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Crop production

Protected cultivation of 'BH-65', 'Siluet', 'Sensation', 'Intenzza' and 'Red Lady' papaya cultivars in South East Spain

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Abstract - Papaya (*Carica papaya* L.) is a tropical fruit crop of rapid growth and early yielding. In recent years, papaya cultivation has extended to subtropical regions due to its commercial interest. In South East Spain, protected cultivation is, however, mandatory to ensure the optimal development of the crop. Even more, to assure profitability, the selection of plant material well adapted to the structural constrains and the climatic conditions inside greenhouses is essential. With this objective, different papaya cultivars with diverse geographical origin, characteristics and pedigree have been compared. 'BH-65', 'Siluet', 'Sensation', 'Intenzza' and 'Red Lady' papaya cultivars were thus grown under a plastic greenhouse in Almería, SE Spain and their growth, phenology, yield and fruit quality compared in a 21-month production cycle. The results showed that 'Siluet' and 'Sensation' papayas are well-adapted to greenhouse protected cultivation, produce high yield, and optimal fruit quality for long and short distance markets. Cultivars like 'BH-65' could be of interest for low-height greenhouses due to its reduced plant vigor and high fruit quality. However, 'BH-65' yield is low. According to the European consumer preferences, the cultivation of 'Siluet' and 'Sensation' is recommended, for the harsh conditions the greenhouse cultivation imposes in subtropics.
Index terms: *Carica papaya* L.; fruit quality; protected cultivation; variety trials; yield.

Um novo modo mais lucrativo para o cultivo de mamoeiro selecionando as melhores variedades para o cultivo em estufa

Resumo – O mamoeiro (*Carica papaya* L.) é uma fruteira tropical de rápido crescimento e de produção precoce. Nos últimos anos, o cultivo de mamão estendeu-se às regiões subtropicais devido ao seu interesse comercial. No sudeste da Espanha, o cultivo protegido é, no entanto, necessário para garantir o desenvolvimento ideal da colheita. Ainda mais, para garantir rentabilidade, é essencial a seleção de material vegetal bem adaptado às restrições estruturais e às condições climáticas dentro das estufas. Com esse objetivo, diferentes cultivares de mamoeiro, com diversas origens geográficas, características e genealogia, foram comparadas. As cultivares de mamoeiro 'BH-65', 'Siluet', 'Sensation', 'Intenzza' e 'Red Lady' foram cultivadas em uma estufa plástica em Almeria, sudeste da Espanha, e seu crescimento, fenologia, produtividade e qualidade do fruto foram comparados em um Ciclo de produção de 21 meses, iniciado em junho de 2014 e encerrado em fevereiro de 2016. Os resultados mostraram que as cultivares 'Siluet' e 'Sensation' estão bem adaptadas ao cultivo protegido em estufa, produzem alto rendimento e ótima qualidade de frutos para longas e curtas distâncias dos mercados. Cultivares como 'BH-65' podem ser de interesse para estufas de baixa altura, devido ao vigor reduzido das plantas e à alta qualidade dos frutos. No entanto, o rendimento 'BH-65' é baixo. De acordo com as preferências dos consumidores europeus, o cultivo de 'Siluet' e 'Sensation' é recomendado pelas duras condições que o cultivo em estufa impõe nos subtrópicos.
Termos para Indexação: *Carica papaya* L.; qualidade das frutas; cultivo protegido; ensaios de variedades; produção.

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Introduction

Papaya (*Carica papaya* L.) is a tropical fruit crop of rapid growth but short commercial life, which may reach 9 m height in a relatively short time (CAMPOSTRINI AND GLENN, 2007). Papaya is a trioecious species, with male, female and hermaphroditic plants, the latter producing diverse floral types in response to their genetic background and environmental factors (CANCELA et al., 2011). Hermaphrodite plants are, nonetheless, preferred because of its higher commercial value (ALLAN et al., 1987; JIMÉNEZ et al., 2014). Despite considered a fruit crop, papaya is a giant herb of semi-hard wood able to produce fruit in just a few months after sowing. This early production in addition to heavy yields, best-selling price and low labour costs in comparison to vegetables, make papaya an attractive alternative to the annual crops usually grown in greenhouses. These characteristics, attached to the nutritional value of its fruit (TEIXEIRA et al., 2007), make papaya an interesting crop worldwide.

