Effect of temperature on melon development rate

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Abstract. The effect of temperature on melon (*Cucumis melo* L.) development was quantified by means of a phenological model proposed for this species. A field experiment was conducted on five melon cultivars: 'DRT' (Charentais), 'Ruidera' (Piel de Sapo type), 'Row' (Yellow), 'Sundew' and 'Max Honex' (Honey Dew type). Air temperature data were collected in the greenhouse and the field at hourly intervals over the growing season by using two thermocouples located 0.5 m above the plants connected to a meteorological station datalogger. The simplified model for calculating Hourly Thermal Units (*UTH*) was used as a function of air temperature. Cardinal temperatures utilized are 10 °C, 34 °C and 45 °C for *Tb* (base), *To* (optimum) and *Tx* (maximum), respectively. The $\sum UTH$ was correlated with the crop development and calculated Plastochron Interval (*PI*). The results identify differences in phenology of cultivars in response to temperature. The *PI* was significantly higher during the initial stage of growth to about five leaves with respect to subsequent stages. These results may indicate the existence of major post-transplant stress, although their causes were not studied here. The methodology used to study the temperature effect on the crop would have a tool for quantifying and predicting crop phenometry in this crop. However, this methodology may be adapted for other crop management systems.

Key words: *Cucumis melo* L., phenology, plastochron interval

INTRODUCTION

The melon crop (*Cucumis melo* L.) is very sensitive to air temperature, not tolerating frosts at any time of its growth. The higher average temperature causes anincreased rate of crop development and is responsible for earlier fruit maturation (Pardossi et al., 2000). The importance of studies that relate this environmental factor with the development of the plant stands out previously by other authors (Jenni et al*.,* 1996; Amuyunzu et al., 1997; Ventura & Mendlinger, 1999; Baker & Reddy, 2001). In general, the temperature produces the strongest impact upon phenological phenomena as compared with other environmental factors (Romanovskaja & Bakšiene, 2009). The knowledge of the effect of temperature on the crop is of great importance for crop growth models (Hakojärvi et al*.,* 2010).

A better understanding of the effect of the temperature on the development would estimate the number of nodes on the main stem, the time of anthesis or the start of fruit set and harvest. However, these responses to temperature can vary depending on the genotypes (Baker & Reddy, 2001) or growth stages (Pérez-Zamora & Cigales-Rivero,

2001). Additionally, the effect of modifying the microclimate, for example with the utilization of soil mulching, must be taken into account if the air temperature is not measured near the plants (Albert et al., 2010).

The traditional methods of accumulation of heat units use the average daily air temperature (Tm) and the base temperature of the crop (Tb) (Baskerville & Emin, 1969). However, a more realistic approach considers not only Tb but also the optimum (To) and maximum (Tx) temperature of the crop. The To is the value of temperature at which the development rate is maximum; the Tx, that value above which the rate is zero.

By means of the computation of the thermal time, it is possible to calculate the plastochron interval (PI) (Streck et al., 2005) which reduces the variability, compared to using the chronological time; it may also provide useful information on differences in development patterns (Silk, 1980).

The aim of this work was to quantify the melon crop development considering its response to temperature, using a phenological model proposed for this species.

MATERIALS AND METHODS

Experimental sites and treatments

A field experiment was conducted in 2008 at the U.N.L.Agricultural Experiment Station, Esperanza, Santa Fe (Argentina) (31°37'S, 60°35'W), on five cultivars of muskmelon: 'DRT' (Charentais); 'Ruidera' (Toad Skin); 'Fila' (Yellow), 'Sundew' and 'Honex Max' (Honey Dew). The transplanting date was 7 October and previously the seed had been sown in the greenhouse in flats (cell size 6.5 x 4.3 x 4.3 cm) filled with a commercial peat-vermiculite mix (Klasmann KTS 3 substrate, Klasmann-Deilmann, Geeste, Germany) on 29 August. The experiment design was completely randomized with four replications (Gomez & Gomez, 1984). The experiment was conducted on 0.9 m wide shaped beds spaced 1.5 m apart, centre to centre. Individual plots consisted of 6.1 m of bed length with 10 plants per plot spaced every 0.6 m, resulting in a density of 11,000 plants per hectare. In one operation, a black polyethylene mulch (0.025 mm thick and 1.2 m wide) and drip tape was applied in mid-September. Two commercial bee hives were placed adjacent to the field plot area prior to flowering.Fertilizers (urea, ammonium sulfate, diamonic phosphate, phosphoric acid, and potassium chloride) were used, and applied in a fractionary manner during the experiment at rates of 160, 24 and 224 kg ha^{-1} for N, P and K, respectively. The soil is a Typical Argiudoll, silt loam (Soil Survey Staff, 1999).

