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Growth and Nutrient Absorption of Cape Gooseberry (*Physalis peruviana* L.) in Soilless Culture

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ABSTRACT

Cape gooseberry (*Physalis peruviana* L.) is a solanaceous plant. The growth and time-course of nutrient accumulation of the plant and its partitioning between roots, stems, leaves, and fruits were examined. The study was conducted analyzing two nutrient solutions in soilless culture under greenhouse conditions during two consecutive seasons. The macronutrient contents were analyzed. On average, the yield was 8.9 $t \cdot ha^{-1}$. Growth of the plant until 90 d after transplanting obeys an exponential function of time and the relative growth rate for this period was determined. Nitrogen (N) was the element that showed the highest concentration, corresponding to leaves (4.67%), followed by potassium (K) in stems (4.46%). The highest accumulations of N, phosphorous (P), calcium (Ca), and magnesium (Mg) were found in leaves and of K in the stems. Potassium showed the highest nutrient accumulation (29 $g \cdot plant^{-1}$) and the highest specific uptake rate.

INTRODUCTION

Cape gooseberry or golden berry (*Physalis peruviana* L.) is a solanaceous plant originating from the Andean region. It is characterised by the production of orange seedy berries, about the size of a marble, enclosed in an inflated papery calyx, resembling Chinese lanterns (Trinchero et al., 1999; Ramadan and Moersel, 2007). These fruits, which are pleasantly flavored and contain high levels of vitamin A, B, C, carotene, phosphorus (P) and iron (Fe) (Hewett 1993), are consumed fresh – as well as in jam, juice, and other types of foodstuffs (Ramadan and Moersel, 2007; 2009). Colombia is the main producer in the world, followed by South Africa (Mazorra et al., 2006), and there is commercial production in Ecuador, Peru, Kenya, and New Zealand. The cultivation of cape gooseberry is not widely spread in the Spanish Mediterranean area, but it can be considered as an alternative or a complementary option to the traditional crops grown under climatic protection (Cuartero et al., 1983; Maroto, 2002).

Apart from the study carried out by El-Tohamy et al. (2009) in Egypt, referring to nitrogen (N), no studies regarding nutrient absorption and accumulation in cape gooseberry have been found. There are many fertilization recommendations which differ considerably in doses as well as in equilibrium: ranging from 50 to 310 $kg \cdot ha^{-1}$ N; from 0 to 250 $kg \cdot ha^{-1}$ phosphorous pentoxide (P_2O_5); and from 50 to 1400 $kg \cdot ha^{-1}$ potassium oxide (K_2O), depending on soil fertility, cultivation cycles (depending in turn on climatic conditions), and crop management (Collazos, 2000; Convenio MAG-IICA, 2001; Zapata et al., 2002; Angulo, 2005).

The present study examines cape gooseberry plant adaptation to cultivation under greenhouse conditions and in soilless culture in the Mediterranean area during a winter-spring cycle. Two nutrient solutions and two experimental seasons are analyzed for total nutrient absorption, and the absorption rate is also analyzed in order to establish the bases of a rational fertilization programme in which the supplies meet crop demands.

MATERIALS AND METHODS

Experiments were conducted over two consecutive seasons (experiment 1: 2008-2009, and experiment 2: 2009-2010) on the campus of the Universitat Politècnica de València (UPV) (39º 38’ N, 0º 22’ W) in Spain. The experiments were carried out in a Venlo-type glasshouse with cape gooseberry plants of the La Llosa landrace (Castellón; Spain) and with seed propagated by the Plant Production Department of the UPV.

The sowing dates for experiments 1 and 2 were 19 September 2008 and 18 September 2009, respectively. Sowings were carried out in 54-cell polystyrene trays filled with vermiculite. The transplanting dates were 12 January 2009 and 11 January 2010, when plants were approximately 0.15-0.20 m high. Seedlings were fertilized prior to transplanting with the same nutrient solution used after transplanting. Plants were grown as one plant per 25-L polyethylene pot in an open system with grade B12 perlite (0-5 mm in diameter) and placed in four three-row blocks with each row containing 20 plants. Both blocks and rows were north-south oriented, along the radiation gradient, with separation distances of 1.5 and 0.5 m between and within rows, equivalent to 13,333 plants·ha^{-1}.