Nowadays, papaya is the third most produced tropical fruit in the world. The cultivated area worldwide is around 440,000 ha, with 13.1 million tonnes of papaya produced (FAO, 2019). Its cultivation stands out in countries like India, Brazil, Indonesia, Nigeria or Mexico, which also participate in the international market as papaya exporters (CORONA, 2011; EVANS; BALLEN, 2012). Mexico dominates the international market of papaya (CBI MARKET INTELLIGENCE: MINISTRY OF FOREIGN AFFAIRS, 2015), although Brazil is the main supplier for Europe, providing more than 30,000 tonnes per year. In Europe, the main papaya importers are Netherlands, with more than 10,000 tonnes per year, Portugal, United Kingdom and Spain, which imports around 6,000 tonnes per year each one (QLIK FRESH, 2017). In Spain, papaya exhibits an increasing demand and represents an interesting complement to the production of vegetables in greenhouses. Here, protected cultivation is mandatory to produce profitably papaya because the low temperatures in winter and higher than optimal temperature in summer characterizing Mediterranean climates.

The objective of this work was to select papaya cultivars able to satisfy European market demand and well adapted to the limitations that greenhouse cultivation imposes in Mediterranean climates.

Materials and methods

This study was carried out in a plastic greenhouse located at the Cajamar Experimental Station 'Las Palmerillas', sited in El Ejido (Almería, Spain) (2°43'W, 36°48'N and 151 m above sea level). The greenhouse was a multi-tunnel type with eight chapels 7.5 m wide each, E-W oriented and covered with low density polyethylene. The greenhouse used for the experiment had 3.4 m height to the eaves and 5.4 m to the ridge. Natural ventilation through one zenithal window per chapel and two laterals panels improved climate conditions inside the greenhouse. Temperature and relative humidity inside the greenhouse were recorded during the experiment, setting to 24 ºC the temperature to start greenhouse windows' opening. Windows' opening was managed through a Priva weather controller.

In this greenhouse, different papaya cultivars already under cultivation in Spain were compared. 'BH-65', 'Siluet', 'Sensation', 'Intenzza' and 'Red Lady' were selected as the most promissory commercial papaya cultivars based on farmers selection and due to their differential growth habit and fruit characteristics. Hermaphrodite plants propagated from seeds were utilized following a conventional sex-determining procedure (MING et al., 2007). Plants spacing was 2.5 x 1.5 m. The plantation cycle was initiated the 5th June, 2014, and terminated at 26th February, 2016.

Plant height from ground to the canopy top, and trunk perimeter at 15 cm from the ground, were measured every other three months using a graded bar and a seamstress tape ruler, respectively. The distance from the ground to the first flower and fruit were also recorded using a seamstress tape ruler. The days from planting to flowering, and from flowering to harvest were counted. The seasonal frequency of elongata, pentandric and carpelloid hermaphrodite flowers, and of female and functionally male flowers (Storey 1941), were seasonally recorded in winter (December 2014), spring (March 2015), summer (June 2015) and autumn (September 2015). The results were expressed in percentage. Finally, initial fruit set was determined by counting the number of growing fruitlets in the last five nodes below just opened flowers and expressed as the number of fruitlets per node.

Total and commercial yield, and the percentage of discard (non-commercial misshapen fruits and fruits lighter than 200 g), the number of fruits per plant and its average weight in each cultivar were compared at the end of the cycle. Fruits were harvested when they reached a 50% of the skin with yellow color.

Papaya fruit quality was evaluated considering the maturity stage recommended according to market distance: fruit with 50-60% yellow (Stage 2) for short distance markets (PINILLOS et al., 2017). Sixteen fruit per cultivar and maturity stage were harvested between May and July 2015. Fruit weight was determined using a precision balance (d = 0.1 g). Length (distance from the insertion point of peduncle to the scar of the flower), maximum equatorial diameter and cavity width were measured with a digital calliper. Pulp firmness was assessed using a texturometer (model EG-50, Mark-10, Co., USA) with a plunger 8-mm diameter and a speed of 20 mm per minute. Two measurements per fruit were taken in opposite equatorial zones of the fruit after peel removal. Firmness was considered as the maximum flesh penetration force, expressed in Newtons (N). Total soluble solids content (TSS) and titrable acidity were measured in the juice of each fruit collected. TSS was measured using a digital refractometer (model PR-101, Atago Co., Japan) and the results expressed in °Brix. Titrable acidity was determined by titration with 0.1 N NaOH using phenolphthalein as indicator. The data were expressed as g of citric acid per L. Finally, skin and pulp color were measured using a colorimeter (model CR-400, Konica Minolta, Co., Japan) in three points of the equatorial zone of each fruit. The results were expressed according to its hue angle (hue°). Hueº indicates the color tone of the fruit, so that an angle of 120º corresponds to yellowish-green color, 90º yellow color, 60º yellow-orange color, 45º orange color and 0º red color.

