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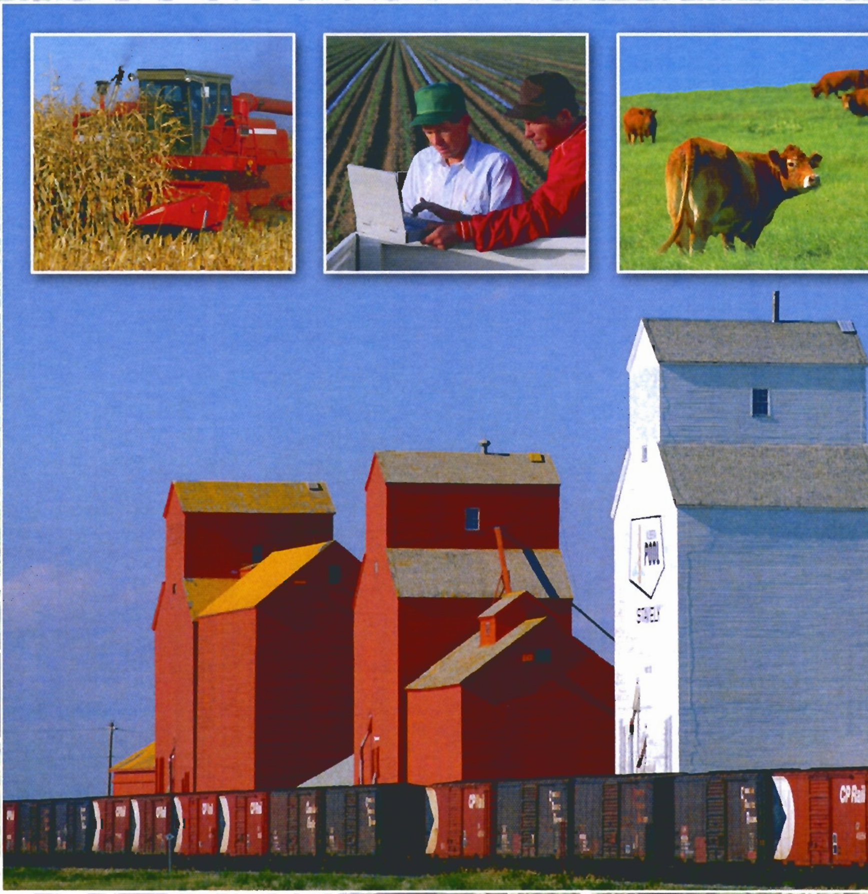

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# Flowering and Fruit Production Dynamics of Sweet Pepper (*Capsicum chinense* Jacq) Under Different Shade Conditions in a Humid Tropical Region

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**ABSTRACT.** Growing sweet pepper (*C. chinense*) under shade has increased in the region south of Lake Maracaibo in Venezuela. We studied the effects of different shade conditions on the dynamics of flowering and fruit production of *C. chinense*. Two experiments were carried out. In the first experiment, weekly measurements of flowering and fruit production in plants shaded by passion-fruit (*Passiflora edulis*) vines and in those in full sunlight were made in replicated field plots. In the second experiment, with a similar design and three replications, the same variables were measured for three shade levels (60%, 40% and full sunlight). In the first experiment there were no significant differences in total number of flowers (TNF), total number of fruits (TNFr) or in total production (TP) ($p < 0.05$). However, total production of shade-grown plants was slightly higher, and the average fruit weight of shade-grown plants was significantly greater ($p < 0.05$). In the second experiment different shade conditions showed no significant differences for either TNF or fruit

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weight. Highest production was obtained for plants with 40% shade, but this was not significantly different from those in full sunlight. However, both were significantly different from plants with 60% shade ($p < 0.05$). Although plants in full sunlight and those with 40% shade showed no significant differences, the results indicate that producers can grow *C. chinense* in partial shade provided by other plants, thereby increasing efficiency of field space usage. For small producers this strategy could provide greater economic returns from the same area. 

