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CONTAINER SIZE EFFECT ON THE PLANT PRODUCTION AND PRECOCITY IN TOMATO (*SOLANUM LYCOPERSICUM* L.)

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Abstract

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This work compares the growth and yield of tomato crop from the study of different plant development stages and container sizes. Two experiments were conducted in order to examine the effects of container size during spring-summer of the years 2012 and 2013. In the first experiment was conducted in a greenhouse to measure the effect on the initial yield. A second experiment was performed outdoors to incorporate the effect of plant age on the development and yield. Commercial hybrid tomato seeds (*Solanum lycopersicum* L.) of the cv. 'Tauro' were dry sown in containers of different volumes (20, 40, 70 and 350 mL) and with variable transplant times (14, 21, 28 and 35 days). We found that an increase in the container size results in plants of higher size, precocity and yield. The physical restriction of root by the use of containers with low volumes (20 mL) severely limited the plant growth beyond the 14 first days after sowing, being worse with increasing plant age. From an age of 28 days, in all the treatments except for a volume of 250 mL, the fruit yield diminished from the values found without container size restrictions.

Key words: rooting volume, root restriction, seedling age, maturity, yield

Introduction

The use of high densities in the production of horticultural plants, allows economy of the unitary costs (Marr and Jirak, 1990; Leskovar and Vavrina, 1999). In the case of tomato, these systems should be compatible with the production of high quality plants, which is essential for a successful transplant. The condition of the plant at the moment of the transplant affects its establishment phase, harvest precocity, total yield and fruit size (Weston and Zandstra, 1986). The factors affecting desirable characteristics of the plant before transplants are the container size, the mineral nutrition before and after transplants, and the age of the plant at transplant (Weston and Zandstra, 1986; Widders, 1989). About the container size there are ample evidences that the physical restriction of the available volume for the root growth limits the plant growth (Ruff et al., 1987). Recently, for the case of tomato it was possible to determine that the decrease of the available volume for the root growth decreases the photosynthetic capacity of the plants, with physiological mechanisms similar to those of the water stress (Shi et al., 2008; Shopova and Cholakov, 2014). The first authors in a former work found that the reduction of the available root volume caused an oxygen deficiency because of the induced radicular high density (Shi et al., 2007).

The confinement of the radicular system leads to changes in the communication process from the root to the aerial parts of the plant (Ternesi et al., 1994), to nutrient deficiencies as consequence of the restriction of the root growth (Rieger and Marra, 1994) and hormonal imbalance, especially for cytokinin and gibberellins (Carmi et al., 1983), as well as abscisic acid (Ternesi et al., 1994).

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The usage of small container volumes is an increasing trend since a few years ago, and due to the use of trays with high plant density, the plant maturity is delayed as well as the start of the harvest (Marr and Jirak, 1990). The root growth is not only affected by the container size but also by its shape and depth (NeSmith and Duval, 1984). Even with cells of the same shape and size, depending on the roughness of the internal wall of the cells, differences in the root growth are found (Liptay and Edwards, 1994). However, from a certain stage in the plant growth, the container volume starts to be restrictive of the root growth. Furthermore, higher plant density due to use of small containers exerts a stronger influence on the physiological features related to the quantity of the synthesized photosynthetic product (Shopova and Cholakov, 2014). This finding requires further investigation to determine the relation between the permanence time of the plant at the nursery and the container size used.

The aim of this work is to compare the growth and yield of tomato crop with plants produced using different container sizes and different chronological ages at the moment of transplant.

Materials and Methods

Seeds of the commercial hybrid "Tauro F1" (Clause) were dry planted in containers of different sizes, and the later tomato plants (*Solanum lycopersicum* L.) of different ages were transplanted to the fields. In the nursery stage, the seedlings were grown in a greenhouse with polyethylene of long thermal duration 150 µm thick. The greenhouse was adapted to the production on horticultural plants, with benches 0.8 m height and fertigation with sprinklers. Two experiments were conducted in order to examine the effects of container size during spring-summer of the years 2012 and 2013. In the first experiment was conducted in a greenhouse to measure the effect on the initial yield. A second experiment was performed outdoors to analyze the effect combination of cell size and plant age on the crop development and yield.

