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EFFECTS OF HEATING STRATEGIES ON EARLINESS AND YIELD OF SNAP BEANS (*PHASEOLUS VULGARIS* L.) GROWN UNDER "PARRAL" PLASTIC GREENHOUSES

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Effects of heating strategies on earliness and yield of snap beans (*Phaseolus vulgaris* L.) grown under "Parral" plastic greenhouses

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Abstract

The influence of different strategies of air heating on the earliness and yield of greenhouse-grown snap beans (*Phaseolus vulgaris* L, Volubilis) was investigated under a plastic "Parral" greenhouse, commonly used in the South East of Spain. The experiments were conducted with the same cultivar (Donna), grown under 5 identical compartments covered with polyethylene film. One compartment was not heated (**C**, reference crop) and the others were heated by means of a pulsed air heating system (direct combustion), with the following heating strategies: constant night temperature of 14ºC during the whole cycle (**T_{14}**); constant night temperature of 14ºC during the vegetative stage, and 12ºC afterwards (**$T_{14}T_{12}$**); split night temperature, 14ºC during the first half of the night and 12ºC thereafter (**T_{14-12}**); and constant night temperature of 12º (**T_{12}**). The snap bean crop responded positively to heating, both in earliness (gain of about 3 weeks, compared to the reference crop) and production (an increase of 150% in Total yield). The analysis of earliness in terms of heat units (degree-days) led to a base temperature of about 6ºC and a heat sum from sowing until first harvest of 757ºC ± 25. The heating energy consumption ranged from 250 MJ m^{-2} (T_{14}) to 120 MJ m^{-2} (T_{12}), while the heating energy efficiency varied from 61 MJ kg^{-1} (T_{12}) to 90 MJ kg^{-1} (T_{14}). The heating strategy $T_{14}T_{12}$, which had a similar production and earliness than T_{14}, a 30% less of energy consumption, and a higher heating energy efficiency (63 MJ kg^{-1}), appears to be best option for greenhouse growers.

Key words: *Greenhouse, heating, snap beans, heat sum, earliness, yield*

Introduction

The major part of greenhouse area in the world consists of simple plastic houses (Enoch and Enoch, 1999). In the coastal plain of the Almería province (South-eastern Spain), around 26000 ha of plastic greenhouses (Sanjuan, 2001) are cultivated for horticultural production and most greenhouses are low-cost structures, mainly "parral" type, covered with plastic, without heating equipment and with soil grown crops (Wittwer and Castilla, 1995). Inside such greenhouses air temperatures during most of the winter period are suboptimal for vegetable production. The night temperature, which could drop to 6-7 ºC (Montero, 1985), is recognised as the main factor that limits the productivity and quality of the winter vegetable production in Mediterranean countries (Verlodt, 1990). Snap or green beans (*Phaseolus vulgaris* L. Volubilis) is one of the main greenhouse crops in the Almería coast, occupying an area of approximately 5000 ha (Junta de Andalucía, 2000). Snap bean production is currently scheduled from the beginning of autumn to the end of spring, but the winter production is significantly lower than that of the remaining production season. Snap bean plants are sensitive to low temperatures, stopping their growth when air temperatures is below 8-12ºC (FAO, 1990).

Heating systems are commonly used for vegetable production in North and Central European greenhouses. Many studies on the optimisation of greenhouse heating with regards to design, management and crop requirements are available (Baille and von Elsner, 1989; Baille, 1999). By contrast, in areas with mild winter climates such as the Almería coast, air-heating systems are just starting to be introduced. Since cropping systems and greenhouse characteristics in Mediterranean areas differed from those of North European countries, theoretical and experimental studies should been undertaken in order to establish heating strategies that optimise grower's income. This work was aimed to study the effect of different heating strategies on earliness and yield of a green bean crop grown under a typical plastic greenhouse.

