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Foliar application of plant growth regulators changes the nutrient composition of sweet pepper (*Capsicum annuum* L.)

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ABSTRACT

Plant growth regulators (PGRs) may have an important role in regulating both yield and fruit quality during the production of sweet pepper in controlled-environment greenhouses, but the uncertainly of results – due to the specificity of the plant response – could limit their use and potential benefits. Therefore, we investigated the effect of the foliar spraying of abcisic acid (ABA), gibberellic acid (GA_3) and indole-3-acetic acid (IAA) on fruit colour, concentrations of carbohydrates, ions and amino acids, plant growth and total fruit yield. Although yield was decreased by the GA_3 and ABA treatments, GA_3 augmented plant height and the levels of tyrosine, phosphate, sulphate, iron and phosphorus while decreasing the amounts of glucose and fructose. The foliar applications of IAA did not produce any change when compared with the control plants, while plants treated with ABA had decreased levels of sucrose but higher levels of iron. GA_3, applied fortnightly, produced a significant improvement in the fruit quality of sweet pepper but did not significantly increase total yield. Further studies will be necessary to determine the best GA_3 concentration and frequency of application, to obtain greater benefits for human consumption this important crop.

1. Introduction

Nowadays, product innovations for improving yield and fruit quality are being carried out more intensively since global markets demand excellent fruit quality and all-season supply stability. Natural biostimulants (Paradiković et al., 2011), foliar fertiliser (del Amor et al., 2009) and plant growth regulators (PGRs) are currently used to improve horticultural products but are usually limited to certain species, such as cucumber, tomato, pepper, potato, onion, pea and melon, with distinct results (Papadopoulos et al., 2006).

The PGRs are a wide category of compounds that can promote, inhibit or change plant physiological or morphological processes at very low concentrations. Thus, the use of PGRs has become an important component of the agro-technical procedures for most cultivated species and especially for fruit plants (Monselise, 1979). The most-studied PGRs include abscisic acid (ABA), indole-3-acetic acid (IAA), brassinosteroids, cytokinin, gibberellic acid (GA_3), ethylene, jasmonic acid, salicylic acid and their antagonists (Santner et al., 2009). These control rooting, flowering, fruiting and fruit growth, leaf or fruit abscission and senescence, and regulate some metabolic processes – such as net photosynthesis or antioxidant enzyme activities – and plant resistance to abiotic stresses.

IAA is the major naturally-occurring auxin and its roles range from virtually every aspect of plant growth and development to defence responses. Auxins are believed to increase ethylene production, which is responsible for fruit maturation. Thus, auxins are used in commercial farming to control fruit drop and to improve fruit quality (Almeida et al., 2004) and it has been reported that polar auxin transport may play a major role in growth, floral and yield-related traits and yield (Tantasawat et al., 2015).

ABA is a compound associated with seed dormancy, responses to stresses such as drought, extreme temperatures and excess light (Hirayama and Shinozaki, 2007; Thompson et al., 2000) and other growth processes. It has proved to be an effective tool in the modification of transplant, shoot growth and leaf abscission and in the enhancement of the drought tolerance of several vegetable species, including pepper, tomato, melon and artichoke (Leskovar et al., 2009).

Gibberellins have a particularly-interesting role in commercial farming since they lead to plant elongation and development

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and delay fruit maturation and abscission of leaves (Yilmaz and Ozguyen, 2009). Application of GA_3 to tomato plants has been shown to induce marked stem elongation (Bukovac and Witter, 1956), increase fresh weight (Bukovac and Witter, 1956; Rappaport, 1956), accelerate flowering and produce greater numbers of flowers per plant (Witter and Bukovac, 1957) and increase fruit set. The impact of exogenous GA_3 on growth and yield has been studied in different crops. In strawberry, its application increased vegetative growth although fruit size, weight and yield were reduced (Qureshi et al., 2013), while in pineapple this PGR increased fruit weight (Li et al., 2011).

Pepper (*Capsicum annum* L.) is an important agricultural crop, not only because of its economic importance but also owing to the nutritional value of its fruits. Thus, improvement of the yield and fruit quality in this crop is a priority in global agriculture. To date, only a few studies have reported the effects of PGRs on pepper yield or quality. Belakbir et al. (1998) applied solutions of different PGRs to sweet pepper; an increase in yield was obtained with auxins but no changes were found with GA_3. On the other hand, although Maboko and Du Plooy (2015) did not find differences in fruit production with other PGRs, increases in fresh and dry weights were detected after treatment with GA_3.

Since the reported studies concerning the effect of PGRs on sweet pepper quality and yield are very few, this study supposes a new insight into the impact of PGRs, a common tool in agriculture, in this important crop species. In this work, our objective was to determine the effect of three different PGRs on pepper production, fruit quality and plant growth parameters, through the study of different quality parameters – such as fruit colour, carbohydrates content, ions and amino acids concentrations, plant growth and fruit yield – that may add market value to sweet pepper.

