Scientia Horticulturae 214 (2017) 9–17

Contents lists available at ScienceDirect

Scientia Horticulturae

journal homepage: www.elsevier.com/locate/scihorti

Selecting vegetative/generative/dwarfing rootstocks for improving fruit yield and quality in water stressed sweet peppers

Josefa López-Marín[a,*], Amparo Gálvez[a], Francisco M. del Amor[a], Alfonso Albacete[b], Juan A. Fernández[c], Catalina Egea-Gilabert[d], Francisco Pérez-Alfocea[b]

[a] Hortofruticultura, IMIDA. La Alberca. E-30150-Murcia, Spain
[b] Plant Nutrition, CEBAS-CSIC. Campus de Espinardo, 25. E-30100-Murcia, Spain
[c] Producción Vegetal, Universidad Politécnica de Cartagena. E-30203-Cartagena, Spain
[d] Ciencia y Tecnología Agraria, Universidad Politécnica de Cartagena. E-30203-Cartagena, Spain

ARTICLE INFO

Article history:
Received 3 August 2016
Received in revised form 6 October 2016
Accepted 14 November 2016

Keywords:
Capsicum annum
Vegetative growth
Grafting
WUE
Vigour
Drought

ABSTRACT

Rootstock breeding for vegetable crops includes desirable traits such as compatibility with the scion, increased productivity and quality under stressful environments and improved use of soil, water and fertilizer resources. The effects of three commercial rootstocks (Atlante, Creonte and Terrano) on the agronomical and physiological responses of a commercial sweet pepper variety (cv Herminio) to deficit irrigation (50% of optimal) have been studied. Although the three rootstocks increased total and marketable yield under control and deficit irrigation, Creonte produced the most productive and water use efficient plants, with until 25% more marketable yield than the ungrafted cv Herminio, and about 10% more than the other rootstocks, although in detriment of some chemical fruit quality traits. Moreover, the plants grafted onto Creonte registered the highest photosynthetic activity and leaf water content and more stable leaf area and biomass under water stress, while those parameters were more reduced in the other graft combinations. These Creonte-mediated effects were not related to root biomass (since it was more affected by the stress in this rootstock) but rather to the capacity of maintaining a high reproductive/vegetative ratio, while Atlante is a vigorous vegetative rootstock and Terrano is rather a dwarfing-reproductive rootstock that produces efficient compact plants without negative effects on fruit quality.

1. Introduction

The majority of climate change scenarios predict an increase in drought incidence throughout different regions of the world (IPCC, 2007). Because agricultural activities are water intensive, the increase in arid and semi-arid cropland, along with increases in population, will produce greater water demands and exploitation that will directly affect crop growth, survival and yield (Chaves et al., 2009). The effects of water stress can be direct: such as decreased CO_2 availability caused by diffusion limitations through the stomata and/or the mesophyll (Flexas et al., 2007); or by alteration in CO_2 fixation reactions (Lawlor and Cornic, 2002). Photosynthetic responses to water stress are complex since they involve the interplay of limitations taking place at different parts of the plant (Chaves et al., 2009). The limitation of plant growth due to low water availability is mainly due to reductions of plant carbon balance, which is largely dependent on photosynthesis (Flexas et al., 2009). One possible solution to reduce yield losses and improve crop growth under water-deficit conditions involves the use of grafts using rootstocks capable of palliating the effects of this stress in the shoot (Schwarz et al., 2010; Albacete et al., 2015).

Currently, the cultivated area of grafted Solanaceae and Cucurbitaceae has increased tremendously in recent years because the objective of grafting has been greatly expanded (Lee et al., 2010). Zones that produce grafted horticultural products of great economic importance, have in recent years begun to use grafted plants to enhance growth and yield (Lee et al., 2010), tolerance to abiotic stress as low temperature (Schwarz et al., 2010; Venema et al., 2008), uptake of nutrients (Colla et al., 2010a; Savvas et al., 2010), water-use efficiency (Rouphael et al., 2008a; Cantero-Navarro et al., 2016), reliance on susceptible cultivars to meet specific market demands (Sakata et al., 2007), increase synthesis of endogenous hormones (Dong et al., 2008), improve alkalinity tolerance (Colla et al., 2010b), reduce uptake of persistent organic pollutants from

---

* Corresponding author.
E-mail address: josefa.lopez38@carm.es (J. López-Marín).

http://dx.doi.org/10.1016/j.scienta.2016.11.012

agricultural soils (Otani and Seike, 2006, 2007), raise salt and flooding tolerance (Fernández-García et al., 2004a, 2004b; Yetisir et al., 2006; Martinez-Rodriguez et al., 2008; He et al., 2009), limit the negative effect of boron, copper, cadmium, and manganese toxicity (Edelstein et al., 2005; Rouphael et al., 2008b; Arao et al., 2008; Savvas et al., 2009) and get better photosynthetic rate (Davis et al., 2008; He et al., 2009).

Generally, drought reduces not only nutrient uptake by the root but also nutrient transport from the root to the shoot due to a restricted transpiration rate, depressed active transport, and reduced membrane permeability. On the other hand, several conflicting reports exist on the quality of fruit vegetables influenced by grafting, and whether the effects of grafting are advantageous or deleterious (Flores et al., 2010; Proietti et al., 2008; Rouphael et al., 2010). The differences in reported results may be attributable in part to different production environments and agricultural practices, type of rootstock/scion combinations used, and harvest date. In addition, very little attention has been paid to how the use of different rootstocks can affect fruit quality in grafted sweet pepper (Colla et al., 2008). Through the rootstock, water management can affect the synthesis of phytochemicals. Generally, a reduced water supply increases the contents of phytochemicals, such as phenolic compounds and anthocyanins (Dixon and Paiva, 1995). In this sense, deficit irrigation and grafting strategies are relatively new tools for managing plant growth and improving fruit quality (Sánchez-Rodríguez et al., 2012).