Weather conditions

An automatic weather station (Davis, Weather Wizard III®) with temperature sensors located at 0.5 m above the plants was used to determine hourly temperature values. The average air temperature increased from 18 °C, at the time of planting in the greenhouse, to about 25 °C at the end of the experiment (Fig. 1).

Measurements and analyses

Two plants in each plot were tagged at transplanting. Since leaves are associated with a particular node and these leaves normally senesce as they age, hereafter we refer to node rather than leaf position or number on a vine. The number of main vine nodes on these tagged plants was counted seven times through the growing season, counted as days after seedling emergence (DAE): 13, 24, 37, 49, 63, 77 and 93 DAE. To facilitate counting, the main vines were periodically labelled by loosely tying a length of coloured, non-adhesive, plastic tape around an internode on which the node number of the next youngest adjacent node was recorded.Nodes were counted acropetally with the cotyledonary node being node 0 and the node associated with the first true-leaf being node 1, and thus subsequently. A node was considered to have appeared when its associated leaf exceeded 2 cm in length. The plastochron interval, *PI* (represented as *TU* per node) was calculated as the reciprocal of the slope of the regression of the main vine node number against accumulated hourly thermal units ($\sum TU$). Thermal Units (*TU*) were calculated on an hourly basis according to the method proposed by Baker & Reddy (2001) with *Tb, To* and *Tx* of 10 °C, 34 °C and 45 °C, respectively:

For $T < Tb$; $UTH = 0$

$\quad T \geq Tb$ and $T < To$; $UTH = -14.17 + 1.417 \cdot T$

$\quad T \geq To$ and $T < Tx$; $UTH = 139.09 - 3.09 \cdot T$

$\quad T > Tx$; $UTH = 0$

The number and sex of the flowers were only recorded in the cultivars 'DRT', 'Sundew' and 'Ruidera'. The phenological development was described using the BBCH scale for Cucurbits (Feller et al., 1995).

Statistical analysis

The study results were analyzed by ANOVA table. The differences between variants were determined by the Tukey test and differences at $p \leq 0.05$ were considered statistically significant.

RESULTS AND DISCUSSION

The emergence of the plants (E), when 50% of the plants had cotyledons completely unfolded (BBCH, Code10) occurred six days after planting.Examples of main vine node number vs. accumulated hourly thermal time are shown in Figure 2. As with numerous other crop species, muskmelon main vine node addition was linearly related to accumulated thermal time. However, to linearize the data two lines ($R2 > 0.93$) were used, because the accumulated hourly thermal units ($\sum TU$) showed a consistent linear correlation with the number of nodes on the main stem (Fig. 2). Plastochron intervals (*PI*) were estimated using the reciprocal of the slope of these regressions.

Between emergence and a state of almost five true leaves (BBCH, Code15) the plastochron interval (*PI*) was 5,000 °Ch per node, a value greater than that obtained by Baker et al., (2001). These workers obtained a value of 3400 °Ch per node, but only considering the calculation for the first true leaf.