The following containers were used: i) black polyethylene pots 50 um thick (7.3 cm diameter, 8.0 cm height and 350 mL volume) (V350); ii) plastic trays (32.5 cm × 27.0 cm, 30 cells of 4.3 cm side and 4.0 cm depth with 70 mL per cell) (V70); iii) polystyrene trays (60.5 cm × 39.5 cm; 126 conic cells of 3.5 cm side and 6.7 cm depth with 40 mL volume) (V40); iv) polystyrene trays (51.5 cm × 32.5 cm; 280 rectangular cells of 1.8 cm side and 6.1 cm depth, and 20 mL volume) (V20). Before sowing the containers were manually filled with soils made out of 20% perlite and pre-mix made of 80% peat (Sunshine Premix N° 6, SUNGRO-Horticulture, Canada), the mixture was homogenized with cement mixer, and proportions were calculated as volume ratios. The date of sowing and transplant was in the first experiment August 10th and September 19th, respectively. In the second experiment, the sowing date was: on December 29th, January 5th, 12th and 19th so that at the transplant on February 2nd, plants were 35, 28, 21 and 14 days old, respectively. The treatment was a factorial combination which means 4 × 4 treatments of the different container volumes (V350, V70, V40 and V20) and plant age (14, 21, 28 and 35 days).

During growth at the nursery a spraying irrigation of 5 mm daily was split in two applications over the day. After the 7th day a nutritional solution containing 300 ppm N, 100 ppm P, 100 ppm K, 95 ppm Ca and 30 ppm Mg, was applied once a day.

In the two experiments, the plants were transplanted manually to the field on an Argiudol soil with a typical loamy-sandy texture, at Angel Gallardo (31°30'S y 60°43'W) known as "Horticultural Belt" of the city of Santa Fe, Argentine. In the 2012, the experiment was in a greenhouse, and the crop was done in rows separated 1.50 m and with plant distance of 0.25 m within the row, giving a population density of 26 000 plants per ha^{-1}. In the second experiment was in outdoor, and the crop was done in rows separated 1.40 m and with plant distance of 0.35 m within the row, giving a population density of 20 400 plants per ha^{-1}. The plants were vertically guided to a single shoot by disbudding of lateral buds and using a stake per plant till a height of 1.80 m, when the apical bud was removed. The crop was drip fertigated applying a total of 250 kg ha^{-1} N, 80 kg ha^{-1} P and 350 kg ha^{-1} K over all the cycle. The phytosanitary management in both experiments was the standard recommended for the region.

In both experiments, the experimental design was random blocks in 3 repetitions per treatment. Each experimental unit comprised 7 m of a row with 20 plants. The statistical data analysis was performed with Statgraphics® software. The experiment finished on April 9th, coincident with the harvest start. During the growth stage at the nursery as well as during crop, the hourly temperature was recorded with a data logger (Cava-Logger, Model LM35/01).

In the first experiment only and initial (30 days) yield (kg m^{-2}) were determined. And in the second experiment the dry total matter and per organ weight (g), plant height (cm), number of leaves, foliar area (cm^2 plant^{-1}), plant age at anthesis (days), and yield (kg m^{-2}), were determined. Root weight was determined at transplant. For the dry matter weight measurements, a heater with air circulation at 65°C temperature was used until the weight remained constant. The foliar area was estimated using an allometric equation (Astegiano et al., 2001) relating the leaf area (LA), maximum length (L) and maximum width (A) for each leaf:

$$LA = 0.34(L \times A) - 9.31 \quad (1)$$

Results and Discussion

Average temperatures during the growing season were 24.7 and 21.5°C for the first and second experiment, respectively. The higher temperature in the first experiment was mainly due to the greenhouse effect.