Fertigation was achieved using drip irrigation (testing two nutrient solutions prepared in tap water available at the site) with one outlet supplying 4 L h^{-1} per pot. One nutrient solution was based on Hoagland's No. 2 nutrient solution (Maynard and Hochmuth, 1997) and the solution [electrical conductivity (EC): 2.31 $dS \cdot m^{-1}$; pH adjusted to 6.1] contained the following macronutrient concentrations (all in mM): nitrate (NO_3^-), 14.0; dyhidrogen phosphate ($H_2PO_4^-$), 1.0; sulphate (SO_4^{2-}), 2.45; potassium (K^+), 6.0; calcium (Ca^{2+}), 4.0; magnesium (Mg^{2+}, 2.0). The other nutrient solution was the Sonneveld and Straverd solution recommended for tomatoes cultivated in soilless conditions (Sonneveld and Straverd, 1992); this solution (EC: 2.3 $dS \cdot m^{-1}$; pH adjusted to 6.0) contained the following macronutrient concentrations (mM): NO_3^-, 13.75; ammonium (NH_4^+), 1.25; $H_2PO_4^-$, 1.25; SO_4^{2-}, 3.75; K^+, 8.75; Ca^{2+}, 4.25; Mg^{2+}, 2.0. In both cases, micronutrient concentrations were (μM): Fe^{2+}, 15; manganese (Mn^{2+}), 10; zinc (Zn^{+2}), 5; boron (B^{+3}), 30; copper (Cu^{+2}), 0.75; molybdenum (Mo^{+6}), 0.5. Irrigation doses were established to obtain 20% (v/v) drainage.

One healthy looking plant per row was randomly sampled fortnightly during the exponential growth period and monthly from then until the end of the cycle [185 days (d) after transplanting (DAT)]. Plants were divided into four parts and analyzed separately: (i) roots; (ii) stems; (iii) leaves; and (iv) fruits. After washing, each sampled plant part was dried at 65ºC in a forced-air oven until constant weight to determine dry matter (DM). The remains were then mineralized and analyzed following the analytical methods of the Association of Official Analytical Chemists (AOAC International, 2000). The N content was determined using the Kjeldahl (semi-micro) method; P content was determined using the phospho-molybdovanadate colorimetric method at 430 nm; while K, Ca, and Mg levels were determined with an atomic absorption

spectrophotometer in emission for K (766.5 nm) and in absorption for Ca (422.7 nm) and Mg (285.2 nm) and using an acetylene mixture as fuel. In each sample, nutrients were analyzed in triplicate.

To evaluate the results, the average value of the data corresponding to three sampled plants from each block was used. By using data regarding the DM of each plant part, the proportion of each organ to the total dry matter for roots, leaves, stems, and fruits, was calculated for each sampling. Two different stages – the vegetative and reproductive stages – were considered and the appearance of the first fruit was considered the indicator of the change from vegetative to reproductive stages, as Salazar et al. (2008) reported.

By using data regarding the DM of each part of the plant, as well as the corresponding nutrient contents, it was possible for the exponential growth phase to determine: (i) the mean relative growth rate (RGR; $g \cdot g^{-1} \cdot d^{-1}$) between samplings:

$$RGR = \frac{\ln W_2 - \ln W_1}{(t_2 - t_1)}$$

where W_2 and W_1 were the total biomass at sampling times t_2 and t_1, respectively (Williams, 1946; Radford, 1967; Causton, 1991); (ii) the accumulated nutrient uptake (g $plant^{-2}$); and (iii) the specific nutrient uptake rates (I_M) between samplings (mg nutrient absorbed$\cdot g^{-1}$ dry root weight$\cdot d^{-1}$):

$$I_M = RGR_{root} \times \frac{(m_2 - m_1)}{(r_2 - r_1)}$$

where m_2 and m_1 are the amounts of a given nutrient at sampling times t_2 and t_1, respectively; while r_2 and r_1 are the respective dry root weights, and RGR_{root} is the mean RGR of the root (Williams, 1946; Bellaloui and Brown, 1998; Zerihun et al., 2000):

$$RGR_{root} = \frac{\ln r_2 - \ln r_1}{(t_2 - t_1)}$$

Data was analyzed by analysis of variance using Statgraphics 5.1 plus (Statistical Graphics Corporation, 2005; Statistical Graphics Corp, Princeton, NJ). The year effect was considered to be random.

Mature fruits were harvested weekly and total fresh yields (weights of fruit plus husk) were recorded. To analyze the yield, three plants (different to those sampled to analyze growth and nutrient accumulation) per row were selected.

RESULTS

Registered daily temperatures (maximum, average, and minimum) inside the greenhouse for experiment 1 are presented in Figure 1. No deficiency symptoms appeared and the plants had a good visual appearance. There were no significant effects, at any sampling, of the year or the nutrient solution: (i) on the accumulation and partitioning of DM, or (ii) on the nutrient uptake (data not shown). This statistical insignificance meant that the average data of both experiments could be used.

Accumulation and Partitioning of Dry Matter

Total accumulated DM of the cape gooseberry reached values up to 765.6 g·plant^{-1} and corresponding to 390.6 g·plant^{-1} (51.0%) for stems; 228.0 g·plant^{-1} (29.8%) for leaves; 122.3 g·plant^{-1} (16.0%) for fruits; and 24.7 g·plant^{-1} (3.2%) for roots (Figure 2, Panels A and B).