At this stage of crop development (BBCH, Code15), at 17 days after transplantation, the high value of PI may have been caused by several factors.If plastochron interval were solely a function of ambient air temperature, as calculated by $\sum TU$, one would expect the plastochron interval to be unaffected during the crop development. However, the existence of stress can change the effectiveness of the thermal units. For example, thirteen times during the growth period the hourly temperature was below 10 °C (Fig. 1). Possibly, the exposure of the crop to short-duration chilling temperature can have an effect on growth and development (Major, et al., 1982).
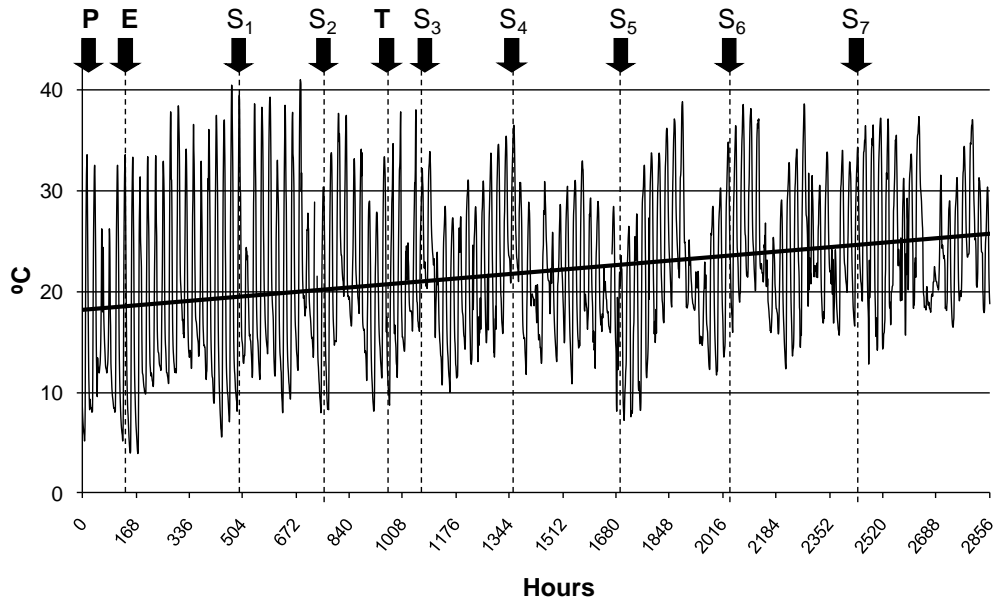

Figure 1.Time temperature recording during the experiment, where each value corresponds to one hour.P, planting; E, 50% emergence of seedlings; T, transplant; and S1 to S7, Sampling date.

Furthermore, the usage of smaller cell sizes may cause numerous physiological and morphological changes of plants in response to rooting volume that can affect transplant quality and performance. In melon, the plant development can be influenced by container size and increased or prolonged root restriction (NeSmith, 1993). Moreover, the relatively low soil temperature during this period (16.8 °C average in September) may have influenced lower crop development (Ibarra, et al., 2001).

During this first period, there was little difference between cultivars, except for some deviations near the end (Fig. 2). This absence of differences in the PI indicate no differences between cultivars in tolerance to early stress, this being the criterion used in tomato to evaluate cold tolerance (Vallejos&Tanksley, 1983). In melon, in early plantings, the effect of low temperatures were also reflected in a higher value of _PI_ compared with later dates (Baker & Reddy, 2001).

Although only the effect of the temperature is discussed here, during the first days after transplantation the intensity of solar radiation was lower; this was a decisive factor in reducing the photosynthetic rate of the crop (Kitroongruang et al., 1992). In

experiments using growth chambers, the temperature and radiation are approximately constant. Under these conditions, the value of *PI* is almost constant, however, under natural conditions this value may differ widely, as was observed in soybean (Vendeland et al., 1982).
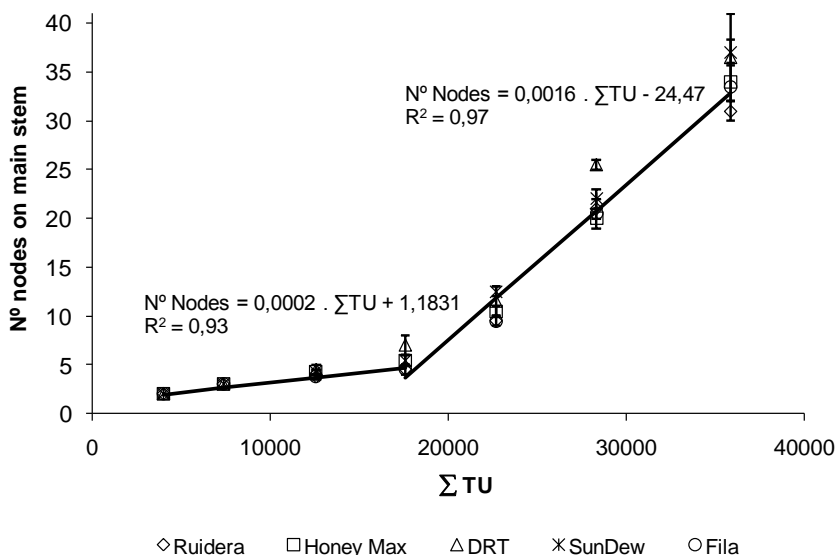