**KEYWORDS.** Associate crop, fruit yield, light levels, *Passiflora edulis*, tropical crop

## *INTRODUCTION*

In addition to *C. annuum*, both *C. frutescens* and *C. chinense* have been commonly cultivated in Latin America. The latter has replaced *C. annuum* in low, wet areas, and recently there has been increasing interest in these species in developed countries (Pickersgill, 1997). Given this growing importance, it is essential to know more *about C. chinense* and *C. annuum* varieties and their behavior under field conditions. In the case of *C. chinense*, the most commonly grown species in the Caribbean region (Bosland and Botava, 2002), there is limited information on its performance under different environmental conditions (Jaimez et al., 1999; Benavides, 1995). According to the Venezuelan Agriculture Ministry sweet pepper yields increased from 2.6 t in 1997 to 6.0 t in 1999. Approximately 65% of production is carried out by small farmers.

With respect to the effect of solar radiation on sweet pepper production, most research has been directed towards the reduction of radiation in winter under glasshouse conditions. This has no relevance to tropical conditions, even in low temperature months. In Israel, Rylski and Spigelman (1986) showed that under field conditions during the summer, a reduction in radiation of approximately 26% had a significant impact and increased production in *C. annuum* compared with exposure to full sunlight. Increased production was due to a significant increase in fruit size, while the number of fruits was the same under both conditions. With roughly 50% shade, commercial production was greater than in full sunlight, although less than with 26% shade. Under greenhouse conditions, also in Israel, an increase in shade between 40 and 90% produced a higher rate of flower abscission (Aloni et al., 1994) and reduced assimilation rates which differed among the cultivars (Aloni et al., 1996). However these authors propose that the different assimilation rates do not explain the susceptibility to shade of each cultivar, but rather that the distribution of assimilates to flowers and flower metabolism is a factor of greater importance. Nilwik (1981) reported a greater leaf area under glasshouse conditions in winter; this was evidenced in a reduced specific leaf weight as well as net assimilation rate (NAR) in plants grown at 0.49 MJ $m^{-2}$ compared with plants grown at 0.65 $MJ^{-2}$. Similar results with reduced solar radiation were obtained for tomato (*L. lycopersicum* L.), cucumber (*C. sativus* L.) and bell pepper (Bruggink and Heuvelink, 1987).

No evidence in the literature on the genus *Capsicum* grown with shade trees has been presented, but recently plantations of *C. chinense* have been observed under shade of passion-fruit vines (*Passiflora edulis*) to the south of Lake Maracaibo in Venezuela (Cedeño et al., 2003). This sort of combination implies a more efficient use of field space and additional income. Unlike the uniform shade given by plastic sheets, shade from trees or other plants produces patches of light which change during the course of the day. It is possible that these changing patches of light affect microclimatic variables such as temperature and relative humidity which in turn influence gas exchange processes. Partial shade prevents a rapid reduction in available water in the soil, which would occur under full sunlight in periods of drought. The purpose of the present study was to evaluate how increasing shade from *P. edulis* affects flowering and fruit production dynamics in *C. chinense* and how different light intensities affect these variables.

## *MATERIALS AND METHODS*

The experiments were carried out in the south of Lake Maracaibo region, State of Mérida, Venezuela (lat. 8° 32 N, 71° 37 W) at an altitude of 130 m.a.s.l. Mean annual precipitation is 1822 mm and mean annual temperature is 27.9°C (data obtained from the Venezuelan Ministry of the Environment and Renewable Natural Resources). Soil was classified as Fluventic Eutropepts, isohyperthermic, well-drained (Kijeweski et al., 1981). The cultivar used was "*Pepón*," which comes from eastern

Venezuela but is extensively cultivated in the study area. According to the descriptions recommended by the International Board for Plant Genetic Resources (IBGPR, 1983) the cultivar has compact growth habits, absence of pubescence on the stem or leaf, fruits of conical form, red when mature and a sweet taste.

