Growth of three color hybrids of sweet paprika under greenhouse conditions

Crecimiento de tres híbridos de pimentón de colores en condiciones de invernadero

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ABSTRACT

The color varieties of sweet paprika are conquering the Colombian vegetables markets, not only because of their fancy colors, but also because they are one of the best sources of ascorbic acid and carotenoids as well as phenolic compounds, important in the human diet. Therefore, basic studies related to the growth and development of the available imported varieties under greenhouse conditions on the Bogota Plateau are required. In a completely randomized block design with five replicates, biometric parameters of the hybrids Plinio, Menta RZ and Orangery were evaluated, showing that the latter one was statistically different for leaf area, leaf area index and number of leaves during the 20 study weeks, while the dry matter in the leaves, stems and roots showed no differences between the varieties. Although, 'Orangery' exhibited the highest percent of final allocation of accumulated dry matter in the fruits, being, in general, the most promising hybrid for cultivation under the research conditions.

Key words: vegetables, Bogota Plateau, leaf area, dry matter, fruit color.

RESUMEN

El pimentón de colores está conquistando el mercado de hortalizas colombianas, no solamente por sus bonitos colores, sino también por ser considerado uno de las mejores fuentes de ácido ascórbico, y carotenoides, como también de compuestos fenólicos importantes en la dieta de los humanos. Por lo tanto se requieren estudios básicos relacionados con el crecimiento y desarrollo de las variedades disponibles, importadas, bajo condiciones de invernadero en la Sabana de Bogotá. En un diseño de bloques completamente al azar, con cinco repeticiones, se evaluaron parámetros biométricos de los híbridos Plinio, Menta RZ y Orangery, mostrando que este último se diferencia estadísticamente en los parámetros área foliar, índice del área foliar y número de hojas durante las 20 semanas del estudio, mientras que la materia seca en hojas, tallos y raíces no mostró diferencia entre ellos. Igualmente, 'Orangery' presentó el mayor porcentaje de distribución final de materia seca acumulada en los frutos, lo que en general muestra a ese híbrido como el más promisorio para ser cultivado bajo las condiciones mencionadas.

Palabras clave: hortalizas, Sabana de Bogotá, área foliar, materia seca, color de frutos.

Introduction

Paprika, bell or sweet pepper, varieties of *Capsicum annuum* (L.), grown under greenhouse conditions, can reach, according to the quality and health, prices up to five times higher than those of varieties cultivated outdoors, especially if they are marketed when the fruits have taken the typical variety color, red, orange, yellow, cream, chocolate or purple (Jovicich *et al*., 2004). The "bell cultivar group" shows large, rectangular, not spicy fruits, which, when ripe, can be red, yellow, green, orange, white, purple, blue, or even brown depending on the specific cultivar. In Colombia, just recently, colored paprika varieties have been introduced and have been marketed profusely in diverse supermarkets, mainly used as decorative ingredients in salads and other fancy dishes. The main marketed colors are orange, red and green. From a health point of view, the fruits are of importance, as shown by Sun *et al.* (2007) who investigated the antioxidant compounds and activity in four different colored, green, yellow, orange and red, sweet bell peppers, detecting in all of the varieties a high total phenolic content; all of the colored sweet peppers revealed substantial abilities in preventing the oxidation of cholesterol or docosahexaenoic acid. Ghasemnezhad *et al.* (2011) even considered that consumer interest in colored bell peppers is mainly due to the content of bioactive compounds and their importance as dietary antioxidants. Different studies have also demonstrated that, for example, the sweet red pepper is one of the best sources of ascorbic acid and carotenoids as well as phenolic compounds that are important in the human diet (Hallmann and Rembiałkowska, 2012).

Up to now, aspects of the growth and development of the different color varieties have not been studied in Colombia and their management depends only on the instructions

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provided by the seed companies, which are introducing the planting material.

The botanical family Solanaceae is recognized worldwide for including important cultivated vegetables and ample agronomic utility of the species, mainly of the genera *Solanum* and *Capsicum* (SOL, 2004). Colombia, which is situated in the tropics and subtropics, can ensure the continued production of many species of this family, representing promising alternatives with better opportunities to ensure competition in global market scenarios.

Therefore, a growing demand for fruits, for example *Capsicum* species, both sweet and spicy, can be observed in the country, using imported materials for planting. Only recently, a variety of sweet and hot paprika has been cultivated profusely and, in view of its good profitability, production and export possibilities, has started to expand. Currently, production is concentrated in the departments of Santander, Valle del Cauca, Huila and Antioquia with 656, 532, 412 and 349 ha, respectively; corresponding to 79% of the cultivated area nationwide, during the period 2000-2009, the highest production was obtained in 2002, reaching 54,796 t, grown in 2,480 ha (Casilimas *et al*., 2012).