2 - Material and methods

Greenhouse

The experiment was conducted during the autumn-winter period of 1998/1999 in 'Las Palmerillas' research station (Cajamar), located at the Almería province, South-eastern Spain (latitude 36º 48' N, longitude 2º 3' W, altitude 155 m). A "parral" greenhouse, east-west oriented, composed by five identical compartments of 24 m by 18 m (432 m^2), was used. The greenhouse, of metallic structures with asymmetrical roofs (13º south and 25º north slopes) was covered with a thermal polyethylene film of 0.2 mm thick. A local air heater with an integrated propane burner that discharged the flue gases directly into the greenhouse compartment was automatically activated when the air temperature was below the established set-point temperatures. In order to minimize the differences in energy consumption among compartments that could be due to differing surrounding environments, 4 m wide buffer zones were kept in between compartments and at both ends of the greenhouse. Greenhouse air temperature was measured by means of ventilated psychcrometers. Data was recorded every 2 seconds and averaged for 30 minutes periods. Daily gas consumption (m^3 d^{-1}) was recorded by means of a volumetric counter.

Crop

Seeds of snap beans (*Phaseolus vulgaris* L. Volubilis, cv. Donna) were sown on 6 November 1998. Plants, in rows 2 m apart and 0.5 m within rows, were vertically supported to a height of 2 m by polypropylene guides. The soil was the typical "enarenado" soil, commonly used in the greenhouses of the Almería region. The onset of the harvesting period was defined as the time when the cumulative fresh weight of fruits was 100 g m^{-2}. The crop cycle finished 126 days after of sowing (DAS), on 12 March 1999. The snap bean crop was subjected to five thermal treatments: crop without heating or reference crop (**C**); crop heated at a constant night temperature of 12 ºC (**T_{12}**); crop heated at a constant night temperature of 14 ºC during the vegetative stage, and 12ºC afterwards (**$T_{14}T_{12}$**); crop heated at an split night temperature: 14ºC during the first half of the night, 12 ºC thereafter (**T_{14-12}**); and crop heated at a constant night of 14 ºC (**T_{14}**). Treatments were arranged in a nested factorial design with four replications per treatment. Snap bean fruits were collected throughout 15 harvests, and total and marketable production was determined

3 - Results and discussion

Greenhouse air temperature

Figure. 1 shows the time course of the greenhouse air temperature during a typical winter night for the different treatments. In the unheated greenhouse, the air temperature decreased throughout the night reaching a minimum value of 8.5 ºC at predawn**,** whereas night air temperatures in the heated greenhouses maintained slightly higher than the set-points (Fig. 1). In general, heated greenhouses maintained these values throughout the crop season, when the outdoor temperatures were lower than the set-point temperatures.

During the crop season, daily mean temperature varied between 10 and 20 ºC for all treatments, and the minimum temperature, measured in the greenhouse air without heating, was 4.4 ºC (data not shown). The mean daily temperature averaged over the crop cycle ranged from 14.2 ºC in the reference greenhouse (**C**) to 16.4 ºC in the heated greenhouse maintained at a constant night temperature above of 14 ºC (**T_{14}**).

Crop production

Earliness

Figure 2 shows, for each thermal treatment, days from sowing to onset of harvesting of snap bean fruits (days after sowing) versus mean daily air temperature averaged for this growth period. It can be clearly evidenced that heating advanced the onset of harvesting with respect to the unheated crop (**C**), the difference varying between 5 days (**T_{12}**) to 18 days (**T_{14-12}**). The duration of the period from sowing to first harvest was inversely linearly related (R^2 = 0.90) to the mean 24h-temperature averaged over this growth period (Fig. 2).

Based on the observed experimental relationship, crop development from sowing to onset of harvesting was characterised using the concept of thermal time or heat units. Although many environmental factors have been related to plant development, temperature is usually recognised to be the main variable that modulates plant development in photoperiod insensitive genotypes, whenever severe stresses are absent. Because of the short growing season of the green bean crops, photoperiod is not likely to be a major factor. The base temperature, biologically defined as the temperature value at which development stops, was determined statistically as the value with the lowest standard deviation in degree days (Yang *et al.*, 1995). The calculated base temperature was 6ºC and the heat sum from sowing to onset of harvesting, using this temperature value, was 757 ± 25 ºC, which means that the onset of harvesting could be fairly predicted from air temperature data with 2-3 days error. A similar value of 6.6ºC for the base temperature was obtained by Ferreira *et al.* (1997) in a field snap bean crop during the sowing - pod development phase.

