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Age-dependent effectiveness of exogenous abscisic acid in height control of bell pepper and jalapeño transplants

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Height control of vegetable transplants is important for improving their adaptability to shipping and transplanting operations. Abscisic acid (ABA) inhibits stem elongation but can also induce undesirable growth modification. To optimize its application timing for effective height control, we examined age-dependent sensitivity of various growth variables to ABA in two pepper cultivars (*Capsicum annuum* L.). Bell pepper 'Excursion II' seedlings were sprayed once with 3.8 mM ABA at 25, 18, or 11 days before transplanting (DBT), or twice with 1.9 mM ABA at 25 and 18 DBT. Jalapeño 'Colima' seedlings were sprayed once with 3.8 mM ABA at 22, 15, or 8 DBT, or twice with 1.9 mM ABA at 22 and 15 DBT. For all treatments, the application rate was 0.71 mg ABA per plant with the spray volume of 0.61 L m^{-2} (0.71 ml/plant). Only 'Excursion II' maintained significantly shorter plant height in all ABA treatments until the transplanting stage, ranging from 80% to 88% of the control. By contrast, leaf chlorosis and overall growth delay were induced by ABA in 'Colima'. Age-dependent sensitivity to ABA was evident in leaf area of both cultivars, and in stem diameter and shoot and root biomass of jalapeño 'Colima', all of which showed maximal reductions when 3.8 mM ABA was applied at the cotyledon stage (first application). These results suggest that ABA is effective in height control for bell pepper 'Excursion II', and that it should be applied at least one week after the emergence of first true leaf to minimize the negative side effects. Importantly, subsequent field evaluations demonstrated that the growth modulation by ABA was only transient with no negative impact on marketable yield.

1. Introduction

Height control of vegetable transplants is important for maintaining quality during shipping and improving adaptability to transplanting operations (Latimer, 1998; Björkman, 1999). Because vegetable transplants are typically grown in high-density plug trays (Marr and Jirak, 1990), stems can grow excessively elongated and weak as a result of shade avoidance responses (Smith, 1994). Compared with stocky transplants, such weak transplants are more difficult to handle and are easily damaged during shipping (Garner and Björkman, 1996). They are also more susceptible to damage during mechanical transplanting (Shaw, 1993) and to lodging in the field (Latimer and Mitchell, 1988; Garner and Björkman, 1999). As a result, their field establishment can be slow and non-uniform, delaying growth and early harvest and potentially limiting marketable yield.

The cellular basis for stem elongation is a combination of cell division and cell elongation, both of which are stimulated by gibberellins (Sachs, 1965; Taiz and Zeiger, 2010). Ethylene has antagonistic effects by inhibiting cell elongation and promoting stem thickening (Zarembinski and Theologis, 1994). In ornamentals and flowers, several gibberellin inhibitors, such as daminozide, paclobutrazol, and uniconazole, are commercially used to produce compact plants (Whipker et al., 2000; Gibson and Whipker, 2001). However, as they have long-term growth inhibiting effects (Latimer, 1991; Cantliffe, 1993), only uniconazole is currently available for vegetable crops at relatively low application rates to avoid phytotoxicity. Alternatively, stem elongation can be reduced by mechanical stimulation that increases ethylene production (Hiraki and Ota, 1975; Baden and Latimer, 1992; Garner and Björkman, 1997, 1999). Such mechanical treatments include brushing the upper canopy, shaking, and vibration by wind or forced aeration, but their commercial application is limited by high costs of automation and labor (Latimer, 1998).

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Abscisic acid is another plant growth regulator, which application has shown to inhibit stem elongation (Latimer and Mitchell, 1988; Leskovar and Cantliffe, 1992; Yamazaki et al., 1995). In contrast to gibberellin inhibitors, ABA can be rapidly inactivated in plant tissues by oxidation or conjugation (Davies and Jones, 1991), suggesting that it may be more suitable for vegetable transplants that require only transient growth inhibition. The potential of ABA to control transplant height has been studied in bell pepper. For example, Leskovar and Cantliffe (1992) reported that the concentration effect of ABA on stem elongation was quadratic, with height suppression occurring above 10 μM. Biai et al. (2011) suggest that the effectiveness of height control is age-dependent, and that ABA application should be initiated at the cotyledon stage. However, this recommendation is based solely on plant height, although other growth components are also known to be affected by ABA (Taiz and Zeiger, 2010). Moreover, high-dose applications of ABA tend to have negative side effects, such as leaf chlorosis and abscission (Waterland et al., 2010; Kim and van Iersel, 2011; Agehara and Leskovar, 2012). Therefore, understanding overall growth modification will provide the basis to further optimize ABA application methods for height control.

Our first objective is to examine the age-dependent sensitivity of various growth variables to ABA in bell pepper and jalapeño seedlings. Such information will be useful to determine the application timing for the most effective height control. To justify the advantages of height control, our second objective is to evaluate field performance of the ABA-treated transplants.

2. Materials and methods

2.1. Plant material

Seeds of two pepper cultivars (Abbott & Cobb, Feasterville, PA, USA), bell pepper 'Excursion II' and jalapeño 'Colima', were sown on 16 February and 6 March 2010, respectively, in a polystyrene tray with 200 inverted pyramid cells each containing 23 mL of peat-lite mix (Speedling Peat-lite; Speedling, Sun City, FL, USA). Seedlings were grown in a commercial nursery greenhouse (Speedling, Alamo, TX, USA) until they reached optimal size for transplanting according to the nursery's commercial standard. Average daily air temperature during seedling growth ranged from 9 to 27 °C.