In the Amazon region, Solanaceae is the most cultivated genus, by the diverse ethnicities, being part of their cultural heritage, which has resulted in varieties adapted to different environments and agricultural requirements; unfortunately, they have not been evaluated for commercial purposes. The Amazon is considered the center of origin of *C. annuum*, *C. chinense* and *C. frutescens* due to the morphological, reproductive and molecular variations seen in the genus *Capsicum* as mentioned by Melgarejo *et al*. (2004).

Growth, as indicated by Cebula (1995) for sweet paprika, is the increase in the size of the total plant or part of it, which can be expressed as dry matter or in dimensions due to the formation of new cells; the growth rate, therefore, is stated as weight, volume, area and length increases per unit time.

Generally, the plant growth rate decreases with increasing sizes until it becomes zero when it reaches maturity or final dimension. According to Daşgan and Abak (2003), development is an orderly and progressive change, often, to a more ordered and complex stage.

To describe the growth and development of crops, it is necessary to identify phases and stages within the development and predict of each span at different temperatures (Wurr *et al*., 2002; Soto-Ortiz *et al*., 2006; Soto-Ortiz and Silvertooth, 2008). For *Capsicum* sp., Torres (2009) suggested four phenological phases: emergency, seventh leaf, flowering and maturity; meanwhile, the USDA (2010) identified three specific phases: 50% from planting to thinning; 75% from thinning or transplanting to fruit tying and 100% from fruit tying to harvest or harvest finishing. The flowering period fluctuates between 70 and 93 d, fruit ripening starts at 85 d in the most precocious varieties and at 107 d in the more delayed ones (Silva Filho *et al*., 2004).

Phenology comprises the study of biological phenomena that are related to certain periodic rhythms or phases and their relationship with the environment where they occur. In their cycles, plants suffer visible changes that are influenced by the genotype, the ecosystem and their interaction (Mundarain *et al*., 2005). From the point of view of environmental supply, climate, temperature, and radiation, among others, knowledge of the phenology of a specific crop is important for proper management (Soto-Ortiz *et al*., 2006; Soto-Ortiz and Silvertooth, 2008); they are the fundamental basis for interpreting changes that occur in the plant and the possible implementation of management plans and agricultural practices (Cautín and Agustí, 2005).

Montes-Hernández *et al*. (2004) pointed out heat unit accumulation during different developmental stages of *Capsicum* sp., showing differences between paprika types and between different degrees of domestication. Agarwal *et al*. (2007) found that, for *C. annuum*, depending on the degree of precision required when the developmental stagesare defined, heat units can be used once each variable and the environment to be evaluated has been defined as well, but noted that it is impractical to handle many developmental phases associated with different stages of the plants development.

Paschold and Zengerle (2000) mentioned three developmental phases for sweet peppers, which are related to dry matter weight per crop in unit area or individual plants in relation to time; this behavior generally corresponds to a sigmoidal curve characterized by a) a logarithmic phase, where size increases exponentially with time, the growth rate is proportional to the size of the organism, the higher the size the faster the growth, and it ranges from germination to the juvenile stage, b) a linear phase, where the vegetative growth continues at a nearly constant rate, having an increased demand for water and nutrients, and c) a constant state phase, where the largest amount of dry matter accumulates, known as physiological maturity; at this stage, the dry matter gain is balanced with the losses.

The objective of this research was to determine the differences in biometric growth parameters, such as foliar area index, foliar area, leaf number, plant height and dry matter, of Plinio (yellow), Menta RZ (green) and Orangery (orange) hybrids under greenhouse conditions, unknown up to now for these cultivars on the Bogota Plateau.

Materials and methods

The research was carried out at the experimental unit "El Remanso" of the Universidad de Ciencias Aplicadas y Ambientales (U.D.C.A), under cover in a greenhouse, chapel-type with straight walls and a side ventilation rate of 40%, located on the Bogota Plateau, 4°35'N and 74°04 W, altitude 2,560 m a.s.l. Hybrid seeds of yellow Plinio (35-702 RZ), green Menta RZ and orange Orangery from the Holland company Rijk Zwaan were employed; the seeds were germinated in a growth chamber at 26°C and 80% relative humidity, within 128 alveoli trays, filled with a mixture of peat, perlite and vermiculite as propagation substrate. The seedlings were transplanted after approximately 3 weeks when well-formed with true leaves and a length between 12 and 15 cm. The research had a total duration of 140 d.

The treatments, each consisting of a color hybrid, were placed in a compartment of an area with a 6.8 m width and 20.0 m length, arranged in a complete randomized block design with five replicates. The replications corresponded to five beds per area, each 0.80 m wide with a distance between the beds of 0.50 m; in each bed, 4 plants/m^2 were planted, corresponding to 40,000 plants/ha, at a distance of 50 cm between plants under the triangle system.