In the first experiment, and after 7 days of starting the harvesting, V20 treatment reached a value in kg m^{-2} several times lower than the other treatments. Later, at 30 days, the V350 reaches a value between 30–40% higher than the V40 and V20 treatments; respectively (Figure 1). These results are representative of the field experiences of the authors and that several years ago were observed by Liptay and Edwards (1994) in tomato, and Porter et al. (2012) for others plant species. Based on these lines of evidence and for a more detailed study the second experiment was conducted to evaluate the effect of container size and transplant age on crop development and yield. This hypothesis is strengthened further by the recent results published by Shopova and Cholakov (2014). These authors studied the effect of the influence of the seedlings age and growth area for late field tomato production, concluding that the physiological potential was affected by age and area of growth of seedlings.

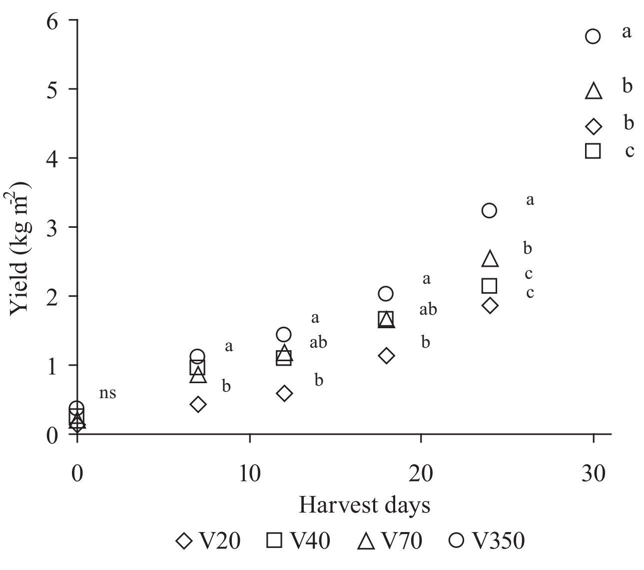

Fig. 1. Effect of treatments as function of the container size (20, 40, 70 and 350 mL; V20, V40, V70 and V350; respectively) on yield (kg m^{-2}) in the first 30 days of harvest

Values with different letters in each date are significantly different according to Tukey test ($P < 0.05$)

In the second experiment, the visual aspect of the plants at the transplant evidenced differences caused by the treatments (Figure 2). The treatment V350 resulted in bigger sized plants (measured as weight of dry mass) compared to the other treatments ($P \leq 0.05$) (Table 1), independently of plant age. For example, starting from 14 days, plants grown in the treatment with the smallest container (V20) showed a reduction of about 60% weight of total dry mass compared with the treatment using the biggest volume (V350) (Table 1). Even treatments V40 y V70 also presented a smaller growth with significant statistical differences ($P \leq 0.05$) respect to treatment V350. The observed results during plant growth indicate that the onset of the perception of stress due to radical confinement occurs during the first stages of development. This has been observed in other works in tomato, showing that plants grown in volumes of 25 mL had a growth decrease already at 18 days in comparison with plants grown in bigger volumes (1500 mL) (Peterson et al., 1991).

At 28 and 35 days the differences in growth of the plants under treatment V350 were 12 times higher than for treatment V20 (Table 1). For 35 days old plants the total dry mass weight (TDMW) showed an exponential relation with the container volume (V) [TDMW = 0.267 exp (0.007 V)]; R^2 = 0.97). The increase of the dry mass with container volume was also found in another work, that used container volumes of 3.3; 27.0; 37.1 and 80 mL, but a quadratic relation was found (Kemble et al., 1994).

The size of the plants could be partially modified by the mineral nutrition, besides the effect of radical confinement. This might explain the results on tomato plants of Weston and Zandstra (1989). The authors used a container volume of 18.8 mL, to obtain plants with a higher weight of dry mass than those obtained in this work (V20 treatment) for the same age. The authors of that work used similar thermal and photoperiodic conditions to those of our work, but applied a 30% higher concentration of N in the fertigate.

