering that low temperatures are one of the main limitations for the expansion of papaya-cultivated areas to higher latitudes (11, 26), all hybrids genotypes could be taken into account in improvement programs, being suitable for greenhouse cultivation due to their smaller height or dwarf habitus (figure 3b). In contrast, the use of the naturalized cultivar T in GC is not recommended because of its high stature.

Floral parameters

Flowering time

During 100 DAT, there was only vegetative growth in GC (figure 4b), in agreement with what was reported by Khan *et al*. (17) for varieties of papaya in Hawaiian fields, where flowering occurs approximately at 120 DAT. In F, precocity was observed in cultivars H1, H2 and H5, with flowering starting at 45 DAT (figure 4a).



The upper arrows indicate season beginning. A: Autumn; W: Winter; S: Spring; Su: Summer.

Las flechas en la parte superior indican el comienzo de cada estación. A: Otoño; W: Invierno; S: Primavera; Su: Verano.

Figure 4. Number of flowers per plant in field (a) and greenhouse cultivation (b) cultivars.

Figura 4. Número de flores totales por planta al aire libre (a) y en invernadero (b) en los genotipos estudiados.

Genotypes T and H7 did not present this behavior (figure 4b). The differences between these two groups of genotypes (H1, H2 and H5 *vs.* T and H7) may have been caused by the maximum temperature during this period (Autumn, figure 1a, page 301), since minimum temperatures were similar under both conditions (figures 1a-1b, page 301).

Number of flowers

In this species, the available information on phenology is relatively scarce (6, 10, 17, 19). Temperatures above 32°C and below 10°C would severely affect the production of pollen and its viability (3, 4). After 200 DAT, flower production increased in GC, with no substantial modification in maximum temperatures, even though an increase in minimum temperatures was certainly observed (figure 1, page 301; figure 4b). In this period there was an increase in solar radiation coinciding with a higher LAI (figure 2a, page 303). These factors are directly involved in both an increase in the photosynthesis rate of the crop (3, 7, 8) and a greater amount of the photoassimilates available for flowering (3, 4). Only two genotypes showed differences in total number of flowers, having a high number of flowers compared with all the genotypes under study (hybrid H4 in GC between 100 and 375 DAT, figure 4b; and T in F between 300 DAT and the end of trial, figure 4a).

Fruit yield

Differences between environmental conditions

Average yields were 15.48 kg pl^{-1}in F and 60.48 kg pl^{-1} in GC (291% > in GC). Average productivity for hybrid genotypes (without taking into account T) under greenhouse conditions was 71.3 kg pl^{-1} while in F it was 17.5 kg pl^{-1}. The difference in yield was higher if the hybrid average was compared to T (307% in the hybrids and 201% in T). The yields in GC were 134 Mg ha^{-1} (expressed in Mg ha^{-1}). These values show first the production potential represented by the greenhouse production of this crop, and second, that better benefits are achieved if hybrids are used instead of naturalized materials (T). The same conclusions were arrived at with greenhouse production in the Canary Islands, where better yields and quality were obtained than in field conditions (15). Another reason for the yield in GC being higher than in F was probably due to the fact that during the winter months, the plants kept their leaves (figure 2a, page 303) whereas in F defoliation was complete (figure 2b, page 303). Although LAI in GC decreased during winter, the few leaves produced allowed the rapid growth of previously established fruits. Likewise, the growth rate of these fruits was lower than that obtained under optimal conditions (3).

Difference between genotypes

The production of fruit presented statistically significant differences between genotypes for both environmental conditions (table 1, page 304).The maximum production in GC was obtained with hybrid H2 (91.8 kg pl^{-1}) whereas in F, this genotype produced 24.3 kg pl^{-1} (table 1, page 304). The greatest production of this hybrid in both experiments was well correlated with the highest value of LAI reached at the end of the experiment mainly (450-550 DAT; figure 2, page 303). On the contrary, the naturalized material presented lower yield values. Different from hybrid cultivars, the height of this genotype in GC (figure 3a, page 305) caused that parts of the flowers were subject to temperatures above the optimal level (threshold).This could bring about flower abortion and abscission and, consequently, a lower production of fruit.