2. Material and methods

2.1. Plant material and growth conditions

Sweet pepper plants cv. Inciso, California type, were obtained from a commercial nursery. Plants were grown in 1.2-m long bags filled with coconut fibre, in a greenhouse equipped with a computer-regulated drip-irrigation system, under controlled environmental conditions. Each bag had three plants and three drippers ($4\,L\,h^{-1}$). The irrigation was managed according to local commercial soilless cultivation and the drainage percentage was maintained at 30 %. Sixty days after transplanting (DAT), the treatments started. Thirty-six plants were used for each treatment. Each treatment consisted of the application of a plant hormone to the aerial part of the plants, every two weeks for two months, with the addition of a surfactant (Tween 20): T0, distilled water + 0.5% (v/v) Tween 20; T1, $100\,mg\,L^{-1}$ ABA + 0.5% (v/v) Tween 20; T2, $32.2\,mg\,L^{-1}$ GA_3 + 0.5% (v/v) Tween 20 and T3, $32.2\,mg\,L^{-1}$ IAA + 0.5% (v/v) Tween 20. The PGRs were applied in the early morning and the plants were covered with a shadow greenhouse sheet to shield them from direct sunlight during spraying and for at least 1 h afterwards, to avoid solar burn. Guard rows were placed at both ends to avoid contamination of the foliar application. Treated plants were sprayed completely and homogeneously with the plant hormone solutions (young and old leaves, stems and fruits).

2.2. Yield production and growth parameters

Starting 42 days after the first plant hormone application, peppers were harvested weekly at the mature, red stage. Total fruit yield was determined multiplying the total yield per plant by the plant density in the greenhouse (1 plant per $2.5\,m^2$). The fruit quality was established by the following quality criteria: marketable, extra (>200 g, uniform colour, good health state, square shape), class I (>200 g, uniform colour, good health state, non-square shape), class II (150–199 g, uniform colour, good health state, square shape), class III (105–149 g, uniform colour, good health state, square shape) and non-marketable (physically damaged or of unsuitable colour or size).

In order to determine the effect of the foliar application of different PGRs on plant growth, 16 plants per treatment were harvested at the end of the experimental period. Different parameters were measured: total plant height and weight (without roots), stem weight and leaf fresh and dry weight (FW and DW). The DW/FW ratio was calculated in order to study the effects of the PGRs on leaf water accumulation.

2.3. Reflected colour

Pepper fruits at the red colour stage were analysed with a Konica-Minolta CR-300 colorimeter, taking three measurements along the equatorial perimeter. Surface colour was measured as reflected colour in the CIELAB (L^*, a^*, b^*) colour space, using a Minolta model CR-300 colorimeter (Minolta, Osaka, Japan). Before the analysis the instrument was calibrated with a ceramic plate. Lightness (L^*), chroma (C^*) and hue angle (h°) were determined, with L^* ranging from 0 (black) to 100 (white). $C^* = [((a^*)^2 + (b^*)^2)^{1/2}]$ and represents colour saturation, which varies from dull (low value) to vivid colour (high value), while $h^\circ = \tan^{-1}(b^*/a^*)$ and is defined as a colour wheel, with red-purple at an angle of 0°, yellow at 90°, bluish-green at 180° and blue at 270°.

2.4. Carbohydrates determination

Carbohydrates were extracted from fruits frozen at −80 °C at the end of the experiment. Sap was extracted by vortexing at 5000 rpm (10 min, 4 °C) and filtering (nylon membrane filter, 0.2 μm), and carbohydrates were determined in an ion chromatograph (METROHM 861 Advanced Compact IC; METROHM 838 Advanced Sampler) and a METROHM 871 Advanced Bioscan. The column used was a METROHM Metrosep CARB1 (250/4.0 mm; 5 μm), with a METROHM Metrosep CARB1 Guard pre-column. External standards (Sigma Aldrich) were used for quantification of (suc) sucrose, (glu) glucose and (fru) fructose.

2.5. Ion determination

Pepper fruits were dried at 65 °C in a heater for 72 h. Anions were extracted from ground material (0.4 g) with 20 mL of deionised water. Samples were analysed in an ion chromatograph (METROHM 861 Advanced Compact IC; METROHM 838 Advanced Sampler) and the column used was a METROHM Metrosep A Supp7 250/4.0 mm.

Cations were determined after calcination at 550 °C, by inductively coupled plasma–optical emission spectrometry (ICP-OES) (Varian Vista-MPX, Varian Australia, Mulgrave, Vic., Australia).

2.6. Free amino acids

Free amino acids were extracted from fruits frozen at −80 °C at the end of the experiment. After liquefying fruit samples, the sap was vortexed at 5000 rpm (10 min, 4 °C) and filtered (nylon membrane filter, 0.2 μm), and the free amino acids were determined by the AccQ Tag-Ultra Performance Liquid Chromatography (UPLC) method (Waters, 2006). For derivatisation, 70 μL of borate buffer were added to the hydrolysed sample or to 10 μL of the fruit sap. Following this, 20 μL of reagent solution were added. The reaction mixture was mixed immediately and heated at 55 °C for 10 min. After cooling, an aliquot of the reaction mixture was used for UPLC