Figure 2. Linear regression between the nodes in the main stem of the plants and the hourly thermal unit accumulated ($\sum TU$) for melon cultivars used in the experiment. The $\sum TU$ correspond to the thermal unit accumulated from the emergence of plants (BBCH, Code10). The bars indicate standard deviation of each mean value.

After the 5th leaf, the regression line changes abruptly with an increase in the slope, indicating a lower average value of *PI* for all cultivars (625 °Ch per node) (Fig. 2).Thus, when plants have surpassed the transplanting stress, with increased temperature and shoot development rate, this resulted in a higher emission of leaves rate. The average value of PI calculated was similar to, but somewhat less than that observed by other authors; for example 908 °Ch per node (Baker & Reddy, 2001), 981 °Ch per node (Timlin et al., 2006) or 798 °Ch per node (Baker et al., 2001).However, differences were observed between cultivars that indicate a more or less rapid rate of development. For example, the cvs. 'DRT' and 'Sundew' had a PI of 588 °Ch per node, indicating a greater response to temperature than in the cv. 'Ruidera' (668 °Ch per node).

Another environmental factor that changed during the experiment was the photoperiod. For example, unlike wheat (Baker & Gallagher, 1983), in melon the plastochron apparently is not modified by the photoperiod (Purcell, 2003). Therefore, the phenological development of melon is appropriately described with the thermal time calculation.The prediction of node appearance is an important part of simulation models of crops with decumbent growth like muskmelon and other cucurbits. One way to predict node appearance is by using the concept of plastochron.

The prediction of the rate of node appearance, by using the concept of plastochron, has been proposed as an appropriate measure to describe plant

development (Streck et al., 2005).However, in the computation of the plastochron interval the frequency of time should be considered for calculation. Although using daily weather data offers the necessary accuracy for estimating growing degree-day values (Streck et al., 2005, 2006), the use of hourly temperaturereadings can improve the prediction, especially considering that the diurnal temperature curves are not symmetrical (Cesaraccio et al., 2001).However, some reports indicate, that for warm-season crops with similar cardinal temperatures, there is no advantage in hourly calculations of thermal units over daily values (Purcell, 2003).
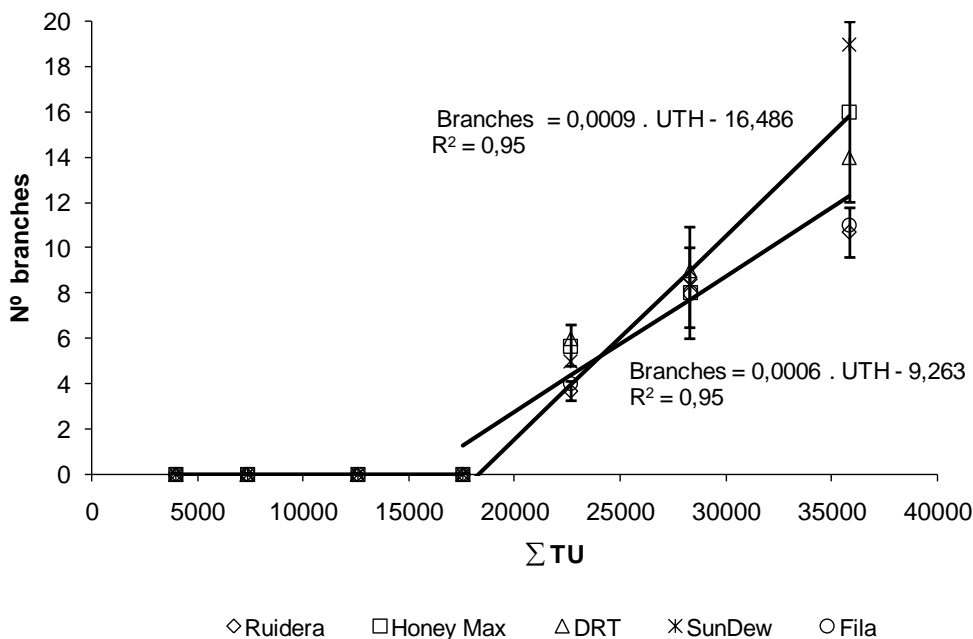