Fruit size would be a function not only of efficient pollination but also of LAI and photosynthetic activity (6, 25).Hybrid H2 had the longest production time of hermaphrodite flowers (data not shown) and presented the highest yield (table 1, page 304; figure 4, page 306) but not the highest fruit number and fruit weight. These two parameters overall led hybrid H2 to have the highest yield per plant. Moreover, it is known that both variables are not independent from one another because the fruit average weight partly depends on the number of fruit present (6, 25).

Cultivar T in GC obtained the highest number of fruit per plant and, accordingly, the lowest weight per fruit (table 1, page 304). Although LAI in T was high (figure 2a, page 303), when the average foliar area was related to the number of fruit per plant during the whole experiment, the latter was one of the lowest (1107 cm^2 of leaf per established fruit), thus showing the high efficiency of this genotype for the establishment of fruit per foliar area unit (data not shown). On the contrary, hybrids H2 and H8 presented the highest individual weight per fruit (1.531 and 1.718 kg $fruit^{-1}$, respectively) (table 1, page 304) but the ratio average leaf surface to fruit was 1764 cm^2 and 2318 cm^2 of leaf per fruit. Beyond the commercial need of obtaining bigger fruit, genotype T would have a better efficiency in the source/sink ratio, *e.g.* a higher capacity of producing fruit per foliar surface area. As observed for other species, obtaining a better efficiency in the source/ sink ratio is detrimental to fruit weight (2, 6, 25).

Hybrid H2 could be a good candidate for use in semi-forced systems just as it is good for greenhouse utilization. This claim is sustained by the fact that it had the best performance with the parameters measured, high weight of fruits per plant and intermediate number of fruits per plant compared with the other genotypes.

The decrease in fruit number per plant was the main component explaining the lesser yield in F. In the genotypes which tolerated low temperatures in F and then regrew (H1, H2, H5, H7 and T), this variable was 79% lower in F than in GC. Considering survivor genotypes in F, fruit weight did not explain the decrease in yields between F and GC. On the contrary, there was an increase in the average weight fruit in F of about 19% compared with GC. (table 1, page 304). This increase in fruit weight in F compared with GC was not enough to compensate the greater decrease in fruit number, leading to a steep decline in fruit number per plant (table 1, page 304).

CONCLUSIONS

Environmental factors profoundly affect growth and productivity parameters in papaya. Therefore, an accurate understanding of the interaction between environmental conditions and the different genotypes is extremely important for the profitable, sustainable production of this plant.

Considering the LAI parameter, hybrid H2 had the highest values in F (in Summer) and in GC (Autumn-Winter), possibly being a genotype with good adaptation to cool conditions given its tolerance to frost and rapid regrowth with increasing temperatures.

Considering the height parameter, all hybrid genotypes could be taken into account in improvement programs, being suitable for greenhouse cultivation due to their smaller height or dwarf behavior.

Considering the number of flowers, hybrid H4 had the highest value, correlating well with a high yield.

The higher temperatures and the non-existence of temperatures that might cause frost in GC allowed all genotypes to obtain higher yields than in F. The average productivity of hybrid genotypes compared to that of the naturalized variety was more than double in both environments. In the same way, average productivity for hybrid genotypes under greenhouse conditions was 71.3 kg pl^{-1} while in F it was 17.5 kg pl^{-1}. The average yields obtained with greenhouse hybrids indicate their productive potential when they are placed under optimal environmental conditions.

Considering behavior in height, LAI and yield, hybrids H2 and H4 presented a high level of adaptation. These genotypes were the most promising ones in the greenhouse production of papaya in temperate climates.

Finally, we would like to emphasize the need for carrying out this crop under semi-forced systems in temperate climate latitudes (as the area studied in this work) where outdoor growing is not feasible. The use of greenhouse and short stature papaya hybrids allows its feasible and surely profitable cultivation in non-tropical climates.

