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Determination of the Best Planting Season for the Protected Cultivation of Papaya

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Abstract: Papaya is a tropical crop increasingly cultivated in the greenhouses of subtropical regions such as South East Spain, where the determination of the best planting season is important to ensure a stable fruit production and quality during the year. In this work, we studied plant growth, yield, and fruit quality, comparing spring and autumn planting seasons in 'Intenzza' cultivar. The results showed that planting in spring favors plant growth, leading to an earlier entry into production. Total yield and fruit quality were similar in both planting seasons, although the spring cycle provided higher profits due to greater commercial yield and lower discards. Our results confirm that adverse environmental conditions affect the crop in a similar way regardless of the planting season, so different growing cycles are not very useful for filling the production gaps and fighting against seasonality in our region, unless unfavorable climate conditions are avoided inside the greenhouse.

Keywords: *Carica papaya* L.; seasonality; yield; fruit quality; environmental conditions

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1. Introduction

Papaya (*Carica papaya* L.) is a tropical fruit crop with a short juvenile phase that exhibits continuous flowering after reaching adult phase [1,2]. This juvenile phase lasts between three and eight months, depending on genotype, management, and climate. Harvest often starts 9–15 months after planting [3]. Under favorable conditions, papaya grows nonstop and lives for up to 20 years [4]. However, most commercial plantations are removed after two or three years mainly because its enormous plant height and plant damages due to pests and diseases [3].

The benign climate in tropical areas permits papaya planting all throughout the year, allowing continuous fruit production [5]. In Europe, only a few areas present the climate required to produce papaya, and, where possible, protected cultivation is almost mandatory [6,7]. In these areas, performing plantation in the best season determines when the plants enter into production and selects the most favorable dates for initial growth, flowering, and fruit setting. In this regard, climate during flowering strongly affects productivity, since papaya flowers are highly sensitive to extreme environmental conditions of temperature and humidity, resulting in flower malformations that lead to non-commercial fruit [8]. However, under favorable conditions, papaya cultivation under greenhouses has proven to be very interesting, with yields reaching 200 t ha^{-1} in 2 years after planting.

In subtropical papaya-producing areas of Europe, seasonal climate occurs and temperatures above optimum are reached in summer, and below in winter [6,9,10]. Seasonality affects crop performance, resulting in fruit setting failures in different sectors of the trunk. Besides, unstable fruit quality is common in the subtropics. Thus, for these regions, it is necessary to select the season that provides the best yields and fruit quality, and check if we can obtain a more stable supply by combining transplanting seasons. In the Canary Islands, papaya plantations are usually carried out under mesh and are initiated in spring or summer (April or July). These greenhouses up to 7 m high allow plantations lasting for over three years and more. On the contrary, greenhouses of lower height and the more continental climate impede the extrapolation of this model to mainland Europe. It is important to consider that fast growth due to high summer temperatures generates taller plants, even more so if first flowers do not set. This work aims to select the best planting season for papaya grown in plastic greenhouses in subtropical regions of Europe, seeking rapid and stable fruit production and quality throughout the year.

2. Materials and Methods

2.1. Site and Plant Material

The research was performed at the Cajamar Experimental Station 'Las Palmerillas', situated in El Ejido, Almería (South East Spain) (2°43′ W, 36°48′ N, 15 km from the Mediterranean Sea and 151 m above sea level). Papaya plants under study grew in a multi-tunnel type greenhouse with five chapels, each 7.5 m wide each, covered with low density polyethylene, and E–W-orientated. The structure was 3.4 m high in the eaves and 5.4 m up to the ridge.

Hermaphrodite plants of the cultivar 'Intenzza', provided by the company Semillas del Caribe (Mexico), were selected for the experiment. This hybrid is characterized by red pulp, fruit weight around 1.5 kg (in Spain often less), total soluble solid content between 10 and 13 °Brix in the best seasons, and high and regular production under plastic greenhouses. Hermaphrodite 'Intenzza' seedlings were selected at the nursery using molecular markers base on SNPs (Single-Nucleotide Polymorphism), following the procedure described by Parasnis et al. [11]. The feasibility and profitability of this sexing procedure is compared to the traditional morphological sexing of papaya in the work of Salinas et al. [12]. Accurate molecular sexing of papaya seedlings, although still expensive, allows planting only one plant per hole, instead of using three–four seedlings per hole and selecting later one hermaphrodite, as it is mandatory when sexing is based on flower appearance weeks after planting. Molecular sexing is also convenient because it avoids the intense initial competition for light among papaya seedlings, unavoidable when 3–4 seedlings are planted together, which provokes taller and thinner plants.