Production

Table 1 shows early and total yield of marketable snap bean fruits (all harvested fruits were classified as marketable). Heating increased both early and total production of snap bean fruits ($P<0.05$). Heated crops presented a significantly higher early and total yield than the reference crop, except for the early production of $\mathbf{T_{12}}$ (Table 1). Among heating strategies, the crop heated at a constant night air temperature of 12ºC ($\mathbf{T_{12}}$) had a significantly lower early and total fresh weight of fruits than the crops maintained totally or partially at higher night air temperatures (Table 1). No significant differences in early and total yield were found between the treatments $\mathbf{T_{14}}$, $\mathbf{T_{14}T_{12}}$ and $\mathbf{T_{14\text{-}12}}$ (Table 1). Within the range of temperatures obtained in this study, the effect of temperature on early and final yield can be approximated by a linear relationship, as shown in Figure 3, where early and total yield were plotted against the mean 24h-temperature averaged over the corresponding crop growth periods. It can be concluded that greenhouse air temperature in the Almería coast limits rather drastically the winter production of snap bean fruits.

Energy consumption

Energy consumption was highest for T_{14} (around 250 MJ m^2) and lowest for T_{12} (120 MJ m^2) as it is shown in Figure 4. The two others heating treatments had a similar consumption of 180 MJ m^2. The heating strategies evaluated consumed only about 10% of the energy currently consumed in North European greenhouses (Baille, 1999). Moreover, the heating strategies $T_{14}T_{12}$ and $T_{14\text{-}12}$ led to 30% energy savings, compared to T_{14}, without affecting the snap bean production, neither the earliness. The heating energy efficiency [energy (MJ) per unit of fruits fresh weight (kg)] was highest for T_{12} (61 MJ kg^{-1}) and lowest for T_{14} (90 MJ kg^{-1}), whereas the $T_{14}T_{12}$ and $T_{14\text{-}12}$ treatments had values closed to T_{12} (63 MJ kg^{-1} and 67 MJ kg^{-1}, respectively). Therefore, the heating strategies $T_{14}T_{12}$, which could be operated by a simple climate controller, appears to be best option for commercial greenhouse growers.

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Table 1. Early (87 dds) and total (126 dds) marketable yield of a snap bean crop under different heating strategies.

Thermal treatments	Early yield (g m^{-2})	Total yield (g m^{-2})
$T_{14}T_{12}$	1074 a	2869 a
T_{14}	954 a	2863 a
T_{14-12}	795 a	2767 a
T_{12}	231 b	1952 b
C	58 b	1123 c

Mean values in a column followed by different letters are statistically different (P<0.05).

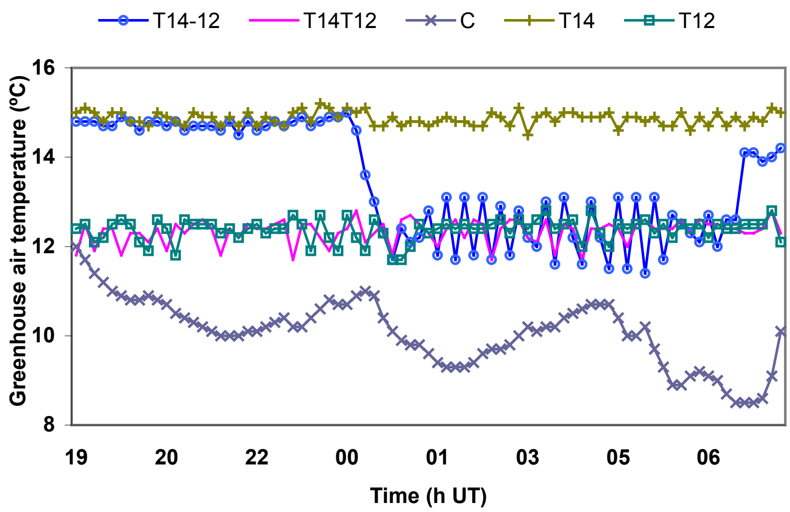

Figure 1. Greenhouse air temperature during a typical winter night of February for different heating strategies.