### *Experiment with Shade from P. edulis*

Pepper seeds were planted in disinfected beds made up of equal parts of sand and organic matter. Seedlings were transplanted 50 days after sowing (das) (9/11/2001), 65 days after the passion-fruit plants had been transplanted. The seedlings were planted at 1 m in-row spacing and rows were separated by 1.5 m. Passion-fruits were 12 m apart between rows and 3 m between them. Shade was gradually given to some pepper plant by training the passion-fruit on wire mesh. In this manner some plants grew in the shade and others were exposed to full sunlight. Photosynthetic photon flux density (PPFD) was measured with a quantum sensor (LI-COR). Fertilizer was applied 25 days after transplanting (dat) at a rate of 40 kg $ha^{-1}$ of N in the form of diamonic phosphate. At 60, 100 and 130 dat the equivalent of 20, 19, 30 and 5 kg $ha^{-1}$ of N, P, K, Mg was applied in the form of commercial fertilizer, 12-11-18-3 plus microelements. In this experiment plants only received water in the form of rainfall. Plots were chosen at random with 5 replications for both growth environments. Each plot contained 7 plants and data was collected from the 4 central plants (20 for each treatment). A weekly record was kept of the number of open flowers and fruits, and the weight of the fruits. Leaf area (25 leaves chosen randomly, 5 per plot) was measured as well as the corresponding dry weight in order to calculate specific leaf area (SLA).

### *Experiment with Artificial Shade at Different Light Intensities*

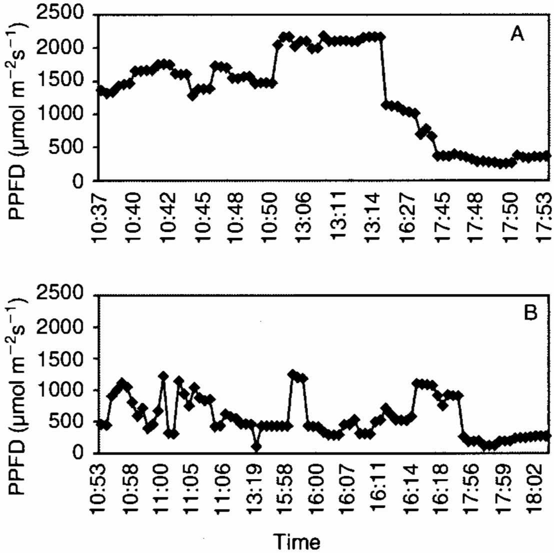
As in the previous experiment, plants were sown in beds and transplanted 45 das at 1 meter intervals (27/03/2003). 60 dat solar radiation was modified by means of polyethylene screens with different sized mesh. Two types of shade were produced: heavy (60%) and partial (40%), with exposure to full sunlight used as control. Plots were chosen randomly, with three replications. Each plot contained 10 plants. Four central plants were chosen from each plot and a weekly record was kept of flower and fruit production a month after the shade introduction. Fertilizer was applied as in the previous experiment. However, in this experiment plants were watered every 6 days during the dry season. Differences in production, total number of fruits and flowers, and fruit weight were evaluated by analysis of variance (ANOVA), while Tukeys procedure was used to compare the effects of different light intensities.

## *RESULTS*

In the first study, shade from passion-fruit plants increased progressively so that between 12:00-13:00 at 80, 114 and 124 dat of the pepper seedlings shade was 35, 42 and 52%, respectively. Values for PPFD at this time varied between 1750 and 2110 $\mu molm^{-2}s^{-1}$ on sunny days and from 700 to 920 $\mu molm^{-2}s^{-1}$ when cloudy. Approximately 300 days after transplanting, the passion-fruit vines covered the wire mesh to such an extent that only 30% of solar radiation was able to pass through. At this time *Capsicum* plants were still bearing fruits. Shade was not uniform in that there were patches of light which changed during the course of the day and fell on different parts of the plants. It was possible to find horizontal differences in PPFD greater than 500 $\mu molm^{-2}s^{-1}$ at a given time (Figure 1).