Plant growth, flowering, yield, and fruit quality of plantations implemented in spring versus autumn were compared. The spring plantation, with seedlings spaced 2.5 m × 2 m, was carried out on 6 April 2016, and the autumn plantation, with seedlings spaced 2.5 m × 1.5 m, was carried out on 20 September 2016 (Figure 1). At the of the experiment, all plants were pulled out at the same date, on 6 July 2018, 27 months and 21 months after transplanting, respectively, once harvesting all commercial fruit took place and when the plants, above 3 m height, were reaching the greenhouse ceiling.

(**a**)

(**b**)

Figure 1. 'Intenzza' papayas planted in spring (**a**) and autumn (**b**).

After transplanting, seedlings were given copious irrigation and maintained free of weeds by white plastic mulching (Figure 1) to assure establishment and good initial growth. Afterward, irrigation and fertilization of these papayas were carried out, taking into consideration plant size and following recommendations for our climate conditions. Misshapen flowers and non-commercial deformed fruits were removed as soon as they were detected, as it was the blade of senescent leaves. Pests and diseases were controlled following IPM guidelines. Powdery mildew (oidium) and red mite are the two most common threats in the protected cultivation of papaya in our experimental conditions.

2.2. Plant Growth Conditions

Climate conditions inside the greenhouse were regulated through natural ventilation provided by one zenithal window per chapel and a lateral side panel. The temperature set point to activate the opening of the windows was established at 24 °C. Throughout the study period, a ventilated aspyropsychrometer with a PT-100 probe recorded the temperature in the greenhouse, while a Priva climate controller stored the data and managed the window activity. Roof whitening was also performed on 1 June 2017, as it is common in the greenhouses of Almería, and consisted of 25 kg of Whitefix® (Royal Brinkman's, Gravenzande, The Netherlands) diluted in 300 L of water.

2.3. Plant and Fruit Measurements

Plant growth was evaluated every three months. Plant height, considered as the distance from the ground to the top of the canopy, was measured with a grader bar, while trunk perimeter, recorded at 15 cm above the ground, was measured using a seamstress tape ruler. This seamstress tape ruler was also used to measure the distance from the ground to the first flower and later to the first fruit formed. The time, expressed in days, from planting to flowering, and from flowering to harvest, was counted too. The frequency of elongata-type, pentandric and carpelloid hermaphrodite flowers, and that of female and functionally male flowers [13], was seasonally recorded in selected days of spring (16 May 2017), summer (16 August 2017), autumn (17 November 2017), and winter (14 February 2018). The percentage of flowers with regard to the number of total open flowers at the measurement day was therefore expressed.

Total and commercial yield, the discards (the percentage of non-commercial misshapen fruits not removed and fruits lighter than 200 g), the number of fruits per plant, and their average weight were compared between spring and autumn planting seasons. Harvest was performed several times per week, seasonally dependent, when fruits had 50% of their skin becoming yellow.

Fruit quality was evaluated by its size, firmness, color, and sweetness in papayas harvested from both treatments on 8 May 2018. Fruit size was characterized by its weight, length, and equatorial diameter. Fruits were weighed in a precision balance (d = 0.1 g) (model SB12001, Mettler Toledo, Barcelona, Spain). Fruit length, maximum equatorial diameter, and the width of internal cavity were measured with a digital caliper (model Z22855, Powerfix Profi, Heidelberg, Germany). Pulp firmness was assessed after peel removal, in two opposite equatorial spots of each fruit, through a firmness texter (model Pénéfel DFT 14, Agro-Technology, Forges Les Eaux, France), and expressed in newtons. The juice of each fruit was used to quantify its total soluble solid content (TSS) and its titratable acidity. TSS, measured in °Brix, was determined with a digital-type refractometer (model PR-101, Atago Co., Tokyo, Japan). Titratable acidity (TA) was assessed by titration using 0.1 N NaOH and phenolphthalein as an indicator, expressing the results in g of citric acid per L. TSS changes along the year were compared between planting seasons. Finally, for skin and pulp color determination, three different positions of each fruit were measured with a colorimeter (model CR-400, Konica Minolta Co., Tokyo, Japan). To express the results, we used hue angle (hue°), which indicates the fruit color tone as follows: red at 0°, orange at 45°, yellow-orange at 60°, yellow at 90°, yellowish-green at 120°, green at 180°.