The leaf area was higher for the higher sized containers and higher aged plants (Table 1). At 35 days of life the leaf area in treatment V350 was five times higher than in treatment V70. The height reached by the plants and the number of leaves followed the same trend as the leaf area. The higher leaf area in treatment V350 was due not only to the higher number of leaves but also that those leaves were bigger sized (more than 20 cm^2) starting from day 21st, in comparison to the other treatments that never exceeded 7 cm^2 per leave (data not shown). This marked reduction in plant growth and especially in leaf area, due to radical restriction, was found not only for tomato (Weston and Zandstra, 1986), but for other horticultural species, like peppers (Weston, 1988), cabbage (Csizinszky and Schuster, 1993), water melon (Liu and

Latimer, 1995) and zucchini (NeSmith, 1993). All those authors agree that the smaller values of leaf area were due both to the decrease of the area per leaf, as well as to the decrease in the number of leaves.

The radical restriction exerts an initial effect on the plant growth, but also with smaller container volumes, the plant density in the area increases, so does the competence for aerial resources, like light (NeSmith and Duval, 1984). For example, treatment V350 had a plant density of 249 plants m^{-2}, while for V70, V40 and V20 was of 341, 527 and 1673 plants m^{-2}, respectively. In other works using volumes of 7 mL, 35 mL and 230 mL, modifications in the morphology of the tomato plants were observed, as well as modifications in the dry mass weight and foliar area (Mugnai et al., 2000).

Fig. 2. Plant size at transplant in the second experiment (2013): (*a*) 14 days; (*b*) 21 days; (*c*) 28 days and (*d*) 35 days

From left to right, in each case: plants undergoing treatments V350, V70, V40 andV20, respectively

Table 1
Changes in dry mass weight (g), number of leaves, leaf area, LA (cm^2) and height, H (cm) for tomato plants transplanted on February 2nd, as function of the treatments with different container volumes and permanence time at the nursery in the second experiment (2013)

Age,	Container	Dry weight, g (*)				Leaves,	LA,	H,
Days		Leaf	Stem	Root	Total	Nr.	cm^2	cm
14	V350	0.092^{a}	0.022^{a}	0.032^{a}	0.146^{a}	2.0^{a}	16.8^{a}	5.0^{a}
	V70	0.065^{ab}	0.011^{b}	0.033^{a}	0.108^{b}	2.0^{a}	11.8^{b}	5.0^{a}
	V40	0.061^{bc}	0.011^{b}	0.031^{a}	0.103^{b}	2.0^{a}	11.1^{b}	5.0^{a}
	V20	0.035^{c}	0.007^{c}	0.015^{b}	0.058^{c}	2.0^{a}	6.4^{c}	4.0^{a}
21	V350	0.438^{a}	0.168^{a}	0.228^{a}	0.834^{a}	4.2^{a}	83.5^{a}	14.5^{a}
	V70	0.092^{b}	0.035^{b}	0.073^{b}	0.200^{b}	3.8^{a}	17.6^{b}	9.4^{b}
	V40	0.087^{bc}	0.031^{b}	0.051^{b}	0.169^{b}	3.7^{a}	15.8^{b}	8.0^{b}
	V20	0.059^{c}	0.017^{c}	0.020^{c}	0.096^{c}	3.7^{a}	11.3^{c}	7.0^{b}
28	V350	0.980^{a}	0.720^{a}	0.550^{a}	2.250^{a}	6.1^{a}	144.1^{a}	35.0^{a}
	V70	0.169^{b}	0.112^{b}	0.115^{b}	0.396^{b}	5.2^{b}	28.2^{b}	18.4^{b}
	V40	0.153^{bc}	0.130^{b}	0.089^{b}	0.372^{b}	4.8^{b}	24.2^{b}	15.2^{b}
	V20	0.106^{c}	0.045^{c}	0.037^{c}	0.187^{c}	4.1^{c}	15.6^{c}	13.0^{c}
35	V350	1.140^{a}	1.020^{a}	0.691^{a}	2.851^{a}	7.3^{a}	190.4^{a}	50.4^{a}
	V70	0.234^{b}	0.119^{b}	0.140^{b}	0.493^{b}	5.1^{b}	34.4^{b}	25.5^{b}
	V40	0.165^{bc}	0.140^{b}	0.109^{b}	0.414^{b}	5.8^{b}	25.5^{c}	20.0^{c}
	V20	0.110^{c}	0.073^{c}	0.051^{c}	0.234^{c}	3.7^{c}	18.4^{d}	15.0^{d}