For the vegetative stage, leaves accounted for the highest proportion of DM, while for the reproductive stage the fraction accounted for by the leaves dropped and the fraction partitioned to the stems increased.

Growth of the whole plant, as well as that corresponding to the different plant organs, until 90 DAT, obeys an exponential function of time, enabling the use of expressions such as RGR, RGR_{root}, and Specific Nutrient Uptake Rates (I_M) (Williams, 1946) as derived from these exponential relationships. Changes in RGR values during 90 DAT are presented in Figure 3, the highest value (0.103 $g \cdot g^{-1} \cdot d^{-1}$) being found between days 0 and 15.

In terms of fresh fruit weight, the plants produced 666 $g \cdot plant^{-1}$ (the equivalent to 8.9 $t \cdot ha^{-1}$). Fruits were mostly harvested (90%) from 90 to 185 DAT (Figure 4).

Concentration and Accumulation of Nutrients

The element found in the highest concentration in the plants was N, with the highest concentration found in leaves (4.67% at the end of the cycle; Figure 5, Panel A). Nitrogen was followed by K, with the greatest proportion found in stems (4.46%; Figure 5, Panel C). The highest Ca concentration (Figure 5, Panel D) was found in roots (1.11%). The lowest concentrations found in plants were for P (Figure 5, Panel B) and Mg (Figure 5, Panel E) and leaves presented the highest concentration (0.39% P; 0.84% Mg) for both these elements.

Total N accumulation reached 19.8 $g \cdot plant^{-1}$ (Figure 5, Panel F), 53.7% being in leaves, 28.2% in stems, 15.5% in fruits, and 2.6% in roots. The least absorbed nutrient was P, with accumulations of up to 2.1 $g \cdot plant^{-1}$ (Figure 5, Panel G), some 42.3% of this quantity being in

leaves, 33.5% in stems, 20.1% in fruits, and 4.1% in roots. Potassium was the most absorbed nutrient, equivalent to 28.8 g·plant^{-1} (Figure 5, Panel H), with some 60.5% being in stems, 27.9% in leaves, 10.6% in fruits, and 1% in roots. Total Ca accumulation was 3.9 g·plant^{-1} (Figure 5, Panel I), 40.2% of which was found in leaves, 39.5% in stems, 13.3% in fruits, and 7% in roots. Total Mg accumulation reached values of 3.1 g·plant^{-1} (Figure 5, Panel J), 61.6% of which was found in leaves, 26.8% in stems, 9% in fruits, and 2.7% in roots. The analyzed nutrient equilibrium relation was: 1: 0.1: 1.5: 0.2: 0.2 (N: P: K: Ca: Mg, respectively).

Specific Nutrient Uptake Rates (I_M)

Changes in the I_M of all the analyzed macronutrients during 90 DAT are indicated in Figure 6. In this 90 d period, the I_M values obey a second order polynomial equation, reaching the highest value for each nutrient early in the growing season, coinciding with the maximum RGR values. I_M of P, Ca, and Mg were similar, with low and nearly constant values. The evolution of the I_M values for N and K were similar, with higher values for K. The maximum values for these elements were 43.1 and 59.1 mg·g^{-1}·d^{-1}, respectively.

DISCUSSION

The cape gooseberry plants revealed a high proportion of DM for leaves in the vegetative stage, and this proportion decreased for the reproductive stage. These results agree with those reported in the literature, in the sense that the DM fraction for the leaves was higher (lower) than that for

the stems in the vegetative (reproductive) stage (Angulo, 2005; Salazar et al., 2008). This fact could be a consequence of the large size of the first formed leaves, and the gradual size reduction in later leaves, together with the constant ramification displayed by the plant, agreeing with Salazar et al. (2008). This trend, showing the highest leaf/stem DM rate at the beginning of the cultivation cycle, has also been verified in other solanaceous species such as pepper (*Capsicum annuum* L.; Miller et al., 1979) and tomato (*Lycopersicum esculentum* Mill.; Scholberg et al., 2000).

The DM partitioning patterns and their associated values at harvest, differ from the results obtained in experiments carried out in the high altitude tropics of Colombia [Chia: 4º53' N, 2560 m.a.s.l (Angulo, 2005; Salazar et al., 2008); Miraflores: 5º11'N; 1850 m.a.s.l; (Salazar et al., 2008)] where fruit accounted for a much higher proportion of the total DM (62 – 69%) than those obtained in the present experiments (namely, 16%). The present results are lower than those reported in other solanaceous species such as pepper (45-60%; Bennett et al., 1979; Leskovar and Cantliffe, 1993; Wubs et al., 2007), tomato (69-74%; Heuvelink et al., 2005), cucumber (*Cucumis sativus* L.; 52-59%; Marcelis, 1993) and pepino (*Solanum muricatum* Ait.; 30%; Fresquet et al., 2001).