REFERENCES

1. Acuña, L. 2007. El cultivo del mamón (*Carica papaya* L.). Frutales Alternativos. E.E.A. INTA Montecarlo. Misiones, Argentina.
2. Alkio, M.; Schubert, A.; Diepenbrock, W.; Grimm, E. 2003. Effect of source-sink ratio on seed set and filling in sunflower (*Helianthus annuus* L.). Plant Cell and Environment. 26: 1609-1619.
3. Allan, P. 2002. *Carica papaya* responses under cool subtropical growth conditions. Acta Horticulturae. 575: 757-763.
4. Allan, P. 2007. Phenology and production of *Carica papaya* Honey Gold under cool subtropical conditions. Acta Horticulturae. 740: 217-223.
5. Almeida, F. T.; Salassier, B.; Fernandes de Sousa, E.; Marin, S. L. D.; Grippa, S. 2003. Growth and yield of papaya under irrigation. Scientia Agricola. 60: 419-424.
6. Campostrini, E.; Glenn, D. M. 2007. Ecophysiology of papaya: a review. Brazilian Journal of Plant Physiology. 19: 413-424.
7. Castillo, B.; Smith, M. A. L.; Madhavt, D. L.; Yadava, U. L. 1997. Interactions of irradiance level and iron chelate source during shoot tip culture of *Carica papaya* L. HortScience. 32: 1120-1123.
8. Clemente, H. S.; Marler, T. E. 1996. Drought stress influences gas-exchange responses of papaya leaves to rapid changes in irradiance. Journal of American Society Horticultural Science. 12: 292-295.
9. Crane, J. H. 2005. Papaya Growing in the Florida Home Landscape, University of Florida. Hort. Sci. Dept, HS 11. Florida, IFAS Extension: p. 1-8.
10. Deputy, J. C.; Ming, R.; Ma, H.; Liu, Z.; Fitch, M. M. M.; Wang, M.; Manshardt, R.; Stiles, J. I. 2002. Molecular markers for sex determination in papaya (*Carica papaya* L.). Theoretical and Applied Genetics. 106: 107-111.
11. Dhekney, S. A.; Litz, R. E.; Moraga, D.; Yadav, A. 2007. Is it possible to induce cold tolerance in papaya through genetic transformation? Acta Horticulturae. 738: 159-164.
12. Drew, R. A.; Magdalita, P. M.; O'Brien, C. M. 1998. Development of Carica interspecific hybrids. Acta Horticulturae. 461: 285-292.
13. Espin, N.; Islam, M. N. 1998. Stabilization of papain from papaya peels. Food Science and Technology International. 4: 179-187.
14. Fitch, M. M. M.; Moore, P. H.; Leong, T. C. W.; Akashi, L. A. Y.; Ych, A. K. F.; White, S. A.; De la Cruz, A. S.; Santo, L. T.; Ferreira, S. A.; Poland, L. J. 2005. Clonally propagated and seed-derived papaya orchards: I. Plant production and field growth. HortScience. 40: 1283-1290.
15. Galán Saúco, V.; Rodríguez Pastor, M. A. C. 2007. Greenhouse cultivation of papaya. Acta Horticulturae. 740: 191-195.
16. González Cárdenas, J. C.; Maruri García, J. M.; González Acosta, A. 2005. Antagonistic comparison of *Trichoderma spp*. against *Fusarium oxysporum*, causal agent of damping off of seedlings in papaya in Tuxpan, Veracruz, México. Revista Científica UDO Agrícola. 5: 45-47.
17. Khan, S.; Tyagi, A. P.; Jokhan, A. 2002. Sex ratio in Hawaiian papaya (*Carica papaya* L.) variety 'Solo'. South Pacific Journal of Natural Science. 20: 22-24.
18. Krishnaiah, D.; Awang, B.; Rosalam, S.; Buhri, A. 2002. Commercialization of papain enzyme from papaya. Proc. of the Reg. Symp. on Environmental and Natural Resources. April 10-11, Hotel Renaissance Kuala Lumpur, Malaysia. p. 244-250.
19. Malo, S. E.; Campbell, C. W. 1986. The papaya. University of Florida, Cooperative Extension Service Fruits Crops Fact Sheet FC-11. Gainesville.
20. Manshardt, R. M.; Drew, R. A. 1998. Biotechnology of Papaya. Acta Horticulturae. 461: 65-73.