The fertigation consisted of a drip system caliber 8000 (RODRIP John Deere Water, Moline, IL) with a distance between issuers of 0.10 m and a flow rate of 0.80 L h^{-1}, with an irrigation schedule of 4.5 to 6.0 L m^{-2} per day, including Cadahía´s standard nutritional solution for sweet peppers (Cadahía, 2005).

In order to prevent damage in the branches, 30 d after transplanting (DAT), staking or trellis with polyethylene raffia was initiated, permanently until harvest. The first flower bud was removed to reduce competition and to achieve fruit uniformity.

The parameters leaf area index (LAI), leaf area (LA), leaf number, plant height and dry matter were estimated. The LAI was determined using a previously established model by De Swart *et al.* (2004), which relates the leaf area obtained with the ground area occupied by the plant. The LA was measured on nine occasions, every 15 d, starting day 0 after transplanting, estimating simultaneously the individual leaf area, measured by an integrator (300 LI-COR, Lincoln, NE). The variables leaf number and plant height were recorded on a weekly basis, starting on week two during the 20 weeks of research. The dry matter was estimated biweekly through destructive sampling of 4 plants per treatment, separating the leaves, stems, roots and fruits, which were dried in an oven at 70°C for 48 h.

Assumptions of variance normality and homogeneity were evaluated using SAS/STAT® software (Cary, NC) (statistical package); data which did not present any result once the SAS run was finished were submitted to a Friedman test for the parameters LA and LAI and Kruskall-Wallis test for variables radiation and dry matter in root and stems. Because of the absence of normality of the data, the non-parametric Kruskall-Wallis test was employed. For the variables number of leaves, height, and leaf dry matter, an ANOVA was applied and the differences between the treatments were determined by a Tukey test ($P \leq 0.05$). The statistical package SAS (Statistical Analysis System) v.9.2, was employed.

Results and discussion

Leaf area (LA):

According to the analysis of variance, significant differences between the treatments related to the leaf area were observed within the three hybrids. Figure 1 shows that the treatment with the highest value was 'Orangery', for which 3,299 cm^2 were recorded, significantly higher than 'Plinio' and 'Menta RZ', which measured 2,802 and 2,503 cm^2, respectively. 'Orangery' presented a significant increase after 75 DAT due to the generation of photosynthetic organs for the growth and development of new tissue. The data are similar and agree partially with those registered by Reséndiz-Melgar *et al.* (2010), who reported an LA of 0.25 m^2 at a density of 4 plants/m^2 in hybrids of the purple bell pepper.

Under the study conditions, 'Orangery' had a higher development, with more leaves and a higher formation of structures such as branches and crosses, and showed an ampler foliar expansion and a defined architecture as compared with the other two hybrids 90 DAT. Usually, the leaf surface area is a good indicator of a crop's ability to intercept radiation and a bigger plant canopy captures more photosynthetically active radiation, which determines the LAI and the light absorption of each stratus (Cabezas and Corchuelo, 2005; Vieira *et al.,* 2009). These positive

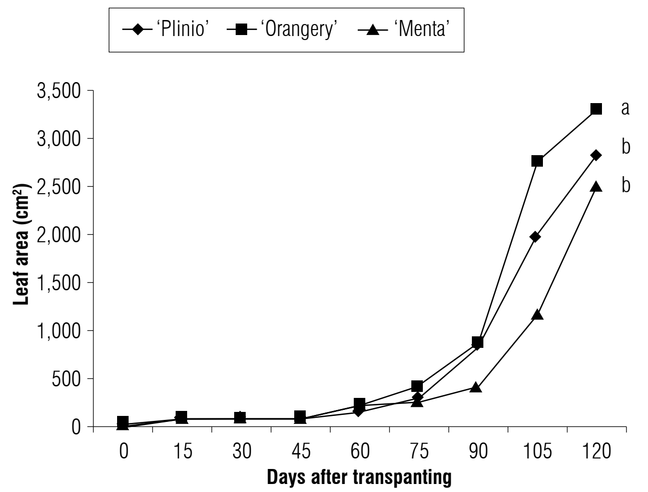

FIGURE 1. Leaf area variation of the three planted paprika hybrids under greenhouse conditions in the Bogota Plateau. Means with different letters indicate significant differences according to the Friedman test ($P\leq0.05$).

characteristics of the hybrid Orangey, besides its notable color, make it stand out from the other hybrids.

Leaf area index (LAI): This variable showed highly significant differences (P = 0.0128) among the three hybrids. Figure 2 illustrates that 'Plinio' and 'Orangery' presented a higher LAI, as compared to 'Menta RZ', recording, respectively, values of 3.3, 3.2 and 2.5. Similar results were obtained by Cruz-Huerta *et al.* (2005), who claimed that the optimum LAI for sweet paprika is between 3 and 4 in order to achieve maximum growth values, plant weight and general performance, a parameter value reached by the yellow and the orange hybrids.