Figure 3. Linear regression between the branch number per plant of the main stem and the hourly thermal unit accumulated ($\sum TU$) for melon cultivars used in the experiment. The $\sum TU$ correspond to the thermal unit accumulated from the emergence of plants (BBCH, Code10). The bars indicate standard deviation of each mean value.

The branching of the main stem began at about 17,500 °Ch (Fig. 3). Here again were observed differences in development between cultivars, because the two cvs. Honeydew ('Sundew' and 'Honey Max') produced a greater number of branches in comparison with the 'Ruidera' and 'Fila'. For its part, the cv. 'DRT' was at an intermediate position to the above groups. Then, linearization of the experimental points indicate differences from the second branch (BCCH, Code 22) that was achieved in 'Ruidera' and 'Fila' with 18,770 °Ch, and 'Sundew' and 'Honey Max' with 20,540 °Ch, although the rate at which these last cultivars released branches was higher (Fig. 3).

According to the results of the PI and the number of primary branches, the highest rate of development of the cvs.'Honey Dew' and 'Charentais' indicate, for example, that nutritional management should probably be different from that of the 'Ruidera' and 'Fila', including special care with nitrogen, due to a greater tendency to luxury

growth (Cabello et al., 2009). These differences in the rate of development are likely to be better understood by counting the number of main stem nodes formed per day (Baker & Reddy, 2001). At the beginning of the period of the budding, 'Ruidera' had a low rate of bud formation with 0.04 nodes per day and 'DRT' the highest, with 0.25 nodes per day, with accumulated hourly air temperature of the 17,573 °Ch, at 49 days after emergence (DAE) (Fig. 3). Subsequently, with increasing temperatures and with an accumulation of 28,315 °Ch at 77 DAE, 'DRT' produced 1.0 node per day and 'Ruidera' 0.82 nodes per day.

These rates of node formation are approaching the maximum values for plants growing in controlled environments at 35 °C (Baker & Reddy, 2001). This method, based in the phenological model in muskmelon and the computation of the *UTH* makes it possible to predict crop development. However, one must consider that some management factors different from those followed here (e.g. pruning or staking plants in the greenhouse) can alter the *PI* or the *UTH* for the set fruit. On the other hand, we must consider that this work was carried out with optimal irrigation scheduling of crops during the entire cycle. However, if these same cultivars are affected by water stress, it would modify the energy balance of the crop, resulting in an increase in plant temperature (Munguia et al., 2004). This situation is likely to produce the differences in PI values obtained in this work.

When considering the total number of leaves formed in relation to *UTH*, the previously observed differences are justified, since in this case are considered not only leaves produced on the main stem but also on the branches (Fig. 4). The differences in temperature response among melon cultivars Honey Dew type ('Sundew' and 'Honey Max'), Charentais type ('DRT'), Yellow type ('Fila') and Spanish Green type ('Ruidera') was very evident.

The results in terms of the *UTH* would have a high degree of repeatability, provided the crop management conditions do not change, since other authors in several years found a high degree of consistency of *UTH* as predictors (Soto-Ortiz &Silvertooth, 2008). However, if the planting had taken place during a period with higher temperatures, a decreased *PI* value in the early stages would be likely to occur (Baker & Reddy, 2001). Thus, with an optimum transplanting system and protection at low temperatures the value of the *PI* could have been lower.