Temperatures registered in studies carried out by Angulo (2005) in Chia (average maximum and minimum temperatures of 25.8ºC and 9.8ºC, respectively) and Salazar et al. (2008; average daily and night temperatures, respectively of 19.9ºC and 11.9ºC in Chia, and 21.3ºC and 15.7ºC in Miraflores, respectively) were lower than those registered in this study (Figure 1).

The yield herein obtained, 666 g·plant^{-1}, equivalent to 8.9 t·ha^{-1}, is higher than that achieved for plants grown in Egypt in field conditions (up to 5.9 t·ha^{-1}) by El-Tohamy (2009), and lower

than those reported by Angulo (2005), who reported values of 60 t·ha^{-1}, with lower temperatures (shown above) and a longer cultivation cycle (390 DAT). Dry matter accumulation (766 g·plant^{-1}) was also considerably lower than that obtained by Angulo (2005; 7000 g·plant^{-1}) in the above mentioned conditions.

Puente et al. (2011) reported that cape gooseberry growth is affected by temperatures under 10ºC and that the optimum temperature is 18ºC, while high temperatures can affect flowering and fruiting. Wolff (1991) used three *Physalis peruviana* cultivars in a study carried out in the southern Mississippi Delta region, obtaining that none of the three cultivars produced mature fruit, and concluding that this lack of flowering and fruit set was possibly due to the summer temperatures (average 30ºC), citing that Morton and Russell reported lack of flowering in the Bahamas during the hot summer months, with flowering and fruit set occurring during the cooler autumn season.

In the present study, a lack of flowering and fruit set were stated around 165 DAT and coinciding with high temperatures (Figure 1); and some plants later senesced, which led to the finishing of the cycle.

With earlier cycles (transplanting at the beginning of autumn) the cultivation cycle could be extended and yields would probably increase, as reported Martí et al. (2003) who obtained yields up to 11.2 t·ha^{-1} in soil and under greenhouse in the same UPV campus, using a longer autumnal–spring-like cycle, and with sowings in the second two weeks of August and transplanting in the first two weeks of October. The data indicates that cape gooseberry could do well as a crop in the Mediterranean region.

The highest RGR value, 0.103 $g \cdot g^{-1} \cdot d^{-1}$, corresponded to the initial phase of the cultivation cycle (between 0 and 15 DAT); and after this period there was a drop in the value of this parameter. The RGR values were slightly higher than those determined for pepper (Turner and Wien, 1994) and pepino (Fresquet et al., 2001).

Nitrogen was the element that showed the highest concentration in cape gooseberry, with 4.67% for leaves – and similar values to those obtained by El-Tohamy et al. (2009; 4.52% on average when applying 200 kg $N \cdot ha^{-1}$). The highest N, P, and Mg concentrations were found in leaves, while the highest K concentration was in stems (4.46%), whereas roots presented the highest Ca (1.11%).

Total N accumulation (264 kg $N \cdot ha^{-1}$) was higher than values obtained by El-Tohamy et al. (2009; on average 143 kg $N \cdot ha^{-1}$, when applying 200 kg $N \cdot ha^{-1}$). When comparing nutrient extractions shown in Figure 5 with those of other solanaceous plants grown under greenhouse conditions, such as pepper (with a yield equal to 100 $t \cdot ha^{-1}$; Rincón et al., 1993), pepino (50 $t \cdot ha^{-1}$; Fresquet et al., 2001), or tomato (86 $t \cdot ha^{-1}$; Cornillon, 1974), the amounts of N extracted are similar for the different species (264 kg $N \cdot ha^{-1}$ for cape gooseberry, 293 kg $N \cdot ha^{-1}$ for pepper, 266 kg $N \cdot ha^{-1}$ for pepino, and 242 kg $N \cdot ha^{-1}$ for tomato). However, for K the cape gooseberry extractions were higher than those for other species (463 kg $K \cdot ha^{-1}$ for cape gooseberry, 382 kg $K \cdot ha^{-1}$ for pepper, 350 kg $K \cdot ha^{-1}$ for tomato; and 374 kg $K \cdot ha^{-1}$ for pepino), being N and K the nutrients that reached the highest values for all four crops. Phosphorous was the element least absorbed by the plant – with similar extractions for cape gooseberry to those for pepper, tomato, and pepino (28, 33, 30 and 28 kg $P \cdot ha^{-1}$, respectively). The extracted Ca (52 $kg \cdot ha^{-1}$) was lower than that reported for pepper (101 $kg \cdot ha^{-1}$) and for pepino (256 $kg \cdot ha^{-1}$). Finally, the amount of