During the first samples, up to sample number 5, the LAI had a similar behavior performance; from then on, as shown in Fig. 2, a significant increase in 'Orangey' and 'Plinio' was noted; this change was attributed to the existence of a dichotomous growth and to more leaves and branches in these hybrids, unlike the green 'Menta RZ', which presented low bearing, fewer leaves and little dichotomous development. According to the results obtained by Vos and Van der Putten (2001), the size, distribution and canopy shape comprise an essential part of a crop's capacity to sustain high yields and biomass production and its conversion into organisms of agricultural relevance. Furthermore, the LAI of a crop is considered the morpho-physiological characteristic of greatest prominence in the capture, distribution and utilization of incident solar radiation. Provides, in addition, parameters to perform very accurate yield estimates and define the methodologies for calculating assimilated source-demand relationships (DeJong, 1999). Within a canopy with a defined and homogeneous AFI, a correct and proper solar radiation distribution is reached, allowing better use of light, increased photosynthetic efficiency and, hence, higher yields (Lee *et al*., 2000).

Leaf number: As detected by the ANOVA, significant differences existed between the leaf number developed by the three hybrids (P = 0.004). Figure 3 reveals that 'Orangery' presented a trend of significant increase in this variable over the other two hybrids, recording an average of 207.2 leaves/plant at 140 DAT; a low average was presented by 'Menta RZ' and 'Plinio', 105.8 and 115 leaves/plant, respectively. These results highlighted the importance of the amount of photosynthetic organs present in a plant, in order to

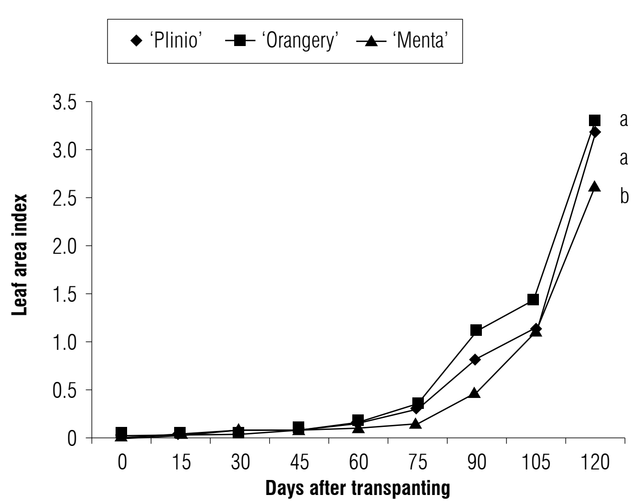

FIGURE 2. Behavior of the leaf area index for the three color paprika hybrids under greenhouse conditions in the Bogota Plateau. Means with different letters indicate significant differences according to the Friedman test ($P\leq0.05$).

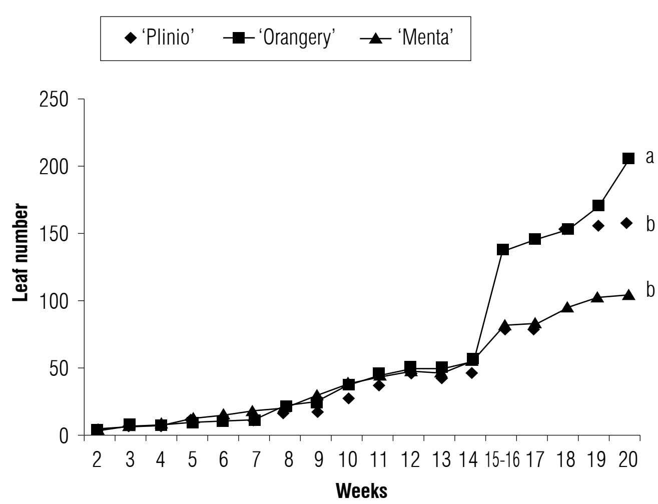

FIGURE 3. Leaf number of the three color paprika hybrids during the 20 week period under greenhouse conditions in the Bogota Plateau. The means with different letters indicate differences according to the Tukey test ($P\leq0.05$).

potentiate the uptake of sunlight (energy) for the formation and development organs (Vieira *et al.,* 2009). According to Sabater (1977), the higher the energy content, the greater the rate of chemical reactions is.

The hybrid Orangery, of non-determined growth, developed a defined architecture with more leaves, which revealed an inclination for a greater projection of the leaf blade. The inclination, distribution and orientation of the leaf might be important for determining light interception. Cabezas and Corchuelo (2005), noted that, under natural conditions, the amount and quality of light establish continuous production of assimilates, morphogenesis and biological and agronomic performance.