21. Manugistics Inc. 2000. Statgraphics Plus 5. Manugistic Product, Rockville, Maryland, USA.
22. Marin, S. L. D.; Gomez, J. A.; Salgado, J. S.; Martins, D. S.; Fullin, E. A. 1995. Recomendações para a cultura do mamoeiro dos grupos Solo e Formosa no Estado do Espírito Santo. 4.ed. Vitória: EMBRAPA, Brasil.
23. Marler, T. E. 2011. Growth responses to wind differ among Papaya roots, leaves and stems. HortScience. 46: 1105-1109.
24. Ming, R.; Yu, Q.; Moore, P. H. 2007. Sex determination in Papaya. Seminars in Cell and Developmental Biology. 18: 401-408.
25. Mora, E.; Bogantes, A. 2004. Evalución de híbridos de papaya (*Carica papaya* L.) en Pococí, Limón, Costa Rica. Agronomia Mesoamericana. 15: 39-44.
26. Muthulakshmi, S.; Balamohan, T. N.; Amutha, R.; Rani, W. B.; Mareeswari, P.; Indira, K. 2007. Breeding for Cold Tolerance in Papaya (*Carica papaya* L.) through Hybridization. Research Journal of Agriculture and Biological Science. 3: 264-266.
27. Nakasone, H. Y.; Paull, R. E. 1998. Tropical Fruits. In: Crop production science in horticulture series, Vol. 7, CAB International, Wallingford, England.
28. Niklas, K. J.; Marler, T. E. 2007. *Carica papaya* (Caricaceae): A case study into the effects of domestication on plant vegetative growth and reproduction. American Journal of Botany. 94: 999-1002.
29. Ocampo, J.; d'Eeckenbrugge, G. C.; Bruyère, S.; de Lapeyre de Bellaire, L.; Ollitrault, P. 2006. Organization of morphological and genetic diversity of Caribbean and Venezuelan papaya germplasm. Fruits. 61: 25-37.
30. Parés, J.; Basso, C.; Jáuregui, D. 2002. Momento de antesis, dehiscencia de anteras y receptividad estigmática en flores de lechosa (*Carica papaya* L.) cv. 'Cartagena Amarilla'. Bioagro. 14: 17-24.
31. Peterson, R. N. 1991. Pawpaw. Acta Horticulturae. 290: 567-600.
32. Pomper, K. W.; Layne, D. R.; Peterson, R. N.; Wolfe, D. 2003. The pawpaw regional variety trial: background and early data. HortTechnology. 13: 412-418.
33. Rodríguez Pastor, M. C. 2002. Consideraciones sobre la utilización de diferentes densidades en el cultivo de papaya (*Carica papaya* L.) Baixinho de Santa Amalia en Islas Canarias. Revista Brasileira de Fruticultura. 24: 707-710.
34. Rodríguez Pastor, M. C.; Lobo Rodrigo, M. G.; Suárez Sánchez, C. L. 2010. Comportamiento de los cultivares de papaya Sunset, Sunrise y de los genotipos Baixinho de Santa Amalia y BH-65 en la zona sur de la isla de Tenerife. Revista Brasileira de Fruticultura. 32: 1105-1115.
35. Salazar, R. 1978. Determination of photosynthesis in commercial varieties of pawpaw (*Carica papaya* L.) and its possible relationship with the production and quality of the fruits. Rev. ICA. 13: 291-295.
36. Salomão, A. N.; Mundim, R. S. 2000. Germination of Papaya seed in response to desiccation, exposure to subzero temperatures, and gibberellic acid. HortScience. 35: 904-906.
37. Vázquez García, E.; Román Avendaño, E.; Ariza Flores, R. 2008. Fenología y unidades calor de genotipos de papaya en el sur de Tamaulipas, México. Rev. Fitotec. Mex. 3145-48.
38. Yahiro, M. 1979. Effects of seed pre-treatments on the promotion of germination in papaya, *Carica papaya* L. Mem. Fac. Agr. Kagoshima 15: 49-54.
39. Zhou, L.; Christopher, D. A.; Paull, R. 2000. Defoliation and fruit removal effects on papaya fruit production, sugar accumulation, and sucrose metabolism. Journal of the American Society of Hort Science. 125: 644-652.

Acknowledgments

To Universidad Nacional del Litoral for the support in supplying the infrastructure and equipment needed to carry out this research study.

To CONICET (Consejo Nacional de Investigaciones Científicas y Técnicas) for allowing G. Céccoli and E. S. Panigo devote time to the processing and realization of this work.

To Dr. Abelardo Vegetti for his useful comments and advice.