2.4. Statistical Assessment

A randomized complete block experiment was designed with two treatments (spring versus autumn planting season) and four replicates constituted by three experimental plants each (12 plants per treatment in total). Analyses of variance (ANOVA) and mean separation by Tukey's test were performed, when needed, using Statistix 8.0 software (Analytical Software, Tallahassee, FL, USA).

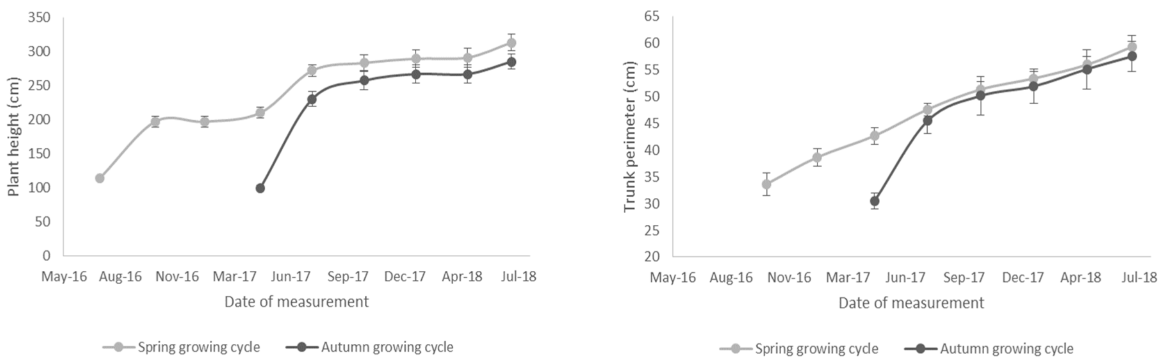
3. Results

3.1. Plant Growth Conditions

Monthly average temperature inside the greenhouse ranged from 13.8 °C in January 2017 to 27.9 °C in July 2016. The average of the monthly minimum temperatures ranged from 7.2 °C in January 2017 to 22.2 °C in August 2017, while the monthly maximum temperatures ranged from 24.7 °C in December 2016 to 36.6 °C in July 2016. The recorded temperatures pointed to a benign 2017 summer compared to other years. On the other hand, the monthly mean relative humidity (RH) fluctuated between 53% recorded in November 2016 and 86% in August 2017, being the mean RH of the minima between 26% in November 2016, and 76% in August 2017, while the mean RH of the maxima ranged between 72% measured in July 2017 and 94% in August 2017.

3.2. Plant Growth

Plant growth was mainly determined by the temperatures in the greenhouse and growth pattern was similar in both treatments (Figure 2). In this regard, the plantlets transplanted in spring showed fast initial growth, exceeding 1 m height in July, just three months after planting, reaching 2 m in October (Figure 2a). Thereafter, slow growth followed during autumn and winter, coinciding with lower ambient temperatures and ripening of the first fruits. This behavior was reproduced in the second year of the experiment.



(**a**) (**b**)

Figure 2. (**a**) Plant height and (**b**) trunk perimeter changes along the experiment in 'Intenzza' papayas planted in spring and autumn. Symbols represent mean values. Bars represent standard deviations. Figures represent growth according to date and not to plant age.

The plantlets transplanted in autumn took six months to reach 1 m height (in April), much longer than seedlings planted in spring, due to the low temperatures occurring during winter. However, during the following spring and summer, the autumn plantlets grew fast, even more so in plants with few fruits (Figure 2a). At the end of the study, the spring plants were only slightly taller, exceeding 3 m height on average, than seedlings planted in autumn (Figure 2a).