It can be observed that the three hybrids showed a significant increase in leaf production starting with the accumulation of approximately 800 degree-days (°C day) at week 14 (Fig. 3), which coincides with fruit formation and filling. Moreno-Pérez *et al.* (2011) stated that the productivity of plants depends on the physiological activity of the leaves, which is reflected in the fruit filling. Similar results were obtained by Bowen and Frey (2002) when evaluating the effects of staking, drip irrigation frequency and fertigated N rate on the dry matter partitioning and yield of bell peppers, concluding that resources were remobilized from the leaves to support fruit development.

Height: The statistical analysis indicated significant differences between the treatments ($P = 0.0048$). The elongation of the stems and branches of the orange colored hybrid, as compared 'Plinio' and 'Menta RZ' (Fig. 4), showed a significant increase from week 14 on, presenting a maximum average height of 60 cm at 140 DAT. 'Plinio' and 'Menta RZ' behaved similarly, presenting only a final height of 38.8 and 39.2 cm, respectively. Similar results were found by Reséndiz-Melgar *et al.* (2010). In this study, the authors reported that bell pepper varieties reach, as observed in this study for 'Orangery', an average height of 59.6 cm/plant, sown also at a density of 4 plants/m^2. Generally, increases in plant height indicate greater competition for light between plants and efficient uptake and utilization of the available radiation.

Dry matter distribution: The behavior of the distribution of assimilates for the evaluated hybrids can be appreciated in Fig. 5. The final dry matter accumulation in the aerial part of the plants was higher in 'Orangery' (93%), followed by 'Plinio' (91%) and, finally, 'Menta RZ' (90%). High percentages indicate greater leaf number, source, and production of photo-assimilates for the filling of demanding organs. The allocation is regulated within the source leaves, based on control points, which are enzymes, that allow either the regeneration of intermediaries for the Calvin-Benson cycle for starch synthesis or sucrose synthesis, its division in temporary storage centers, and its transport over long distances (Bustan *et al.*, 1996; Thornley and Cannell, 2000). Also, 'Orangery' showed a lower percentage of final leaf dry matter, whereas the demanding organs, the fruits, occupied the highest value, distinguishing again and favoring this hybrid.

A similar behavior can be appreciated regarding the final amount of stem dry matter (DM) for the evaluated hybrids (Fig. 5). The opposite occurred in the accumulation of leaf

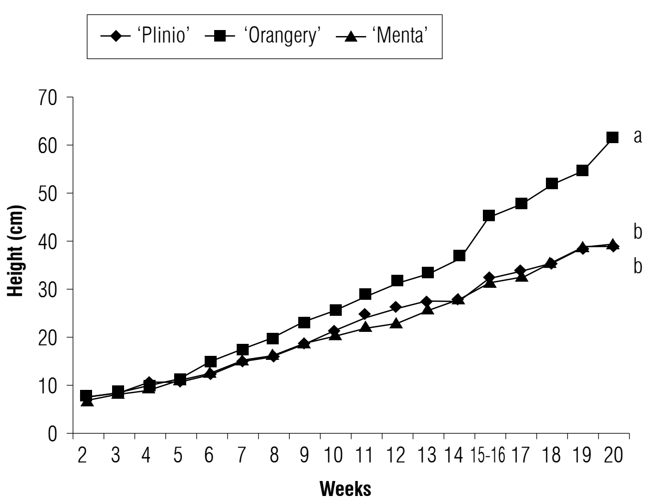

FIGURE 4. Plant height reached by the color paprika hybrids during the 20 weeks under greenhouse conditions in the Bogota Plateau. Means with different letters indicate significant differences according to the Tukey test ($P \leq 0.05$).

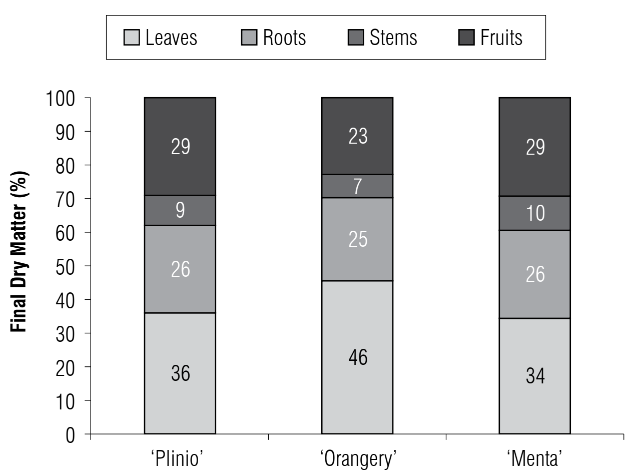

FIGURE 5. Final percentage of accumulated dry matter distribution in different organs: leaves, stems, roots and fruits, for each evaluated colored paprika hybrid under greenhouse conditions in the Bogota Plateau.