A randomized complete block design with four replicates was followed. Each replicate was constituted by a tree row in which the four central trees were selected for measurements. The data were subjected to analysis of variance (ANOVA) and the means separated by Tukey’s Test using Statistix 8.0 software (Analytical Software, Tallahassee, Florida, USA).

Results and discussion

Plants height increase followed a sigmoid curve in all cultivars (Figure 1-A). This curve is the result of a phase of rapid growth in the juvenile stage followed by a slow down after July when first fruit started to grow and approached maturation. In the first phase of rapid growth, a lower rate was noted in winter (between December and March) after which an accelerated growth was regained, when environmental conditions improved. Despite the changes in growth rates, the increase in plant height was also well predicted using simple linear equations with coefficients of determination (R^2) between 0.92 and 0.97.

Comparing cultivars, ‘BH-65’ reached the lowest height at the end of the trial, being significantly lower than the others (Figure 1-A). ‘BH-65’ low height can be advantageous in terms of crop management and harvesting reducing thus labour costs (ALONSO et al., 2008; RODRÍGUEZ et al., 2010). On the other side, ‘Siluet’, ‘Sensation’ and ‘Red Lady’ reached final heights close to 400 cm. No significant differences were observed among them regarding plant height. ‘Intenzza’ plants ended the experiments at 440 cm height (Figure 1-A). The extraordinary vigor and rapid growth of papaya plants limits orchard plant density and makes more difficult crop management, especially when grown in greenhouses.

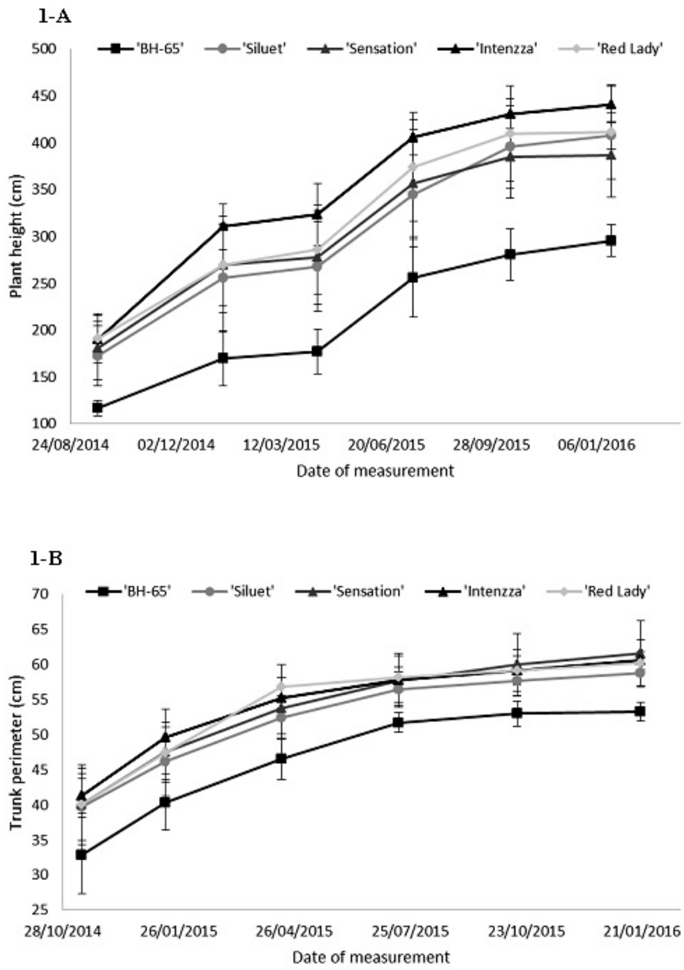

Figure 1. Changes along the season in plant height (**1-A**) and trunk perimeter (**1-B**) in ‘BH-65’, ‘Siluet’, ‘Sensation’, ‘Intenzza’ and ‘Red Lady’ cultivars grown under a plastic greenhouse. Symbols represent mean values. Bars represent standard deviations.