(*) The different letters in each column corresponds to significant differences according to Tuckey for $P \leq 0.05$

Considering the quantitative effect for the competence for light, the tomato leaves adapt to a low photosynthetically active radiation (PAR) by increasing the specific foliar area, thus diminishing their respiratory rate (Boardman, 1977). This means a plasticity reaction of the plants to the density increase. However, the increase of the specific leaf area brings an unfavorable aspect at the moment of transplant, facilitating the dehydration of the leaves when in the field and increased of water stress (Evans and Pooter, 2001). Besides, as observed in *Amaranthus spp*., the specific leaf area might be inversely related with the water use efficiency, even in plants with full water supply (Liu and Stützel, 2004). Analyzing the qualitative effect of the solar radiation, it was observed that the morphological development of young tomato plants measured by the phytochrome is altered even by subtle changes of the light composition (Decoteau et al., 1989). With a plant density increase, the relation Red (R): Far-Red (FR) in the light spectrum decreases, in addition to an increment of the horizontal reflection (HR). This induces the "shadow avoidance" response, which causes an upward movement of the leaves (hyponasty) and elongation of the stem (de Witt et al., 2012). Even though in this work only quantitative changes were measured, at 14 days significant differences in the development of plants due to the treatments were first noticed (Figure 2a), and by 35 days the differences became outstanding (Figure 2d). In plants under the least volume treatment (V20), longer length hypocotyls were observed (Figure 2c).

Analyzing the development after the transplant, it was determined that the observed differences with age of the plants and container sizes had an effect in the ulterior foliar development of the crop. At the end of the experiment, in plants with already 35 days, the leaf area index of the treatment V350 gave 45-58% higher values than the other treatments (Table 2). In a crop starting from 14 days old implanted plants, this differences were lower, with values for V70 and V20 being 3% and 30% higher, respectively, than for V350 (Table 2). A higher radical restriction for the older plants in smaller volume containers resulted in significant differences ($P \leq 0.05$) in growth (Table 2) and yield (Table 2), this last depending on the plant age. For example, when the transplant was performed at 14 days, there were no statistical differences in the production of fruits ($P \leq 0.05$) (Table 2), independently of the container volume used.

The total yield of fresh fruit (commercial and non-commercial) at the end of the experiment had a maximum value in 35 days old plants for treatment V350, while for the other treatments plants staying longer than 28 days started to show a yield decrease (Figure 3). The differences were remarkable in 35 days old plants under treatment V350, doubling the

Table 2
Changes in dry mass weight (g), number of leaves, leaf area, LA (cm^2) and height, H (cm) for tomato plants at the end of the experiment on April 9th, as function of the treatments with different container volumes and permanence time at the nursery in the second experiment (2013)