DM, registering the highest percentage of 29% in 'Plinio' and 'Menta RZ', while 'Orangery' presented 23%. The cumulative percentage of DM was higher in the 'Orangery' fruits, as compared to the other hybrids. Magán *et al.* (2007), in a study of paprika production in multi-tunnel cover in a greenhouse, found that the final dry matter in leaves, stems and fruits at 102 DAT was 29, 28 and 46%, respectively, similar results as those obtained in this research.

Allocation refers to the way the photosynthetic products are dedicated to meet the different metabolic processes and peculiar needs of the plant development. The distribution or redistribution concerns the mechanism for equitable and successful division ofthe earned resources for each demanding organ, whether they are tissues, cells, subcellular compartments or more complex organic systems (Komor, 2000).

Dry matter in the leaves, stems and roots: According to the ANOVA, no statistical differences were detected within these parameters between the three evaluated hybrids (P = 0.91; P = 0.4419; P = 0.0229 for Orangery, Plinio and Menta RZ, respectively). The content of DM in the leaves was similar in the hybrids up to sample number 5, which coincided with the flowering stage. 'Orangery' increased leaf DM, as compared to the other hybrids, and also presented the highest final value, followed by 'Plinio' and 'Menta RZ', registering 57.1, 51.8 and 44.5 g, respectively. Peil and Galvez (2005) stated that initially, a newly unfolded leaf behaves more like a demand organ, importing assimilates from other similar leaves, until it reaches 30% of its final size, gradually decreasing import and increasing carbon export. When a leaf has reached its full expansion and presents the maximum photosynthetic activity, it is basically a source organ or exporter of assimilates.

Assimilates produced by photosynthesis in the source organs, mainly leaves, are distributed via phloem between a plant's sink organs. In order to obtain an accelerated initial growth of young plants, a substantial increase in the leaf surface at this stage is essential because a large fraction of incident solar radiation is not yet intercepted by the leaves (Peil and Galvez, 2005). Photosynthetic and radiation use efficiency, expressed in the absorptivity of leaves, depend largely on the leaf-angle distribution, as mentioned by Vieira *et al.* (2009).

In respect to stem dry matter, 'Orangery', 45 DAT, showed the highest accumulation, indicating the presence of carbohydrate demands. This hybrid revealed a higher number of branches, leaves, flowers and fruits, contrary to 'Plinio', which registered less dry matter due to the scares presence of branches and internodes and lower stem thickness. Dry matter production is the result of the efficiency of crop canopy interception and the use of solar radiation available during the growth cycle (Vieira *et al.,* 2009; Gardner *et al.,* 2010).

All three hybrids exhibited a similar behavior for the root biomass accumulation, presenting approximately 9% of the dry matter. Somos (1984) stated that the weight of the root system corresponds only to 7-17% of the total plant weight, depending on the varietal type and culture conditions. Roots often make up only a small fraction of the total dry matter of crops grown under greenhouse conditions (Peil and Galvez, 2005); growth and root development is regulated by temperature, with roots and stems having different temperature thresholds and root growth occurring at temperatures above 7°C.

According to Tab. 1, there was a higher performance for hybrid Orangery, as compared to the other materials, presenting the highest number and weight of fruits per plant, reaching the highest yield per area 4.1 kg m^{-2}. Therefore, in this study, we can state that the hybrid Orangery increased photosynthetic capacity due to its greater leaf development; hence, it will be more productive, similar results were reported by Moreno-Pérez *et al.* (2011) for the hybrid Magno orange paprika epidermis, presenting a final yield of 5.7 kg m^{-2}. Casilimas *et al.* (2012) argued that the yield of a crop is determined by environmental factors, such as radiation, efficiency of biomass production and biomass fraction, which distributes the organs of interest.

Conclusions

Based on the results obtained under the greenhouse conditions of this research, it was concluded that the best option

TABLE 1. Performance components for hybrid colored peppers until the first harvest when 40% of the fruits showed the typical color of maturity.

Parameters	'Plinio'	'Orangery'	'Menta RZ'
Average for the final weight (g/fruit)	73	92	78
Average number of fruits/plant	6	12	5
kg/plant	0.438	1,104	0.390
kg m^{-2}	3.2	4.1	3.9

for commercial colored bell peppers is the hybrid Orangery, specifically taking into account the highest fruit dry matter, a total of 46%, as compared to the other varieties. However, before starting mass production of this colored bell pepper, its real productivity has to be established, as well as consumer preferences for any of the available fruit colors. Frank *et al.* (2001) conducted a conjoint analysis in the United States, which, besides other items, revealed a consumer preference for green fruits. A similar result could be obtained in Colombia.

Cited literature

Agarwal, A., S. Gupta, and Z. Ahmed. 2007. Influence of plant densities on productivity of bell pepper (*Capsicum annuum* L.) under greenhouse in high altitude cold desert of Ladakh. Acta Hortic. 756, 309-314.