Contrary to height, trunk grew thicker uninterruptedly throughout the study, being initially greater in plants transplanted in autumn (Figure 2b). During most of the time, the plants of the autumn cycle presented a slightly wider trunk when compared to the plants of the same age of spring. At the end of this study, the trunk perimeter exceeded 55 cm in both treatments (Figure 2b).

The distance from the ground to the first flower formed and to the first fruit set was statistically lower (15–20 cm) in the plants of the autumn cycle than in those of the spring (Table 1). Despite this advantage, the time from planting to flowering and from flowering to harvest was statistically longer in the autumn cycle, since 195 days were needed from planting to first harvest in the plants of the spring cycle, while those of the autumn cycle required 287 days (Table 1). The differences were more acute regarding the time from flowering to harvest than from planting to flowering (Table 1).

Table 1. Morphological features of 'Intenzza' papayas of spring versus autumn planting season.

Growing Cycle	Distance to First Flower (cm) *	Distance to First Fruit (cm) *	Days from Planting to Flowering	Days from Flowering to Harvest
Spring	66.6 a [1]	83.1 a	87 b	108 b
Autumn	52.8 b	62.2 b	110 a	177 a

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

Functional male flowers with rudimentary pistil were the most abundant type of flowers formed under the greenhouse all time, except in the month of May, and this happened regardless of the planting season (Figure 3). The maximum frequency of elongata hermaphrodite flowers (which produce the best commercial fruits) was found in spring, being 30% higher for the plants of the spring cycle than for those of the autumn cycle. In other seasons, 13–15% more elongata-type flowers were found for autumn cycle plants than in those of the spring cycle. Few elongata flowers were formed in November, being almost null in the plants of the spring cycle. Misshapen flowers of pentandric and carpelloid types were mostly found in the plants of the autumn cycle (Figure 3).

(**a**) (**b**)

Figure 3. Seasonal frequency of elongata (green), pentandric and carpelloid (both in orange) hermaphrodite flowers, and functionally male (red) flowers found in 'Intenzza' papayas planted in spring (**a**) and autumn (**b**). Rings from inside to outside: spring, summer, autumn, and winter sampling dates.

3.3. Yield

Harvest started in October 2016 in the seedlings planted in spring (just 6 months after transplanting), and in July 2017 for seedlings planted in autumn (10 months after transplanting) because the low temperatures of the previous winter delayed the beginning of harvesting in the latter. Yield was low (<1 kg m^{-2}) in the plants of the spring cycle between October and February due to the low fruit set in the previous summer. A staggered production followed in spring plants after winter, with peaks of production observed in March, May, and September, as the result of the abundant flowering and setting six months before. In the plants of the autumn cycle, yield increased until reaching the maximum in October, and decreased thereafter due to the low temperatures. The effects of the negative conditions during winter for flowering and fruit set were noted as reduced yields six months later, in the following summer.

Total and commercial yield in autumn plants were somehow lower than those of the spring cycle, but no statistical differences were found (Table 2). Discarded fruit were few in both treatments, and statistically lower in the spring cycle plants. An average of 46 and 52 large fruits per plant were harvested for autumn and spring plants, respectively, without statistical differences between them (Table 2). Statistical differences in fruit weight were found, with significantly heavier fruits formed in the plants of the spring cycle (Table 2).

Table 2. Total and commercial yield, discards, fruit number per plant, and fruit weight in 'Intenzza' papayas grown in spring versus autumn planting season.

Growing Cycle	Total Yield (kg m^{-2})	Commercial Yield (kg m^{-2})	Discards (%)	Fruits Per Plant	Fruit Weight (g)
Spring	14.4 a [1]	13.6 a	5.8 b	52 a	1309 a
Autumn	13.3 a	11.6 a	12.7 a	46 a	988 b

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

3.4. Fruit Quality

Harvest at the maturation stage recommended by Pinillos et al. [14] showed heavier and larger fruits, with larger equatorial diameter and wider internal cavity in fruits of the spring cycle plants. However, statistical differences were only found for the equatorial diameter (Table 3). Statistical differences were also found in fruit firmness, with fruit being firmer in the plants transplanted in spring. Soluble solid content was similar in the fruit of both planting seasons, with average values below 10 °Brix, while TA was always low (Table 3). No statistical differences were found either in skin or pulp fruit color estimated by their hue° angle (Table 3).