2.2. Treatments

There were five treatments for each cultivar: no spray control, three timings of a single spray with 3.8 mM (1000 mg L^{-1}) ABA, and one treatment of a double spray with 1.9 mM (500 mg L^{-1}) ABA. The single spray was performed at 25, 18, and 11 DBT [17, 24, and 31 d after sowing (DAS)] for 'Excursion II' and at 22, 15, and 8 DBT (19, 26, and 33 DAS) for 'Colima'. The double spray was performed at 25 and 18 DBT for 'Excursion II' and at 22 and 15 DBT for 'Colima'. Seedlings had fully opened cotyledons with one or two immature true leaves at the time of the first ABA application. Spray volume was set at 0.61 L m^{-2} (0.71 ml/plant), which wetted the leaves thoroughly to the dripping point. The resulting application rate was 0.71 mg ABA per plant in all ABA treatments.

The formulation of ABA stock solution was VBC-30151 (Valent BioSciences, Libertyville, IL, USA) containing 10% of S-ABA, a naturally occurring active form in plants. Test solutions were prepared immediately before each treatment by diluting the stock solution with irrigation water at the nursery. CapSil (Aquatrols, Paulsboro, NJ, USA) was added at 0.05% (v/v) as an adjuvant according to the manufacture's protocol (Valent BioSciences), which showed no significant effect on transplant growth in our preliminary experiment.

A CO_2-pressured backpack sprayer (Model T; Bellspray, Opelousas, LA, USA) was used to spray the ABA solutions evenly over the seedlings between 10:00 and 11:00 AM. The sprayer was equipped with three flat-fan nozzles (TP8002VS; TeeJet Technologies, Wheaton, IL, USA) and a CO_2 cylinder with pressure maintained at 276 kPa.

2.3. Transplant growth measurements

Six plants per replication (tray) were randomly selected before the first measurement. All measurements were made at 25, 18, 11, and 1 DBT for 'Excursion II' and at 22, 15, 8, and 1 DBT for 'Colima'.

Stem height and leaf chlorophyll index were repeatedly measured on the selected plants between 8:00 and 10:00 AM at each measurement time. Stem height was measured from the medium surface to the shoot apex. To quantify the elongation speed, relative stem elongation rate (RSER, mm cm^{-1} d^{-1}) was calculated as follows:

$$\mathrm{RSER} = \frac{\ln H_2 - \ln H_1}{t_2 - t_1} \times 10$$

where $\ln H_1$ and $\ln H_2$ are the natural logarithm of stem height (cm) at time one, t_1, and time two, t_2, respectively.

Leaf chlorophyll index was measured using a chlorophyll meter (SPAD-502; Konica Minolta Sensing, Tokyo, Japan) on the youngest fully open leaf and the largest leaf. Two readings were taken per leaf on a leaf lamina between major leaf veins.

At each measurement time, three plants per replication were randomly sampled and roots were washed to remove the growth medium. Stem diameter was measured immediately below the cotyledonary node using a digital caliper (Absolute Digimatic Caliper Series 500; Mitutoyo, Kawasaki, Japan). The number of cotyledons and true leaves with unfolded laminae and visible petioles were counted. Leaf area was measured using an LI-3100 area meter (LI-COR, Lincoln, NE, USA). Shoots and roots were separated and dried at 65 °C for 72 h to determine dry weight.

2.4. Field experiment

One d before transplanting, the seedlings were transferred to the Texas A&M AgriLife Research and Extension Center (Uvalde, TX, USA) using a customized enclosed trailer equipped with racks to hold up to 70 trays. The transportation was about a 6-h drive and caused no visual damage on the seedlings. Soil at the site was an Uvalde silty clay loam (fine-silty, mixed, hyperthermic Aridic Calciustolls). At pre-plant, the surface (top 18 cm) soil had pH of 7.6, organic matter of 26 g kg^{-1}, and high available macronutrient (P, K, and Mg) levels (>63 mg kg^{-1}), according to soil tests by the Soil, Water and Forage Testing Laboratory at Texas A&M University (College Station, TX, USA).

Seedlings of 'Excursion II' and 'Colima' were transplanted on raised beds (20 cm high and 70 cm wide) in one row per bed on 30 March and 16 April 2010, respectively. A semi-automatic transplanter (RTME1100; Renaldo Sales & Service, North Collins, NY, USA) was used to control planting depth at the cotyledonary node with 30 cm in-row spacing. Each plot was a 3.7-m long single row with 12 plants. All plots were irrigated through drip tapes (T-Tape 508-12-340; John Deere, Moline, IL, USA) installed at 10 cm depth in the center of each bed. The drip tapes had emitters spaced 30 cm apart, with a flow rate per emitter of 0.77 L h^{-1}. Fertilizers at 120N–37P–100 K kg ha^{-1} were applied in six split applications through drip irrigation. Standard pest management practices for peppers were followed.

All field measurements were made periodically from establishment to early harvest. Stem height and leaf chlorophyll index were measured repeatedly on the same plants (four plants per plot) using