Trunk perimeter growth was similar in all cultivars (Figure 1-B). In general, trunk increase was faster during the first year of the plantation, growing fast even during winter, but slowing down when fruit development started (Figure 1-B). Little growth occurred during the second year of cultivation. Despite this slow down, the increase in trunk perimeter was well described again by linear equations with R^2 values above 0.82. A clear improvement was noted, however, when growth was defined using sigmoid curves (R^2 between 0.96 and 0.98 depending of the cultivar).

The differences in plant vigour among cultivars were slight and non-significant, except for 'BH-65', whose trunk perimeter and plant height were lower in all seasons and measurements (Figure 1). At the end of the cycle, the trunk perimeter of 'BH-65' was significantly lower than the trunk perimeter in 'Sensation', 'Intenzza' and 'Red Lady'. 'Siluet' had an intermediate trunk perimeter (Figure 1-B). The analyses of correlation performed indicate that trunk perimeter and plant height are good indicators of yield potential, influencing the number and size of the fruit produced. However, yield also depends of the adaptation of the cultivar to the environmental conditions where they grow (OLUFEMI et al., 2016), since poorly adapted cultivars fail to set fruit and/or produce many alterations in flower development and hence non-commercial misshapen fruit as was in fact common in 'BH-65'.

The lowest insertion points for the first flower and fruit was observed in 'BH-65', reaching significant differences compared to taller cultivars such as 'Red Lady', 'Sensation' and 'Intenzza' cultivars (Table 1). 'Siluet' bloomed and set first fruit at intermediate heights. Besides, the height of the first flower appearing and the height where the first fruit developed were very similar in 'BH-65' and 'Siluet', suggesting good setting and little fruit abortion at the first reproductive nodes. 'Sensation' and 'Intenzza' showed a small distance between the node in which first flower appeared and where and the first fruit set. On the contrary, in 'Red Lady' this separation was well above 20 cm distance. Planting date influences this parameter, since determines the moment in which first flowers appear, as well as the prevailing environmental conditions that affect the type and fertility of the flowers. All cultivars studied set two fruit per node, except 'Red Lady' that formed only one. These differences were non-significant. The differences in flowering date (~78 days after planting) and the beginning of harvest date (~228 days after planting) were not significant either (Table 1).

Table 1. Morphological features of 'BH-65', 'Siluet', 'Sensation', 'Intenzza' and 'Red Lady' papaya cultivars grown under a plastic greenhouse.

Cultivar	'BH-65'	'Siluet'	'Sensation'	'Intenzza'	'Red Lady'
Distance to first flower (cm)*	56.6 b	76.0 ab	83.5 a	83.8 a	82.0 a
Days from planting to flowering	81 a	78 a	81 a	76 a	74 a
Days from flowering to harvest	226 a	229 a	223 a	231 a	233 a
Distance to first fruit (cm)*	56.8 b	76.8 ab	87.1 a	85.1 a	103.1 a
Fruit per node	1.8 a	2.0 a	1.7 a	1.8 a	1.1 a

[1]Different letters in the same row indicate statistically significant differences between papaya cultivars (Tukey's Test $p<0.05$).* From the ground

Elongata hermaphrodite flowers are those that produce the fruit with the best quality in papaya. Considering the total number of flowers in anthesis, the frequency of the different flower types varied according to the adaptation of the different genotypes trialled to the environmental conditions prevalent in each season, specially temperature (CANCELA et al., 2011). 'Siluet', 'Sensation' and 'Intenzza' were the cultivars best-adapted to the conditions imposed by protected cultivation. Spring conditions were especially good for them, as suggested by the high percentages of elongata flowers produced in June (70-80%) (Figure 2). Autumn is also a good season for producing good-quality flowers and high setting in the greenhouses of Almería. 'Siluet' seemed well-adapted to greenhouse cultivation, with between 30-70% of elongata flowers depending on the season (Figure 2). 'Red Lady' and 'BH-65' were worse-adapted, showing a high frequency of flowers without commercial interest (pentandric, carpelloid and male flowers) (Figure 2).