Table 3. Fruit quality in 'Intenzza' papayas grown in spring versus autumn planting season. Fruit harvested with 50–60% yellow.

Growing Cycle	Weight (g)	Length (cm)	Equatorial Diameter (cm)	Cavity Width (cm)	Firmness (*n*)	TSS (°Brix)	TA (g Citric Acid L^{-1})	Skin Color (hue°)	Pulp Color (hue°)
Spring	1523 a [1]	23.2 a	11.0 a	5.4 a	23.8 b	9.6 a	0.80 a	108.61 a	51.29 a
Autumn	1164 a	22.2 a	10.1 b	4.9 a	26.4 a	9.5 a	0.80 a	103.36 a	53.25 a

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

TSS content throughout the year was similar for both treatments (Figure 4). TSS was above the minimum required for the commercialization of papaya (10 °Brix) most of the time. However, values lower than 10 °Brix were obtained at the end of winter in the fruits of the seedlings of both planting seasons. The maximum values were obtained after summer (~14 °Brix), and the minimum at the beginning of spring (~8 °Brix) (Figure 4).

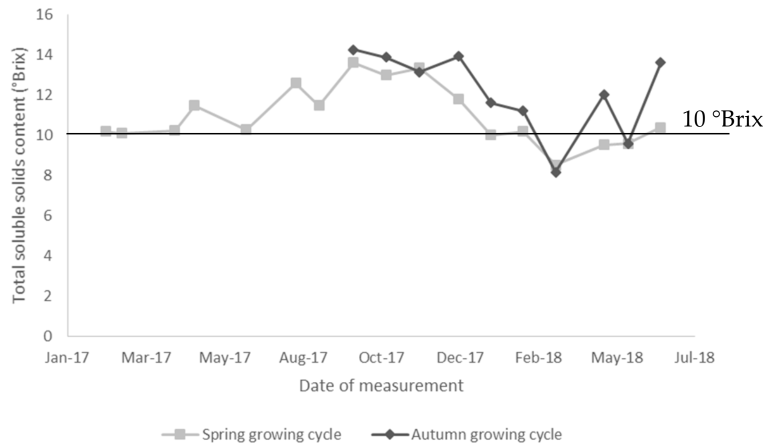


Figure 4. Total soluble solid content (TSS) changes during the year in fruits from spring versus autumn growing cycle. The line marks the 10 °Brix value, commonly referred to as the minimum required for papaya commercialization.

4. Discussion

Plant growth results indicate that winter is a critical period for papaya growth in our experimental conditions. This happens regardless of the planting season. However, low winter temperatures affect more negatively younger plants transplanted in autumn, especially because the cold conditions that occur shortly after planting delay their entry into production. These young plantlets are besides more exposed to diseases common in humid periods such as powdery mildew and root and trunk rot, which have a serious negative impact on yield.

Spring and early summer in our climate favored growth, flowering, and fruit ripening for the spring cycle plants, explaining thus the better results in the plants of the spring cycle. In contrast, winter slowed down these processes in the plants of the autumn cycle. In this regard, temperatures below 15 °C affect internode elongation in papaya [15]. Thus, this slower plant growth explains the statistically lower distance from the ground to the first flower formed and to the first fruit set in plants of the autumn cycle.

The first harvest took place much earlier in plants transplanted spring than in those transplanted in autumn, and six months was saved for the entry into production. In this regard, the fruit that were harvested in August, in the plants of the autumn cycle, came from flowers set in February–March, while in the spring cycle, the first flowers setting at the end of the first summer (August–September) allowed harvesting of the first fruits in early winter.