In the study, 55% of all plants were flowering 46 dat. The maximum number of flowers occurred 97 and 133-146 dat, for shaded and unshaded plants, respectively (Figure 2a). There were approximately 50 days between these two flowering peaks. At 67 dat, 50% of the plants had harvestable fruits, while the number of fruits per plant increased progressively reaching a maximum of 17-20 fruits per plant 125 and 133 dat for shaded and unshaded plants, respectively. Another peak was obtained 188 dat for both groups. Fruit weight was consistently around 17 g for unshaded plants, while for shaded plants the weight varied from 14 to 19 g. Fruit weight (FW) for both groups began to decrease 167 dat (Figure 2c). There were no significant difference in the total number of flowers (TNF), total number of fruits (TNFr) and total production (TP), although the TP of shaded plants was slightly higher (Table 1). Over a period of 197 days an average of 1.7 and 1.5 kg of fruits per plant was obtained for shaded and unshaded plants, respectively. Unshaded plants had a lower TNFr/TNF ratio, but this was not significantly different from shaded plants. However, shaded plants had a significantly higher ($p < 0.05$) average fruit weight (Table 1). Shaded plants had a significantly greater specific leaf area than unshaded plants.

FIGURE 1. Photosynthetic photon flux density (PPFD) received by plants of *C. chinense* exposed to full sunlight (A) and under shade from *P. edulis* (B) for 193 dat of *P. edulis*.




In the second experiment, in which different artificial light intensities were obtained, 50% of the plants were flowering and bearing harvestable fruits at 48 and 72 dat, respectively. The number of flowers per plant did not show a definite trend with respect to light conditions (Figure 3a).The number of fruits on plants with 40% shade and on unshaded plants gradually increased, reaching a peak at 123 dat (Figure 3b). Plants with 60% shade reached maximum production 149 dat, and for most of the cycle lagged behind the two other groups. Maximum fruit production, for both shaded and unshaded plants, was roughly 37% higher than that obtained for plants shaded with passion-fruit in the first experiment. This could be explained by the fact that plants were watered in the second experiment. Weight was greater, around 17 g, 94 dat and declined steadily to approximately 11 g over the course of the study. While fruit weight slowly decreased for unshaded plants. Production was greater in plants with 40% shade, and although this was not significantly higher than unshaded plants, it was significantly higher ($p < 0.05$) compared to plants with 60% shade. Neither TNF nor FW were significantly different in shaded or unshaded plants (Table 2).

FIGURE 2. Number of flowers (a) and fruits per plant (b), fruit weight (c) and yield dynamics (d) of *C. chinense* under *Passiflora edulis* shade (■) and full sunlight (□).