Figure 2. Seasonal frequency (%) of elongata (green), pentandric (orange) and carpelloid (red) hermaphrodite flowers, and female (white) and functionally male (gray) flowers found in ‘BH-65’, ‘Siluet’, ‘Sensation’, ‘Intenzza’ and ‘Red Lady’ cultivars grown under a plastic greenhouse. Rings from inside to outside: winter (December), spring (March), summer (June) and autumn (September) sampling dates.

Harvest started in April 2015, when first fruits reached 30-50% of the skin yellow. From then on, harvest continued uninterrupted until the end of the experiment, with two peaks of production in spring (March-June) and autumn (September-October). These production peaks are the result of good flowering and setting happening six months before (GUNES; GÜBBÜK, 2011). During summer, yield was scarce, as it was during winter (data not shown). This suggests that on certain dates the supply of papayas in Spain can be scarce and only supported by growing papayas in different locations with different climates. Climate control inside the greenhouse using heating systems in winter is also an option to reduce unfruitful empty-of-fruit trunk sections observed the following summer (SALINAS et al., in prep). At the end of the experiment, ‘Intenzza’, ‘Siluet’ and ‘Sensation’ were statistically the most productive cultivars, while ‘BH-65’ and ‘Red Lady’ had the lowest commercial yield. ‘Intenzza’, ‘Siluet’ and ‘Sensation’ produced a high number of fruits per plant and low discards. These figures were especially noteworthy for ‘Siluet’ and ‘Sensation’, with more than 80 fruit per plant and only 10% of them discarded for being non-commercial. In addition, the average fruit weight was close to 800 g, meeting European market’s demand of papayas lighter than 1 kg (Table 2). Experiments performed under mesh in the Canary Islands show similar yields for ‘Siluet’, ‘Sensation’ and ‘Intenzza’ (PÉREZ, 2016; GARCÍA; ACOSTA, 2017).

Table 2. Total and commercial yield, discard (%), fruit per plant and fruit weight in 'BH-65', 'Siluet', 'Sensation', 'Intenzza' and 'Red Lady' papaya cultivars grown under a plastic greenhouse.

Cultivar	Total yield (kg m^{-2})	Commercial yield (kg m^{-2})	Discards (%)	Fruit per plant	Fruit weight (g)
'BH-65'	10.4 c	9.1 b	13 b	70 a	483 d
'Siluet'	18.5 ab	16.7 a	10 b	81 a	781 c
'Sensation'	21.4 ab	19.1 a	11 b	83 a	862 bc
'Intenzza'	22.3 a	18.7 a	16 b	76 a	938 b
'Red Lady'	17.1 b	10.9 b	36 a	26 b	1558 a

[1]Different letters in the same column indicate statistically significant differences between papaya cultivars (Tukey's Test $p<0.05$).

Quality of fruit collected at the maturation stage recommended by Pinillos et al. (2017), showed physical and physicochemical differences among papaya cultivars. The results confirmed a clear relationship between fruit size and plant vigour (Table 3). Cultivars with greater vigour produced fruit heavier than 1 kg ('Intenzza' and 'Red Lady'), while 'BH-65', the less vigorous cultivar, produced fruit of less than 500 g (Table 4). This relationship can be demonstrated by the significant correlation between plant height and trunk diameter and fruit weight and length (Table 3). This significant relationships may explain partially yield, if fruit set is not compromised. Similar results were obtained for an earlier stage of maturation, stage 1 in which the fruit had up to 30% of the skin yellow (data not shown).

Table 3. Pearson correlation coefficients between vigour (plant height (PH) and trunk perimeter (TP)) and fruit size (weight (FW), length (HL) and diameter at harvest (HD)). Correlation analyses were performed using the replicate results for 'BH-65', 'Siluet', 'Sensation', 'Intenzza' and 'Red Lady' cultivars.

Coefficient between FW and PH	Coefficient between FW and TP	Coefficient between HL and PH	Coefficient between HD and PH	Coefficient between HL and TP	Coefficient between HD and TP
0.5865*	0.6298*	0.8192*	0.0909	0.6270*	0.3314

*Values having superscript are significantly different under the limit of $p \leq 0.05$

Table 4. Fruit size in 'BH-65', 'Siluet', 'Sensation', 'Intenzza' and 'Red Lady' papaya cultivars. Maturity stage: Stage 2 (fruit 50-60% yellow).