Mg absorbed by the cape gooseberry plants (42 kg·ha^{-1}) was lower than pepper (63 kg·ha^{-1}) and similar to tomato (45 kg·ha^{-1}) and pepino (40 kg·ha^{-1}). The results herein presented show that cape gooseberry presents, overall, similar N and P extractions to pepper, tomato and pepino, whereas it is more demanding in K than these plants. This finding agrees with fertilization plans suggested by the Convenio MAG-IICA (2001) in Ecuador, and Angulo (2005) in Colombia, in the sense that K and P are, respectively, the elements recommended in the highest and the lowest amounts.

Finally, despite high accumulations, the I_M of nutrients was not particularly high, and the I_M values were lower than those reported for pepino (Fresquet et al., 2001). These low I_M values could explain the similar yield obtained with the two nutrient solutions, differing mainly in K concentration. The maximum I_M values coincide with phases of maximum RGR values (between 0 and 15 DAT) and range from 4.2 mg P·g^{-1}·d^{-1} to 59.1 mg K·g^{-1}·d^{-1}.

These findings are a substantial contribution to the knowledge and understanding of the growth and nutrient absorption of the cape gooseberry, allowing to establish a rational fertilization program for cape gooseberry in soilless cultivation. Moreover, they are the base to develop a rational fertilization program for cape gooseberry in soil conditions and to produce an analysis guide for this plant.

REFERENCES

Angulo, R. 2005. Cape gooseberry growth, development, and yield under greenhouse and open field conditions. In: *Advances in cultivation, postharvest, and exports of cape gooseberry (Physalis peruviana L.) in Colombia*, eds. G. Fischer, W. Piedrahita, D. Miranda and J. Romero, pp. 111-130. (In Spanish). Universidad Nacional de Colombia, Facultad de Agronomía: Bogotá, Colombia.

AOAC International. 2000. *Official Methods of Analysis of AOAC International* (17th ed.). Vol. I, chapter 3: 1-37.: AOAC International. Gaithersburg, Maryland

Bellaloui, N., and P. H. Brown. 1998. Cultivar differences in boron uptake and distribution in celery (*Apium graveolens*), tomato (*Lycopersicon esculentum*) and wheat (*Triticum aestivum*). *Plant and Soil* 198: 153–158.

Bennett, J.P., R.J. Oshima, and L.F. Lippert. 1979. Effects of ozone on injury and dry matter partitioning in pepper plants. *Environmental and Experimental Botany* 19: 33-39.

Causton, D. R. 1991. Plant growth analysis: the variability of relative growth rate within a sample. *Annals of Botany* 67: 137–144.

Collazos, O. 2000. Cape gooseberry agricultural management in the Tierradentro area, department of Cauca, Colombia. (In Spanish). CORPOICA Creced Cauca: Popayán, Colombia

Convenio MAG-IICA (Ministerio de Agricultura y Ganadería. Institución Interamericana de Cooperación para la Agricultura). 2001. The cape gooseberry (*Physalis peruviana* L.,

Physalis edulis). (In Spanish). Subprograma de Cooperación Técnica, Ecuador. [http://www.sica.gov.ec/agronegocios/Biblioteca/ Convenio%20MAG%20IICA/productos/uvilla_mag.pdf]. Acceded on July 2007.

Cornillon, P. 1974. Tomato nutrition and fertilization. In: *Tomato*, pp. 107-106. (in French). INVUFLEC: Paris, France:.

Cuartero, J., J. Costa, G. Palomares, and F. Nuez. 1983. *Physalis* performance under cultivation conditions found in south-east Spain. *Proceedings 1st National Congress of the Spanish Horticultural Sciences Society.* (In Spanish). Vol. I: 161-164.

El-Tohamy, W.A., H.M. El-Abagy, S.D. Abou-Hussein, and N. Gruda. 2009. Response of Cape gooseberry (*Physalis peruviana* L.) to nitrogen application under sandy soil conditions. *Gesunde Pflanzen* 61: 123–127.

Fresquet, J., B. Pascual, S. López-Galarza, A. San Bautista, C. Baixauli, J.M. Gisbert, and J.V. Maroto. 2001. Nutrient Uptake of Pepino plants in soilless cultivation. *Journal of Horticultural Science and Biotechnology* 76: 338-343.

Heuvelink, E., M.J. Bakker, A. Elings, R. Kaarsemaker, and L.F.M. Marcelis. 2005. Effect of leaf area on tomato yield. *Acta Horticulturae* 691: 43-50.