The development rate of 'Ruidera' was more moderate in comparison to 'DRT' and 'Sundew' and there were also differences in the flowering, by changing the flower ratio male / female (Fig. 5). 'DRT' always had four more male flowers than the female or hermaphrodite flower; this situation also was observed in 'Sundew' but only when there was a total of 28,315 °Ch. According to these results, the pattern of flowering was strongly determined by genotype, rather than temperature or light intensity (Wien, 1997).

The early fruits set also corresponded to 'DRT' to the 27,432 °Ch (BBCH, Code 71) (Feller et al., 1995) (Table 1). While both the cv. 'DRT' and 'Sundew' had a high rate of leaf production (Fig. 4), towards the end of the experiment there was no statistical difference between the ratio of leaf area on the number of fruits (Table 2).

Table 1. Mean values and standard deviation of the plastochron interval (PI) (°Ch node^{-1}) and hourly thermal unit accumulated ($\sum TU$) (°Ch) for different phenological stages of melon cultivars expressed through the BBCH Code. S – sowing; E –emergence; 5th L – fifth leaf.

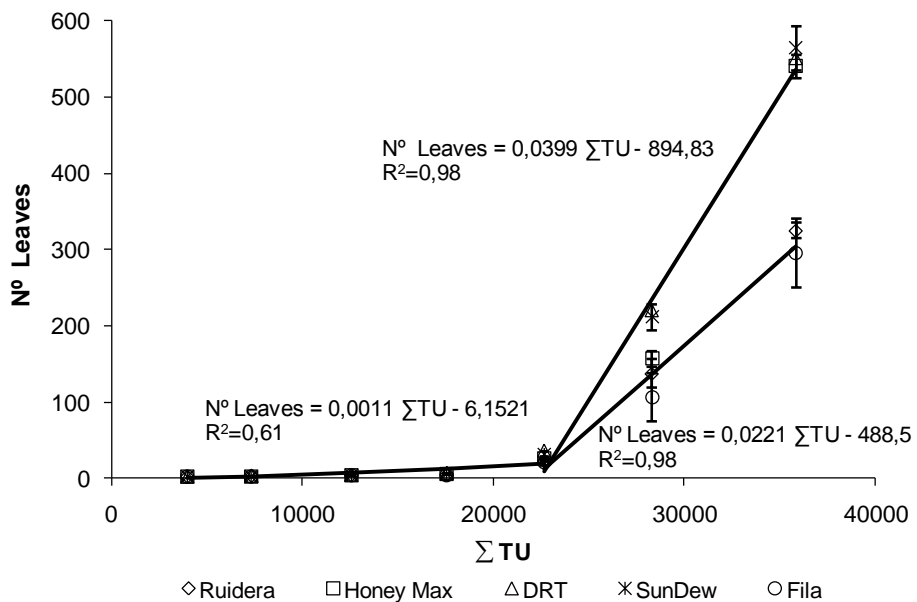| BBCH Code	01–10	10–15	> 15	71
Thermal Time ($\sum TU$)	PI (S–E) (°Ch n^{-1})	PI (E–5th L) (°Ch n^{-1})	PI (> 5th L) (°Ch n^{-1})	PI (Fruit Setting) (°Ch n^{-1})
'DRT'	$1{,}935 \pm 177$	$3{,}322 \pm 513$	588 ± 16	$27{,}432 \pm 944$
'Honey Max'	$1{,}935 \pm 177$	$3{,}746 \pm 578$	625 ± 17	sd
'Sundew'	$2{,}337 \pm 213$	$2{,}073 \pm 320$	625 ± 17	$29{,}956 \pm 1031$
'Ruidera'	$1{,}801 \pm 164$	$3{,}196 \pm 493$	668 ± 18	$28{,}069 \pm 966$
'Fila'	$2{,}222 \pm 203$	$3{,}986 \pm 615$	625 ± 19	sd

Figure 4. Linear regression between the total number of leaves per plant and the hourly thermal unit accumulated ($\sum TU$) for melon cultivars used in the experiment. The $\sum TU$ correspond to the thermal unit accumulated from the emergence of plants (BBCH, Code10). The bars indicate standard deviation of each mean value.