Age, Days	Container	Dry weight, g (*)					Leaves, Nr.	LA, cm^2	H, cm
		Leaf	Stem	Flower	Fruits	Total			
14	V350	81.4^{a}	24.5^{a}	4.8^{a}	63.1^{a}	173.8^{ab}	20.3^{a}	14835^{a}	120^{a}
	V70	78.5^{a}	24.5^{a}	6.0^{a}	80.8^{a}	189.8^{a}	20.1^{a}	14307^{a}	120^{a}
	V40	68.4^{a}	22.5^{a}	4.6^{a}	68.2^{a}	163.7^{b}	20.1^{a}	12466^{b}	114^{b}
	V20	62.2b	25.0^{a}	5.7^{a}	43.4^{a}	136.3^{b}	18.8^{b}	11336^{c}	114^{b}
21	V350	85.8^{a}	30.6^{a}	8.6^{a}	104.4^{ab}	229.4^{ab}	22.1^{a}	16366^{a}	150^{a}
	V70	80.9^{b}	26.2^{b}	7.3^{b}	124.8^{a}	239.2^{a}	20.3^{b}	15432^{b}	139^{b}
	V40	70.8^{b}	25.9^{b}	7.5^{ab}	78.7^{b}	182.9^{b}	20.1^{b}	13505^{c}	138^{b}
	V20	66.3^{b}	25.8^{b}	5.2^{b}	78.0^{b}	175.3^{b}	19.7^{c}	12647^{c}	134^{c}
28	V350	97.6^{a}	31.3^{a}	8.5^{a}	171.6^{a}	309.0^{a}	23.0^{a}	14347^{a}	154^{a}
	V70	83.0^{b}	31.2^{a}	7.3^{b}	138.4^{b}	259.9^{ab}	21.8^{b}	11863^{b}	145^{b}
	V40	72.7^{c}	29.2^{b}	7.3^{b}	101.1^{ab}	210.3^{b}	21.5^{b}	10393^{bc}	143^{b}
	V20	70.0d	26.0^{c}	4.6^{c}	95.7^{b}	196.3^{b}	21.4^{b}	8820^{c}	140^{c}
35	V350	100.3^{a}	36.5^{a}	7.3^{a}	179.3^{a}	323.4^{a}	25.5^{a}	16750^{a}	162^{a}
	V70	85.0^{a}	34.2^{ab}	5.2^{bc}	94.4^{b}	218.8^{b}	23.2^{b}	10637^{b}	122^{b}
	V40	78.0^{ab}	33.1^{bc}	5.9^{ab}	91.6^{b}	208.6^{b}	21.5^{c}	11506^{bc}	120^{b}
	V20	72.0^{b}	28.9^{c}	4.7^{c}	86.9^{b}	192.5^{b}	19.6^{c}	10558^{c}	105^{c}

(*) The different letters in each column corresponds to significant differences according to Tuckey for $P \leq 0.05$

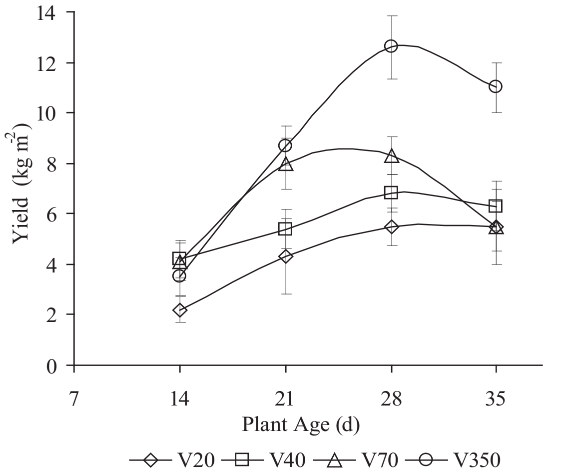

Fig. 3. Changes observed in fresh fruits (kg m^{-2}) as function of the container size (20, 40, 70 and 350 mL, V20, V40, V70 and V350; respectively) and plant age (days) in a nursery at the end of the second experiment on April 9th
The bars on each point give the standard deviation from the average values