Hewett, E.W. 1993. New horticultural crops in New Zealand. In: *New crops*, eds. J Janick and J.E. Simon, pp. 57-64. New York, USA: Wiley.

Leskovar, D.I., and D.J. Cantliffe. 1993. Comparison of plant establishment method, transplant, or direct seeding on growth and yield of bell pepper. *Journal of the American Society of Horticultural Science* 118: 17-22.

Marcelis, L.F.M. 1993. Fruit growth and biomass allocation to the fruits in cucumber. 1. Effect of fruit load and temperature. *Scientia Horticulturae* 54: 107-121.

Maroto, J.V. 2002. *Special herbaceous horticulture.* (In Spanish). Madrid, Spain: Mundi-Prensa.

Martí, E.C., J.V. Maroto, A. San Bautista, S. López-Galarza, J.F. Torres, V. Palau, P. Laza, J.Alagarda, and B. Pascual. 2003. Effects of different pruning approaches on the cape gooseberry (*Physalis peruviana* L.) productive parameters and physiopathies. (In Spanish). *Agrícola Vergel* 261: 448-455.

Maynard, D.N., and G.J. Hochmuth, 1997. *Knott's Handbook for Vegetable Growers.* John Wiley & Sons Inc.: Hoboken, NJ.

Mazorra, M.F., A.P. Quintana, D. Miranda, G. Fischer, and M. Chaparro de Valencia. 2006. Anatomical aspects of the formation and growth of the cape gooseberry (*Solanaceae*). (In Spanish). *Acta Biológica Colombiana* 11: 69−81.

Miller, C.H., R.E. McCollum, and S. Claimon. 1979. Relationships between growth of bell peppers (*Capsicum annum L.*) and accumulation during ontogeny in field environments. *Journal of American Society of Horticultural Science* 104: 852-857.

Puente, L.A., C.A. Pinto-Muñoz, E.S. Castro, and M. Cortés. 2011. *Physalis peruviana* Linnaeus, the multiple properties of a highly functional fruit: A review. *Food Research International* 44: 1733-1740.

Radford, P. J. 1967. Growth analysis formulae. Their use and abuse. *Crop Science* 7: 171–175.

Ramadan, M. F., and J.T. Moersel. 2007. Impact of enzymatic treatment on chemical composition, physicochemical properties and radical scavenging activity of goldenberry (*Physalis peruviana* L.) juice. *Journal of the Science of Food and Agriculture* 87: 452−460.

Ramadan, M.F., and J.T. Moersel. 2009. Oil extractability from enzymatically treated goldenberry (*Physalis peruviana* L.) pomace: Range of operational variables. *International Journal of Food Science & Technology* 44: 435−444.

Rincón, L., J. Sáez, E. Balsalobre, and C. Pellicer. 1993. Nutrition of the greenhouse pepper. (In Spanish). *Hortofruticultura* 5: 37-41.

Salazar, M.R., J.W. Jones, B. Chaves, and A. Cooman. 2008. A model for the potential production and dry matter distribution of Cape gooseberry (*Physalis peruviana* L.). *Scientia Horticulturae* 115: 142-148.

Scholberg, J.M.S., B.L. McNeal, J.W. Jones, K.J. Boote, C.D. Stanley, and T.A. Obreza. 2000. Growth and canopy characteristics of field-grown tomato. *Agronomy Journal* 92: 152-159.

Sonneveld, C., and N. Straverd. 1992. *Nutrient solution for vegetables and flowers grown in water or substrates*. Series: Voedingsoplossingen glastuinbouw, 8. Glasshouse Crops Research Station: Naaldwijk, The Netherlands.

Statistical Graphics Corporation. 2005. Statgraphics Plus for Windows 5.1. Statistical Graphics Corp.: Princeton, NJ, USA.

Trinchero, G.D., G.O. Sozzi, A.M. Cerri, F. Vilella, and A.A. Fraschina. 1999. Ripening-related changes in ethylene production, respiration rate and cell-wall enzyme activity in goldenberry (*Physalis peruviana*, L.), a solanaceous species. *Postharvest Biology and Technology* 16: 139-145.

Turner, A. D., and H.C. Wien. 1994. Dry matter assimilation and partitioning in pepper cultivars differing in susceptibility to stress-induced bud and flower abscission. *Annals of Botany* 73: 617-622.

Wubs, A.M., M.J. Bakker, E. Heuvelink, L. Hemerik, and L.F.M. Marcelis. 2007. Stochastic simulation of fruit set in sweet pepper. *Second International Symposium on Plant Growth Modeling, Simulation, Visualization and Applications. IEEE Computer Society*: 40-47.

Williams, R. F. 1946. The physiology of plant growth with special reference to the concept of net assimilation rate. *Annals of Botany* 37: 41–72.