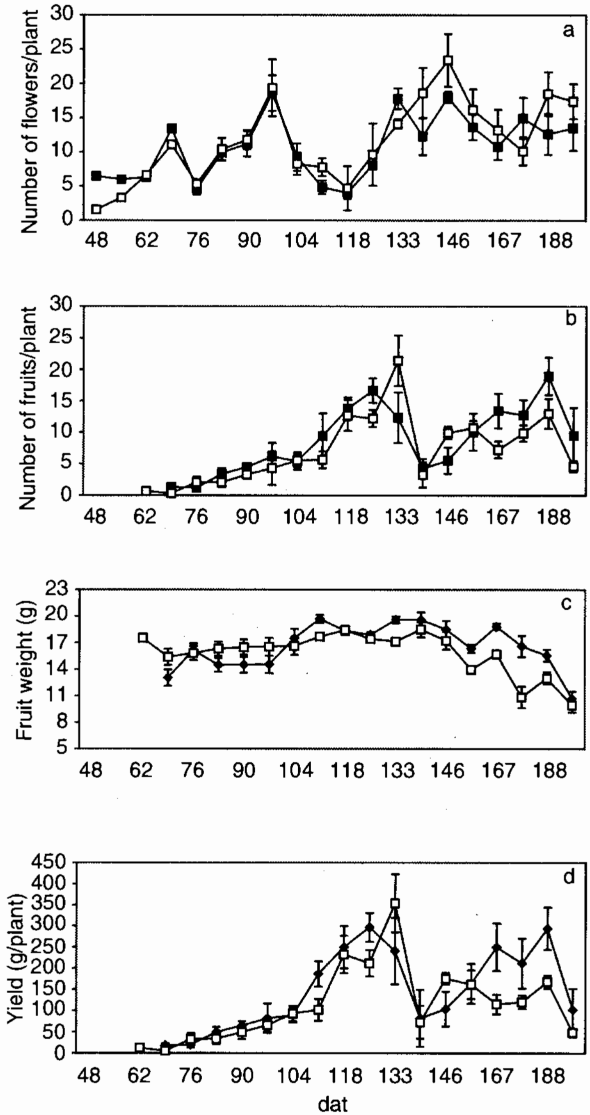


TABLE 1. Total number of flowers per plant (TNF), fruits per plant (TNFr), fruit weight (FW, g), total production per plant (TP, g/plant) and specific leaf area (SLA, $cm^2/g$) for *C. Chinense* under shade from *Parssiflora edulis* and exposed to full sunlight.

| Light conditions | TNF | TNFr | FW | TP | TNFr/TNF | SLA |
|---|---|---|---|---|---|---|
| Full sunlight | 134 | 105 | 15,10 | 1711 | 0,79 | 192 |
| Shaded | 119 | 104 | 17,20 | 1918 | 0,87 | 285 |
| | ns | ns | ** | ns | ns | ** |

** Significant differences ($p < 0.05$) with Tukey's test.

## DISCUSSION

Both experiments established that in this area, 50% of the plants of the cultivar "*Pepón*" start flowering between 45 and 48 dat. Other studies on other cultivars of *C. chinense* have reported that in semi-arid zones flowering begins 70 dat (Jaimez et al., 2000), while Benavides (1995), working with 12 cultivars near Jusepín in eastern Venezuela, reported that 50% of the plants were flowering 26-32 dat. There are clearly great differences and it would seem necessary to evaluate flowering dynamics both for cultivar and region. For bell-pepper cultivars it has been reported that there are no differences in flowering dynamics, but there is variation among the cultivars in the number of flowers (Khah and Passam, 1992). In this study, 50% of the plants had harvestable fruits between 67 and 72 dat. Harvestable fruits have been reported at 90 dat for semi-arid zones (Jaimez et al., 2000) and 81 dat in eastern Venezuela, with average temperatures similar to those of the study region (Montaño, 2000).

Flowering and production dynamics did not change under any of the shade conditions where maximum and minimum flowering occurred in similar periods. Increasing shade to 60% led to a smaller number of fruits during the whole production cycle compared to the two other groups. This difference could be related to a greater number of aborted flowers. Variations were found in the percentage of flower abscission in different *C. annuum*, under glasshouse conditions (Aloni et al., 1996; Aloni et al., 1994). These authors describe progressive increases in flower abscission when shade increased from 40% to 90%.

It would seem that 40% shade results in less flower loss and larger fruits and consequently gives a slightly higher TNFr/TNF ratio. In spite of higher flower number obtained under full sunlight environment in the

FIGURE 3. Number of flower (a), fruits (b) per plant fruit weight (c) and yield dynamics (d) of *C. chinense* under three light conditions: full sunlight (△), 40% (o), and 60% of shade (■).