According to previous experimentation, transplanting 'Intenzza' seedlings in June is worse, since flowering occurs at a higher height (83.8 cm) than in spring and autumn plants, and the setting of the first fruits takes place at 85.1 cm from the ground [16], higher than in seedlings transplanted either in spring or autumn. Besides, seedlings transplanted in summer started to ripen fruit 307 days after planting, requiring only 76 days to reach flowering but 231 days from flowering to harvest [16]. In this context, our results emphasize the importance of maintaining suitable environmental conditions during the first summer following a plantation in a greenhouse, in order to encourage the formation of fertile flowers in the first nodes of the trunk and thus preventing the loss of the first flowers due to fruit set failures. In the work above cited [16], 'Intenzza' seedlings transplanted in June showed an important frequency of functionally male useless flowers during the following months, thus evidencing that harsh conditions of summer affect negatively flower differentiation weeks later. These results also confirm the different performance of a given cultivar (in this case, 'Intenzza') depending on the planting season and especially according to the prevalent environmental conditions, as stated by Cabrera et al. [10]. Nonetheless, in comparison with the yields here measured, that 20-month-long summer cycle was more productive. The commercial yield in that case was 18.7 kg m^{-2}, with production peaks in spring and autumn and lighter fruits formed (938 g). However, harvest started 10 months after planting, much later than the time measured in our spring cycle.

Gunes and Gübbük [6] compared three papaya genotypes under protected cultivation in Antalya (Turkey), transplanting them also in spring, but harvesting first fruit in all of them almost 8 months after, 2 months later than in our experiment, in part, because flowering started also 40 days later. This occurred despite the environmental conditions of Antalya seem very similar to those of Almería (Spain). In warmer and more humid conditions, such as those of Bangladesh, sheltering date considers especially cyclone and rain seasons. Nonetheless, plantations carried out in February under different types of nets also shorten the period to flowering and harvesting and allow more and heavier fruit [17], than in the open field making protected cultivation more profitable.

Cultivation costs of papaya in greenhouses of SE Spain for a 26-month growing cycle are estimated around 0.60 EUR kg^{-1}, which, although still high, is lower than that for vegetable production considering the higher water consumption for papaya but a much lower expenditure on phytosanitary products than in other horticultural crops [18]. These calculations of the production costs in protected cultivation include labor force (mostly for cultivation and harvest); inputs for irrigation, fertilization, pest and disease control, and the indirect costs associated with the depreciation of the infrastructure (greenhouse and equipment) [18]. Considering that the average selling price of papaya paid to farmers is around 1.1 EUR kg^{-1} in the main Spanish cooperative (M Casas, pers. comm.), this lower production cost and its high productivity make papaya an attractive and profitable alternative to vegetable production in Almería greenhouses.

On the other hand, our work suggests that combining different planting dates in the same area is not a solution to the seasonality of papaya production, a challenge in the Mediterranean areas. This approach does not fill the production gaps that occur throughout the year, because the plants respond similarly to the climate regardless of their age. Therefore, seasonality cannot be reduced in our climate unless adverse environmental conditions inside the greenhouse are efficiently avoided. Considering our results, an option to maximize early production in the spring plants is to carry out earlier transplanting (at the end of February or early March), which will lead to flowering under the milder temperatures of May–June, with better initial fruit set. A different option is to rely on active greenhouse climate control, as successfully demonstrated by Salinas et al. [18], or to transplant more developed (and expensive) plantlets raised longer by the nursery, because larger plants with greater leaf area tolerate better the high temperatures of summer. In this context, Honoré et al. [19] support short cycle papaya cultivation in this region (maximum 18 months), and proposes grafting onto female 'Intenzza' rootstock to increase the yield in this cultivar.

Finally, fruit quality was mainly determined by the environmental conditions, so our evaluations support the view that favorable and unfavorable periods affect equally fruit ripening and quality regardless of plant age. Similar total soluble solid changes along the year were also observed in plantations starting in June [16]. Nevertheless, Nascimento et al. [20] indicate, on the contrary, that differences in sugar content are related to fluctuations in source–sink relationships throughout the cycle, so higher sugar content might coincide with a larger canopy and/or with a lower number of fruits per plant, and vice versa.

5. Conclusions

Early flowering, setting, and harvesting, and slightly heavier yields due to more and heavier fruit per plant with lower discard in seedlings transplanted in spring, allow us to recommend this season as the most profitable for transplanting papaya in subtropical and Mediterranean areas where hot summer and cool winter impose protected cultivation.

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