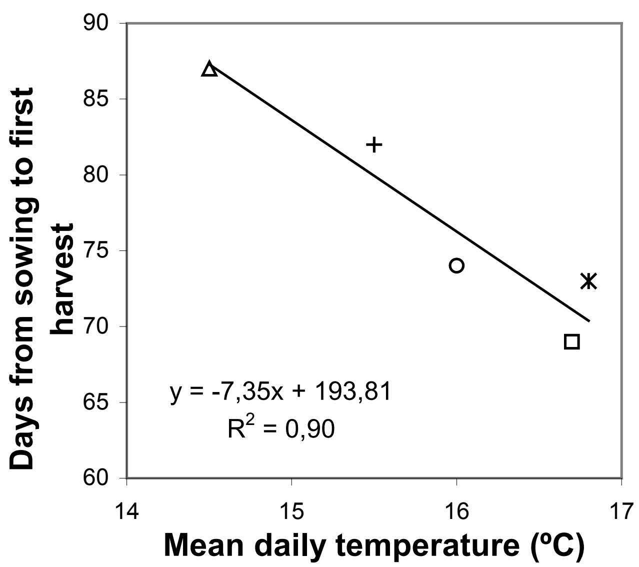

Figure 2. Days from sowing to first harvest versus mean daily temperature averaged for this growth period. (Δ: C; □: $T_{14}T_{12}$; o: $T_{14\text{-}12}$; *: T_{14}; +: T_{12}).

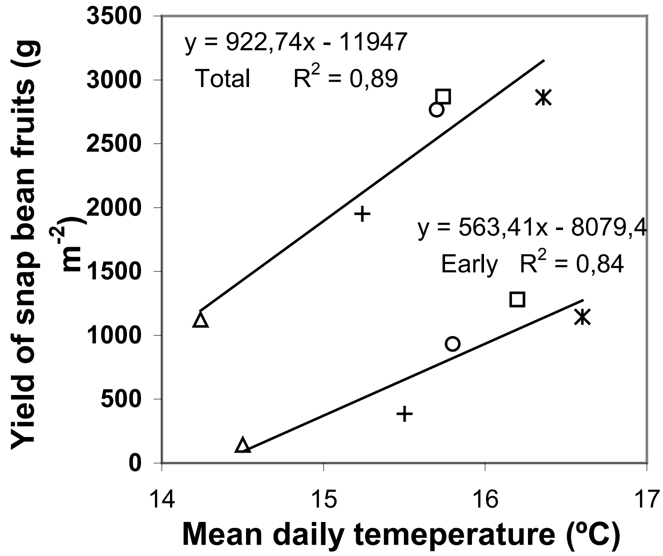

Figure 3. Early (87 dds) and total (126 dds) yield of snap bean fruits versus mean daily emperature averaged for these growth periods. (Δ: C; □: $T_{14}T_{12}$; o: $T_{14\text{-}12}$; *: T_{14}; +: T_{12}).

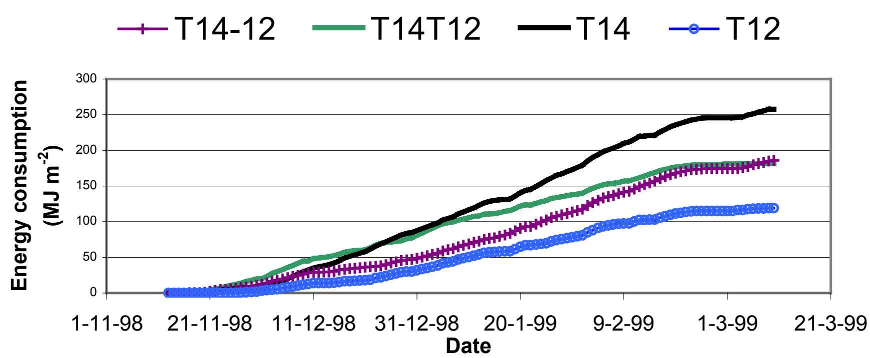

Figure 5. Energy consumption of the 4 heating strategies.