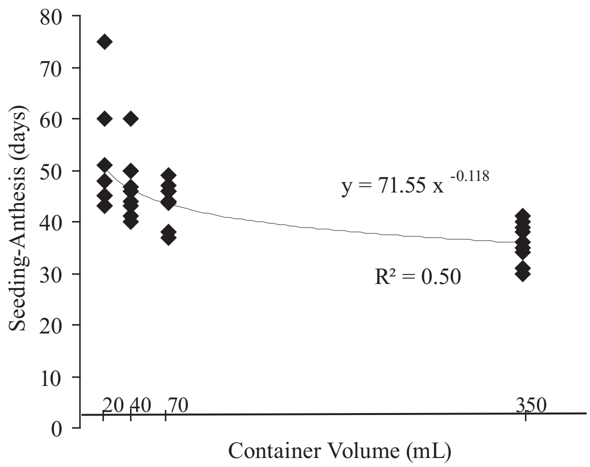

Fig. 4. Regression curve of the average values of number of days between sowing and anthesis for each volume (mL) of container in the second experiment (2013)

yield of all of the other containers with plants of the same age (Figure 3). Regarding the precocity, and calculating the average age values per container volume, an inverse proportional relation was observed between the days to anthesis and the container volume (Figure 4). The difference between V350 and V20 was 15 days (Figure 4). This was already measured by other investigations for transplants at 35 days, who determined that the bigger the container volume, the higher the anthesis precocity (Kemble et al., 1994). Analysis of quantitative trait locus (QTLs) respective to transplant age in tomato showed that the roots could exert an influence on the gene expression for floral anthesis (Sumugat et al., 2011).

To compensate for the weakness of tomato plants produced in high-density trays, treatments with very low temperature watering have been proposed (5ºC) (Sun et al., 2010). Nevertheless, the treatment would not be able to overcome the stress caused by the physical restriction to root growth. For example, in treatments with lower volumes and 35 days old plants for transplant, the decrease in the precocity could be due to the initial difficulty in resuming the root growth after transplant. This can be explained not only by the lower size of the radical system at the moment of transplant (Table 1) but also by the alterations caused in the normal morphology by a reduced size container. This was point out long ago by Ruff et al. (1987).

Besides the alteration in growth, it was observed that the root weight was notably affected by the treatments, especially when comparing differences in root weight at 14 and 35 days (Table 1). Root weight for treatment V350 at 14 days was already double than in treatment V20, and at 35 days it was thirteen times higher (Table 1). The lesser growth in the lower volume containers reveals the direct effect made by the containers. It is expected that in the treatments of lower volume the radical density should increase (cm cm^{-3}), as observed in *Salvia splendens* (van Iersel, 1997). Though actually it wasn't measured in this work, exactly this situation exposes the roots to a competition for oxygen, possibly being the reason of the lower plant growth (Shi et al., 2007). This hypoxia was already noticed in tomato plants grown in 25 mL containers, producing symptoms similar to flooding (Peterson et al., 1991). This effect would be related to an increment of the ethylene synthesis, since hypoxia stimulates the production of this hormone, through the activity increase of key enzymes such as 1-aminocyclopropane-1-carboxylate synthase (ACC) and ACC oxidase (Wang et al., 2002). In the root cortex the visible effect of the hypoxia is the formation of aerial spaces or parenchyma (Campbell and Drew, 1983). In a similar work on cauliflower we have observed the formation of aerenchyma as well as a remarkable increase of the ethylene emission, for 20 mL containers and 50 days old plants (recent data still not published).

Finally, the obtained results will allow a better technical decision making about the selection of the containers and the permanence time of the plant in the nursery. Besides, the results were in agreement with the observed behavior in similar work done on tomato and other horticultural species. Nevertheless, it is recommended to do further studies including the environmental conditions and the genotypes.

Conclusions

The volume increase of the containers allowed obtaining plants of higher size, with a significant increase in weight and foliar area. Besides, the onset of the crop flowering accelerates with increasing of volumes. The physical restriction imposed by the lowest size container (20 mL) severely limited the plant growth after the first 14 days from sowing, and becoming worse with increasing age of the plants. An inverse proportional relation was found between the container size and the precocity, measured as the number of days between the floral anthesis and the first inflorescence. After 28 days, all the treatments, except the treatment with a 250 mL volume, started to decrease the yield of the fruits. In summary, the results gave evidence about the effect of the container size on the crop development and yield, and are in agreement with other formerly reported experimental works.

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