In these cultivars the harvest index was statistically non-significant, although the size of the fruit was significant. However, fruit size is a trait that identifies each genotype (Higashi et al., 1999). For example, 'Ruidera' and 'Fila' produce larger fruits compared to other cultivars, without a direct effect of temperature on the yield component.

Table 2. Leaf to fruit ratio (cm^2 fruit^{-1}), harvest index (*HI*), mean fruit size (kg fruit^{-1}) and yield (kg m^{-2}) for the cultivars used in the experiment in the beginning of harvest.

Cultivars	Leaf / fruit (cm^2 fruit^{-1})	*HI*	Fruit size (kg fruit^{-1})	Yield (kg m^{-2})
'DRT'	1,251 a	0.30 a	1.915 c	5.1 a
'Honey Max'	sd	sd	2.233 b	5.3 a
'Sundew'	1,115 a	0.24 a	2.394 b	4.1 a
'Ruidera'	1,248 a	0.20 a	3.097 a	5.4 a
'Fila'	sd	sd	3.138 a	4.3 a

Means followed by different letters within the same column are significantly different by *Tukey* test at *p≤0.05*.
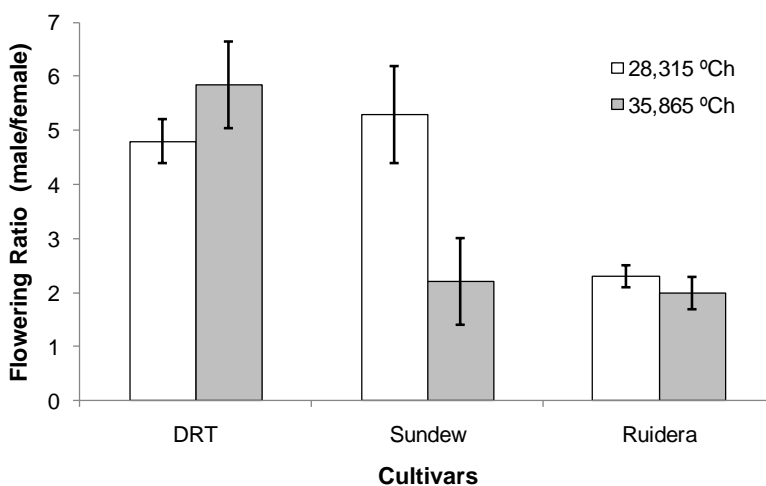

Figure 5. Flowering ratio (male / female) in the plants with two different ∑*TU* (28,315 and 35,865 °Ch, to the days 76 and 92 after emergence, respectively) in the cultivars 'DRT', 'Sundew' and 'Ruidera'. The bars indicate standard deviation of each mean value.

Melon fruits are described as 'dominant' sinks, relative to vegetative growth (Long et al., 2004). In the genotypes with smaller fruits (i.e. 'DRT', Table 2), a greater number of fruits is able to attract more assimilates but with decreasing efficiency as the average fruit weight decreases. Such behaviour shows that fruits do not have absolute priority over assimilates from the vegetative organs (Long et al., 2004). Moreover, in the case of 'DRT' there was no fruit production in 'cycles' (Valantin et al., 1999) but it was constant during this phase of development (BBCH, > Code 71). The absence of yield statistical differences in the cultivars (Table 2), indicates a strong compensation between the different components of yield. Apparently and according to these results, these components of yields appear to be affected indirectly by temperature.

CONCLUSIONS

The results indicated differences in the melon cultivars development in response to temperature, mainly among the early cultivars ('Sundew', 'DRT', 'Honey Max') and late ('Row' and 'Ruidera'). In addition, the plastochron interval (*PI*) in all genotypes was higher during the initial stage of growth (up to 5th leaf) compared to later stages. Despite these differences in the development and *PI*, the final yields were not statistically different. The methodology used to study the effect of temperature on the crop would provide a tool to quantify and predict crop development. However, in cases of different management systems, fruit growers may need to adapt the system followed here.

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