Bowen, P. and B. Frey. 2002. Response of plasticultured bell pepper to staking, irrigation frequency, and fertigated nitrogen rate. HortScience 37, 95-100.

Bustan, A., E.E. Goldschmith, and Y. Erner. 1996. Carbohydrate supply and demand during fruit development in relation to productivity of grapefruit and 'Murcott' mandarin. Acta Hortic. 416, 81-88.

Cabezas, M. and G. Corchuelo. 2005. Estimación de la intercepción de la radiación solar en papa criolla (*Solanum phureja* Juz. et Buk.) en tres localidades colombianas. Agron. Colomb. 23, 62-73.

Cadahía L., C. 2005. Fertirrigación: cultivos hortícolas y ornamentales. 3rd ed. Ediciones Mundi-Prensa, Madrid.

Casilimas, H., O. Monsalve, C.R. Bojacá, R. Gil, E. Villagrán, L.A. Arias, and L.S. Fuentes. 2012. Manual de producción de pimentón bajo invernadero. Fundación Universidad de Bogotá Jorge Tadeo Lozano, Bogota.

Cautín, R. and M. Agustí. 2005. Phenological growth stages of the cherimoya tree (*Annona cherimola* Mill.). Sci. Hortic. 105, 491-597. Doi: 10.1016/j.scienta.2005.01.035

Cebula, S. 1995. Optimization of plant and shoot spacing in greenhouse production of sweet pepper. Acta Hortic. 412, 321-329.

Cruz-Huerta, N., J. Ortiz-Cereceres, F. Sánchez del Castillo, and M.C. Mendoza-Castillo. 2005. Biomasa e índices fisiológicos en chile morrón cultivados en altas densidades. Rev. Fitotec. Mex. 28, 287-293.

Daşgan, H.Y. and K. Abak. 2003. Effects of plant density and number of shoots on yield and fruit characteristics of pepper grown in glasshouses. Turk. J. Agric. For. 27, 29-35.

DeJong, T.M. 1999. Developmental and environmental control of dry-matter partitioning in peach. HortScience 34, 1037-1040.

De Swart, E.A.M., R. Groenwold, H.J. Kanne, P. Stam, L.F.M. Marcellis, and R.E. Voorrips. 2004. Non-destructive estimation of leaf area for different plant ages and accessions of *Capsicum annum* L. J. Hortic. Sci. Biotech. 79, 764-770.

Frank, C.A., R.G. Nelson, E.H. Simonne, B.K. Behe, and A.H. Simonne. 2001. Consumer preferences for color, price, and vitamin C content of bell peppers. HortScience 36, 795-800.

Gardner, F.P., R.B. Pearce, and R.L. Mitchell. 2010. Physiology of crop plants. Scientific Publishers Journals Dept., London.

Ghasemnezhad, M., M. Sherafati, and G.A. Payvast. 2011. Variation in phenolic compounds, ascorbic acid and antioxidant activity of five coloured bell pepper (*Capsicum annum*) fruits at two different harvest times. J. Funct. Foods 3, 44-49. Doi: 10.1016/j.jff.2011.02.002

Hallmann, E. and E. Rembiałkowska. 2012. Characterization of antioxidant compounds in sweet bell pepper (*Capsicum annuum* L.) under organic and conventional growing systems. J. Sci. Food Agric. 92, 2409-2415. Doi: 10.1002/jsfa.5624

Jovicich, E.J., D.J. Cantliffe, and J.J. VanSickle. 2004. U.S. imports of colored bell peppers and the opportunity for greenhouse production of peppers in Florida. Acta Hortic. 659, 81-85.

Komor, E. 2000. Source physiology and assimilate transport: the interaction of sucrose metabolism, starch storage and phloem export in source leaves and the effects on sugar status in phloem. Aust. J. Plant Physiol. 27, 497-505.

Lee, D.W., S.F. Oberbauer, P. Johnson, B. Krishnapilay, M. Mansor, H. Mohamad, and S.K. Yap. 2000. Effects of irradiance and spectral quality on leaf structure and function in seedlings of two Southeast Asian *Hopea* (Dipterocarpaceae) species. Amer. J. Bot. 87, 447-455. Doi: 10.2307/2656588

Magán, J.J., J.C. López, A. López, and J. Pérez-Parra. 2007. Microclima y producción de materia seca de un cultivo de pimiento en invernaderos con cubierta de plástico y cristal en el sureste español. Series Las Palmerillas. Publicaciones de Cajamar Caja Rural, Almeria, Spain.

Melgarejo, L.M., F. Rodríguez, M. Giraldo, G. Cardona, M. Celis, J. Arias, M. García, L. Quintero, M. Cudris, S. Toquica, I. Monroy, M. Rodríguez, M. Duque, and J. Tohme. 2004. Caracterización de accesiones del banco de germoplasma de la región amazónica colombiana. pp. 13-27. In: Melgarejo, L.M., M.S. Hernández, J.A. Barrera, and X. Bardales (eds.). Caracterización y usos potenciales del banco de germoplasma de ají amazónico. Instituto Amazónico de Investigaciones Científicas-SINCHI, Bogota.