Wolff, X.Y. 1991. Species, cultivar, and soil amendments influence fruit production of two *Physalis* species. *HortScience* 26: 1558-1559.

Zapata, J.L., A. Saldarriaga, M. Londoño, and C. Díaz. 2002. Cape gooseberry Management in Colombia. (In Spanish). Rionegro, Programa Nacional de Transferencia de Tecnología Agropecuaria - Corpoica Regional Cuatro: Antioquia, Colombia.

Zerihun, A., V.P. Gutschick, and H. Bassirirad. 2000. Compensatory roles of nitrogen uptake and photosynthetic N-use efficiency in determining plant growth response to elevated CO_2: Evaluation using a functional balance model. *Annals of Botany* 86: 723–730.

Figure 1. Maximum, average, and minimum daily temperatures registered inside the greenhouse in 2008 experiment.

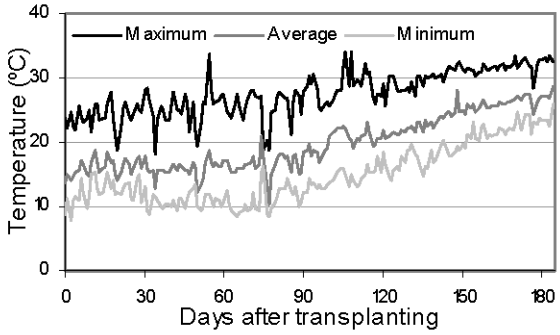

Figure 2. Panel A: Dry matter (DM) accumulation and partitioning in whole plants, stems, leaves, fruits, and roots. Exponential equations fitting the corresponding DM ($g \cdot plant^{-1}$) accumulation for the whole plant and the corresponding different plant organs for 90 days after transplanting (DAT; d = number of DAT) are as follows: Roots = $1.42 \cdot e^{0.023 \cdot d}$, $R^2 = 0.9685$, P = 0.01; Stems = $2.728 \cdot e^{0.042 \cdot d}$, $R^2 = 0.9988$, P = 0.01; Leaves = $6.217 \cdot e^{0.030 \cdot d}$, $R^2 = 0.9906$, P = 0.01; Whole plant = $9.365 \cdot e^{0.036 \cdot d}$, $R^2 = 0.9973$, P = 0.01. Panel B: Evolution of the stem, leaf, fruit and root percentages during the cultivation cycle. Average data for two seasons and two nutrient solutions. Vertical bars represent ± standard error. Their absence indicates the bar size was less than that of the symbol used.

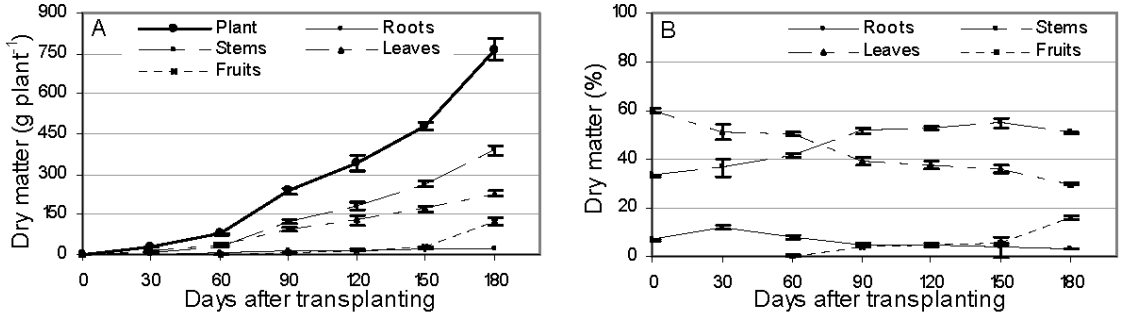

Figure 3. Changes in the relative growth rate (whole plants; RGR; $g \cdot g^{-1} \cdot d^{-1}$) values for 90 d after transplanting (DAT). The curve is the second order polynomial equation fitting the RGR and DAT. The equation of this curve is: $RGR = 0.1122 - 0.0027 \cdot d + 0.00002 \cdot d^2$, $R^2 = 0.8917$, $P \leq 0.05$, d being the number of DAT.

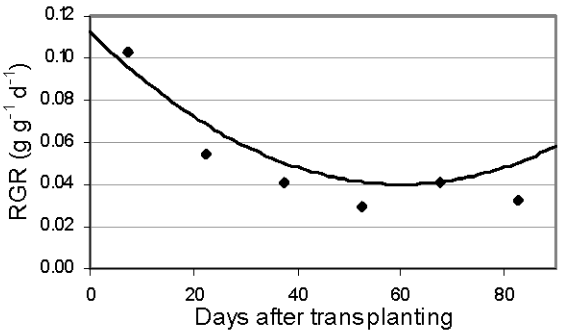

Figure 4. Fresh fruit weight accumulation during the cultivation cycle. Vertical bars represent ± standard error.