Cultivar	'BH-65'	'Siluet'	'Sensation'	'Intenzza'	'Red Lady'
Weight (g)	499 b	925 a	817 a	1083 a	1054 a
Length (cm)	14.1 b	20.5 a	19.5 a	22.3 a	21.6 a
Diameter (cm)	9.6 b	9.7 b	11.1 a	10.1 ab	10.8 ab
Cavity width (cm)	4.8 b	4.9 ab	6.0 ab	5.3 ab	6.2 a

[1]Different letters in the same row indicate statistically significant differences between papaya cultivars (Tukey's Test $p<0.05$).

Fruit length and equatorial diameter, as well as weight, determine the shape and size of each cultivar. Pear-shaped fruit of 700-900 g, preferred in Europe, were obtained in 'Siluet' and 'Sensation'. 'BH-65' also formed fruit with optimal shape and size (Table 4). Firmness in fruit harvested in Stage 2 were lower than firmness measured in fruit harvested in an earlier maturity stage (data not shown), especially in 'Sensation' and 'Intenzza' (47.3 and 18.2 N, respectively) (Table 5). These latter values evidence the limited postharvest life of the fruit of these two cultivars. At that time, total soluble solids content (SST) ranged between 9.7 and 11.6 ºBrix (Table 5), close to the minimum required for papaya (10 ºBrix). Acidity was scarce and of little relevance in the comparison among cultivars (Table 5). Finally, skin color showed marked differences between maturation stages, being fruit more orange in Stage 2 than in an earlier maturity stage, i.e. presenting lower hueº values. Pulp color evidenced the reddest pulp of 'Red Lady' fruit when fully mature (Table 5).

Table 5. Fruit quality in 'BH-65', 'Siluet', 'Sensation', 'Intenzza' and 'Red Lady' papaya cultivars. Maturity stage: Stage 2 (fruit 50-60% yellow).

Cultivar	'BH-65'	'Siluet'	'Sensation'	'Intenzza'	'Red Lady'
Firmness (N)	111.5 a	76.8 ab	47.3 bc	18.2 c	87.6 ab
TSS (°Brix)	10.3 ab	10.2 ab	9.7 b	10.1 ab	11.6 a
Titratable acidity (g citric acid L^{-1})	0.99 b	0.61 c	0.54 c	0.77 bc	1.31 a
Skin color (hue°)	94.9 a	84.5 a	80.7 a	85.4 a	81.0 a
Pulp color (hue°)	58.3 a	59.7 a	58.6 a	56.2 a	48.9 b

[1]Different letters in the same row indicate statistically significant differences between papaya cultivars (Tukey's Test $p<0.05$).

It is noteworthy to comment that all cultivars, except 'BH-65' and 'Red Lady' for different reasons, were highly productive endorsing the protected cultivation of papaya in subtropical regions, with the advantages of suffering a lower number of maladies. So far, main problems due to pests and diseases found in protected cultivation of papaya in our region are red mite (*Tetranychus urticae,* C.L. Koch) and antracnosis (*Colletotrichum gloeosporioides* Penz. and Sacc) oidium (*Oidium caricae,* J.M. Yen), generally well controlled (SALINAS et al., 2017). No report of papaya ring spot virus occurrence in Spain have been documented yet.

Conclusions

Our results permit to recommend the protected cultivation of papaya cultivars 'Siluet' or 'Sensation', due to their high productivity and fruit quality given the good adaptation they showed to the environmental conditions of South East Spain's greenhouses. 'BH-65' could be of interest for low-height greenhouses due to its small plant size and good fruit quality and nice size and shape, although it was less productive and showed high sensitivity to harsh environmental conditions forming quite many flowers setting fruit without commercial interest. 'Intenzza' was the most productive cultivar, producing large fruit that withstand distance to long distance markets, although it seems too vigorous and fruit are too heavy (~1 kg). 'Red Lady' seems not suitable for Almería's greenhouses given its extraordinary vigour and very heavy fruit (over 1.5 kg). Our results endorse the cultivation of papaya as a new crop to complement the protected cultivation of vegetables in Almería with the advantage of much reduced market competition, high prices for farmers and steady fruit demand for tropical fruit crops in Europe.

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