Montes-Hernández, S., E. Heredia G., J. Alfonso, and A. Gómez. 2004. Fenología del cultivo del chile (*Capsicum annuum* L.). pp. 43-47. In: Memorias de la Primera Convención Mundial del Chile 2004. Consejo Nacional de Productores de Chiles, Leon de los Aldama, Mexico.

Moreno-Pérez, E.C., R. Mora-Aguilar, F. Sánchez-Del Castillo, and V. García-Pérez. 2011. Fenología y rendimiento de híbridos de pimiento morrón (*Capsicum annuum* L.) cultivados en hidroponía. Rev. Chapingo Ser. Hortic. 17, 5-18. Doi: 10.5154/r.rchsh.2011.17.041

Mundarain, S., M. Coa, and A. Cañizares. 2005. Fenología del crecimiento y desarrollo de plántulas de ají dulce (*Capsicum frutescens* L.). Rev. Cient. UDO Agric. 5, 62-67.

Paschold, P.-J. and K.-H. Zengerle. 2000. Sweet pepper production in a closed system in mound culture with special consideration to irrigation scheduling. Acta Hortic. 458, 329-334.

Peil, R.M. and J.L. Galvez. 2005. Reparto de materia seca como factor determinante de la producción de las hortalizas de fruto cultivadas en invernadero. Curr. Agric. Sci. Technol. 11, 5-11.

Reséndiz-Melgar, R.C., E.C. Moreno-Pérez, F. Sánchez-Del Castillo, J.E. Rodríguez-Pérez, and A. Peña-Lomelí. 2010. Variedades de pimiento morrón manejadas con despunte temprano en dos densidades de población. Rev. Chapingo Ser. Hortic. 16, 223-229.

Sabater, F. 1977. La luz como factor ambiental para las plantas. An. Univ. Murcia 31, 1-24.

Silva Filho, D.F. da, M.C. Oliveira, L.H.P. Martins, H. Noda, and F.M. Machado. 2004. Diversidade fenotípica em pimenteiras cultivadas na Amazônia. Hortic. Bras. 22(suppl 2), 459-460.

Somos, A. 1984. The paprika. Akademiai Kiados, Budapest.

Soto-Ortiz, R. and J.C. Silvertooth. 2008. A crop phenology model for irrigated New Mexico chile (*Capsicum annuum* L.) type varieties. Vegetable Report P-152. College of Agriculture and Life Sciences, The University of Arizona, Tucson, AZ.

Soto-Ortiz, R., J.C. Silvertooth, and A. Galadima. 2006. Crop phenology for irrigated chiles (*Capsicum annuum* L.) in Arizona and New Mexico. Vegetable Report. College of Agriculture and Life Sciences, The University of Arizona, Tucson, AZ.

Sun, T., Z. Xu, C.-T. Wu, M. Janes, W. Prinyawiwatkul, and H.K. No. 2007. Antioxidant activities of different colored sweet bell peppers (*Capsicum annuum* L.). J. Food Sci. 72, 98-102. Doi: 10.1111/j.1750-3841.2006.00245.x

SOL, The International Solanaceae Genome Project. 2004. SOL white paper. In: www.sgn.cornell.edu/solanaceae-project/; consulted: May, 2015.

Thornley, J.H.M. and M.G.R. Cannell. 2000. Modelling the components of plant respiration: representation and realism. Ann. Bot. 85, 55-67. Doi: 10.1006/anbo.1999.0997; 10.1006/anbo.2000.1168

Torres R., E. 2009. Agrometeorología. 3th ed. Editorial Trillas, Mexico DF.

USDA, United States Department of Agriculture. 2010. Processing chile pepper pilot loss adjustment standards handbook 2011 and succeeding crop years. FCIC-25680 (P CHILE PEPPER). Washington DC.

Vieira, M.I., J.P. de Melo-Abreu, M.E. Ferreira, and A.A. Monteiro. 2009. Dry matter and area partitioning, radiation interception and radiation-use efficiency in open-field bell pepper. Sci. Hortic. 121, 404-409. Doi: 10.1016/j.scienta.2009.03.007

Vos, J. and P.E.L. Van der Putten. 2001. Effects of partial shading of the potato plant on photosynthesis of treaded leaves, leaf area expansion and allocation of nitrogen and dry matter in components plants parts. Eur. J. Agron. 14, 209-220.

Wurr, D.C.E., J.R. Fellows, and K. Phelps. 2002. Crop scheduling and prediction - principles and opportunities with field vegetables. Adv. Agron. 76, 201-234. Doi: 10.1016/S0065-2113(02)76006-9