It is well known that seed market provides a collection of rootstocks for vegetable crops with different properties that make them more or less suitable for specific 'GxE' combinations, where 'G' is the genotype of the variety to be grafted and 'E' the particular environment where the crop will develop. 'E' includes soil/rootzone properties, cycle duration, climatic conditions, pathogens, water quality and quantity, etc. Gaining insights in the physiological/agronomical traits of the available rootstocks (commercial or pre-breeding) will certainly contribute to a better selection of the adequate rootstocks for each agro-environment and to further development of new improved rootstocks able to increase crop productivity, resilience, resource use efficiency, yield stability and quality. For example, vigorous vegetative rootstocks are more adequate for large fruited tomato varieties growing in long cropping cycles, while generative rootstocks that put more energy into reproductive than into vegetative structures are more adequate for small fruited varieties cultivated at any cropping cycle or for large fruited ones growing in short cropping cycles. The aim of this work was to study the behaviour of three commercial pepper rootstocks on vegetative/reproductive balance, gas-exchange and fruit yield and quality of grafted sweet pepper grown in greenhouse under standard and deficit irrigation regimes. This knowledge enables choices to be made about which rootstock is better to cope with abiotic challenges such as low water availability.

2. Materials and methods

2.1. Plant material and greenhouse conditions

Using the procedure of Japanese top graft procedure, the sweet pepper cultivar 'Herminio' F1 (Syngenta Seeds, USA) was grafted onto three commercial rootstocks: Atlante (Ramiro Arnedo, Spain), Terrano (Syngenta Seeds, USA) and Creonte (De Ruiter, Monsanto Seeds, Holland). Ungrafted 'Herminio' plants were used as control. Grafted and ungrafted plants were transplanted on 5th January to an unheated arch-shaped multispan greenhouse covered with thermal polyethylene,located at the 'Torreblanca' Experimental Farm of IMIDA in Murcia, SE Spain (lat. 37°45′N, long. 0° 59′W). The original soil type was clay loam soil, pH 7.7 and the electrical conductivity of saturated soil extract 5.47 dSm^{-1}. Prior to transplanting (10th August), the soil was biosolarized by adding a mixture of 5 $kg\,m^{-2}$ of sheep and chicken manure (2:1, w/w) and covering the soil with transparent, low-density plastic film (50 μm) for 90 days. Plants were grown in single rows 100 cm apart with 40 cm between each plant in a given row (25,000 plants/ha plant density). The field trial was conducted following the cultural practices commonly used in commercial sweet pepper production in this area. The crop cycle ended on 16th of August 2011 after six harvests. The control treatment (no stress: NS) received 100% irrigation requirements (being based on estimations of the weekly crop evapotranspiration, ETc), whereas moderate water stress treatment (stress: S) corresponded to 50% of the amount of the control treatment. The experimental design was a randomized block design with four replications for drip irrigation. They began 181 days after transplant and were maintained during 30 days. Total water applied in Non-Stress was 618.55 $L\,m^{-2}$ and in stress was 506.04 $L\,m^{-2}$.

The treatment was watered with a nutrient with the following composition ($g\cdot m^{-2}$): N, 30.3; P2O5, 28; MgO, 10.36; K2O, 54; CaO, 27.2, throughout the crop cycle. The air temperature inside the greenhouse was monitored during the growing cycle using a Hobo U12 temperature data logger (Onset, Massachusetts, USA), respectively.

2.2. Plant growth measurements

Fifteen grafted and ungrafted plants per greenhouse unit were used for measuring different parameters individually. Plant height, stem diameter, leaf number and area and total leaf, stem and root fresh (FW) and dry (DW) weights were measured at the end of the crop (1st August 2012). Leaf area was measured using a leaf area meter (LICOR-3100C; LI-COR Inc., Lincoln, Nebraska, USA), and the root biomass was extracted from a similar soil volume $40 \times 40 \times 40\,cm^3$ in all plants. DW were determined by drying each separate plant material in an oven at 60 °C until constant weight. Since the differences observed in aerial biomass between genotypes were similar on both FW and DW basis, only FW data are presented.

2.3. Gas exchange measurements

Gas-exchange and chlorophyll fluorescence were monitored in fully expanded leaves in the generative plant stage. The closest leaf to the recently set fruit was used to measure both parameters. Measurements were carried out 20 days after fruit set (205 DAT), from 9:00 am to 11:00 am (GMT). Net CO_2 assimilation rate (Amax, mmol $CO_2\,m^{-2}\,s^{-1}$), stomatal conductance (gs, mmol H_2O $m^{-2}\,s^{-1}$), transpiration rate (E, mmol H_2O m−2 s−1), substomatal CO_2 concentration (Ci, μmol CO_2 mol^{-1} air) and water efficiency, were measured in steady-state under conditions of saturating light (800 $\mu mol\,m^{-2}\,s^{-1}$ and 400 ppm CO_2) with a LI-6400 portable photosynthesis system (LI-COR Inc., Lincoln, Nebraska, USA).

2.4. Fruit yield and quality

Sweet pepper fruits were harvested from the above-mentioned 15 plants used for growth measurement. Quality commercial production was evaluated according to commercial practices, as were discarded fruits with physiological disorders (sunscald, BER, etc.) that were unmarketable. Twelve randomized fruits (4 per replication of the plant material) per treatment were selected at 196 DAT in order to measure fruit quality, which included soluble solid content (°Brix), titratable acid, vitamin C, total phenolics content and antioxidant capacity.

The total soluble solids content (°Brix) was determined using a refractometer (Reichert Analytical Instruments, Depew, New