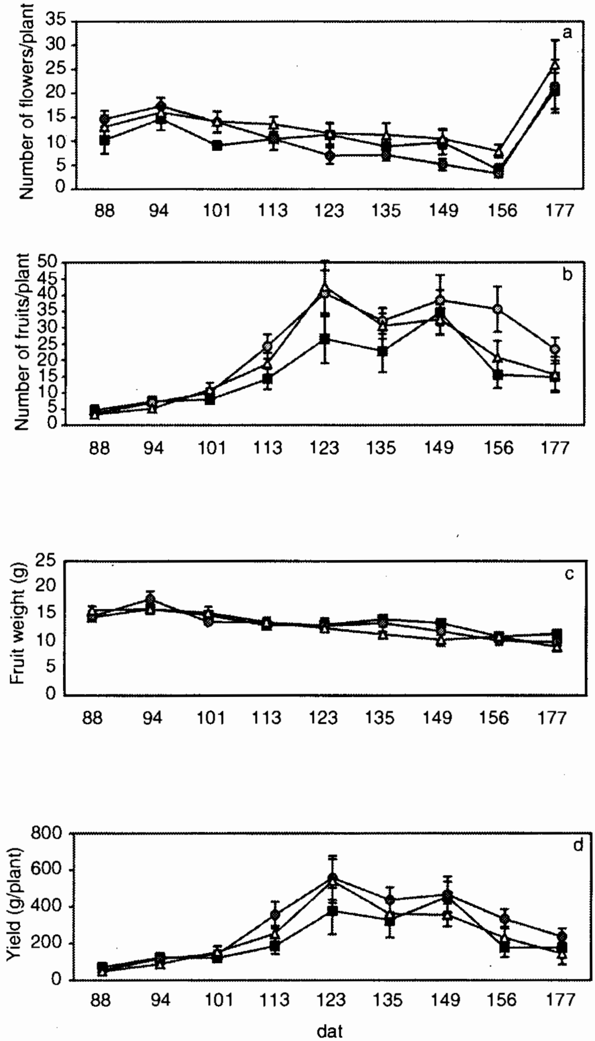


TABLE 2. Total number of flowers per plant (TNF), fruits per plant (TNFr), fruit weight (FW, g), total production per plant (TP, g/plant) for *C. Chinense* exposed to full sunlight (control) and with two shade conditions.

| Shade (%) | TNF | TNFr | FW | TP |
|---|---|---|---|---|
| Full sunlight | 111 | 182 ab | 12.2 | 2317 a |
| 40 | 88.4 | 206 a | 12.9 | 2579 a |
| 60 | 91.7 | 144 b | 13.5 | 1961 b |

Means followed by different letters in the same column are significantly different ($p < 0.05$) with Tukey's test.

first experiment, 21% was aborted as flowers or small fruits compared with 13% obtained in plants under *P. edulis* shade. Shade conditions not exceeding 40% produced a greater number of fruits per plant and also higher weight per fruit which translates into greater production. These results agree with those obtained for bell-peppers with varying shade under field conditions (Rylski and Spigelman, 1986). 60% shade has a negative impact on production, while 40% shade did not affect fruit production. 40% shade under field conditions corresponds to 1200 $\mu molm^{-2}s^{-1}$ on sunny days and 500-600 $\mu molm^{-2}s^{-1}$ when cloudy. However, when shade is provided by plants there is considerable variation in light due to the lack of uniformity of cover. This would lead to different $CO_2$ assimilation rates depending on time and place. Light flecks produce a uneven environment where it is possible to obtain large differences in $CO_2$ assimilation rates. Furthermore, under these environmental conditions and depending on available soil water, stomatal responses may also affect $CO_2$ assimilation. An increase in stomatal opening in response to higher light conditions also implies an increase in plant photosynthetic capacity (Bjõrkman, 1981). $CO_2$ assimilation will also depend on the nature of sunflecks and microsites (Allen and Pearcy, 2000).

Yields between 24 and 9.8 t $ha^{-1}$ have been reported for various cultivars in eastern Venezuela (Montaño, 2000). The cultivar "*Pepón*" showed high yields (17 t $ha^{-1}$). This crop has great potential in this region and it is not negatively influenced by 40% shade or less. There were no significant differences between production in full sunlight and in 40% shade, thus results show that *C. chinense* can grow in partial shade and that producers can thereby increase efficiency of field space usage. For small-scale producers this strategy could provide economic benefits, as well as making them less dependent on only one crop. It appears this strategy could be utilized on farms where irrigation is not available and partial shade can be provided to avoid excessive soil evaporation, particularly during the dry season.

It would seem that shade is beneficial once fruit production has begun, and increases fruit size compared with plants grown in full sunlight. It would be important to determine the effect of shade during the initial growth stage to observe if it is possible to have high yields from *C. chinense* seedlings transplanted directly to shaded areas in this region. The process by which *C. chinense* is being included into various crop-combination systems is beginning. Farmers have incorporated this strategy to improve the efficiency of their production systems and increase their economical returns. It would be necessary to evaluate the adaptation of *C. chinense* under various grades of light to determine if intercropping is appropriate in other production systems.

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