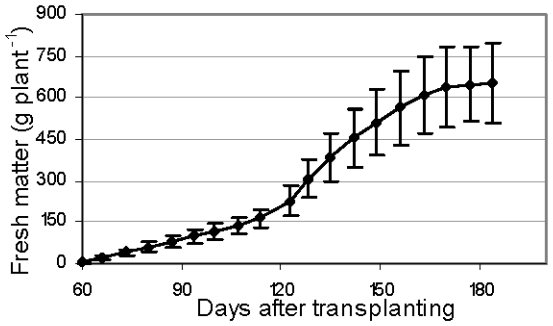

Figure 5. Seasonal changes in N, P, K, Ca and Mg concentrations in stems, leaves, fruits and roots (Panels A-E respectively), and total accumulation and partitioning of macronutrients (Panels F-J respectively). Vertical bars represent ± standard error. Their absence indicates the bar size was less than that of the symbol used.

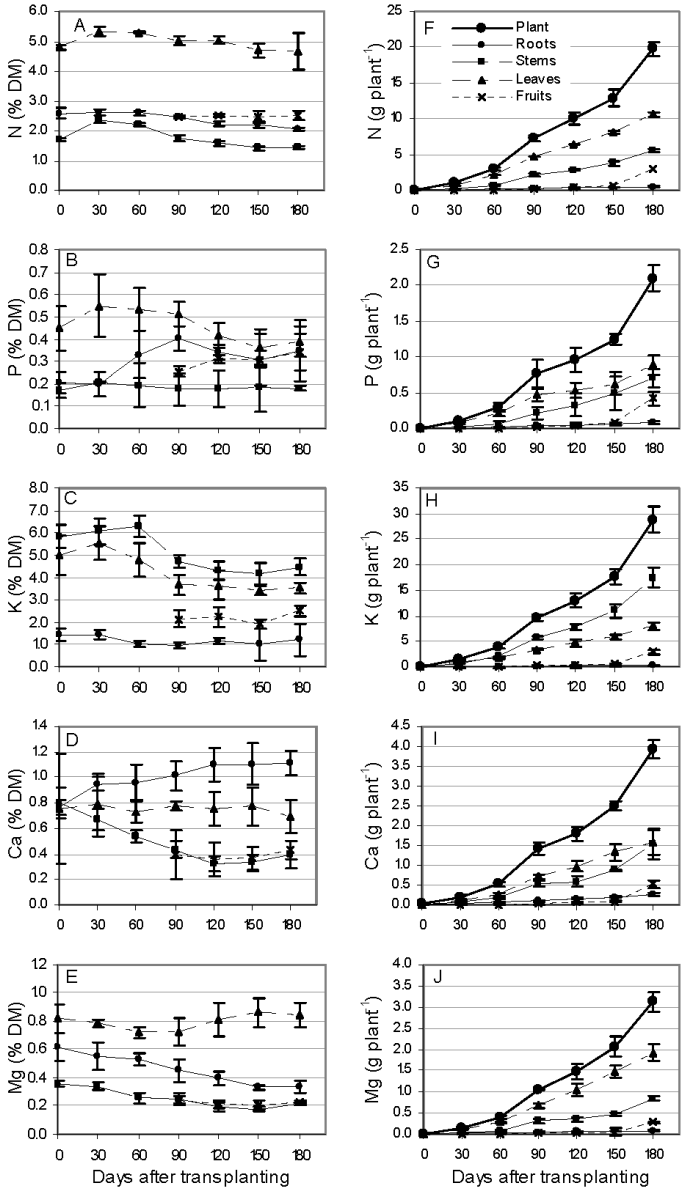

Figure 6. Changes in mean specific nutrient uptake rates (I_M; mg nutrient absorbed·g^{-1} dry root weight·d^{-1}) of N, P, K, Ca, and Mg, for 90 d after transplanting (DAT). The curves drawn are the best-fit, second order polynomials. The equations of these curves are as follows: I_M N = 0.0493 – 0.0014·d + 0.00001·d^2, R^2 = 0.89, P ≤ 0.05; I_M P = 0.0048 – 0.0001·d + 0.000001·d^2, R^2 = 0.89, P ≤ 0.05; I_M K = 0.0663 – 0.0018·d + 0.00002·d^2, R^2 = 0.85, P ≤ 0.05; I_M Ca = 0.0104 – 0.0003·d + 0.000003·d^2, R^2 = 0.90, P ≤ 0.05; and I_M Mg = 0.0083 – 0.0003·d + 0.00002·d^2, R^2 = 0.88, P ≤ 0.05; where d is the number of DAT.