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Growth suppression by exogenous abscisic acid and uniconazole for prolonged marketability of bell pepper transplants in commercial conditions

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ABSTRACT

Vegetable transplants quickly outgrow the optimal size for shipping and transplanting, limiting sales, and marketing flexibility in commercial nurseries. Abscisic acid (ABA) and uniconazole can suppress shoot growth by inducing stress-adaptive responses and inhibiting gibberellin biosynthesis, respectively. We evaluated the effectiveness of the two growth regulators in prolonging marketability of 'Excursion' and 'Revolution' bell pepper (*Capsicum annuum* L.) transplants at commercial nursery greenhouses in Texas and Florida. Spray treatments in the Texas experiment were 0 and 3.8 mM ABA at 7, 5, 3, or 1 day before the anticipated maturity date (DBM), and those in the Florida experiment were no spray control, 3.8 mM ABA at 7, 5, 3, or 1 DBM, and 34 μM uniconazole at 4 DBM. Both experiments showed similar results with minimal cultivar-specific effects. Different growth modifications were induced by ABA and uniconazole. First, suppression of stem elongation by ABA was reversible by 7 days after the anticipated maturity date (DAM), whereas that by uniconazole lasted for 20 days or until 16 DAM with up to 15% reductions in stem length. Second, only ABA inhibited shoot and root dry matter accumulation. The growth modulating effect of uniconazole appears to be limited to height control, which is beneficial for producing compact transplants, rather than as a growth holding strategy. By contrast, the overall growth suppression by ABA is desirable for prolonging transplant marketability. Importantly, the magnitude of this growth suppression was moderate (9%–12% shoot biomass reductions at 7–8 DAM) and mostly reversible by 14–16 DAM. Furthermore, root growth inhibition by ABA occurred with a time lag of over a week, allowing sufficient root development and increasing root-to-shoot ratio at 0 DBM. Although these growth holding effects of ABA were generally maximized when it was applied at 7 or 5 DBM, leaf chlorosis and cotyledon abscission were also induced by ABA in a similar age-dependent manner. These results suggest that ABA application 3 DBM is an effective growth holding strategy with minimal negative-side effects for bell pepper transplants.

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1. Introduction

Vegetable transplants quickly outgrow the optimal size for shipping and transplanting. The consequent limited marketing flexibility is a concern for commercial nurseries especially when transplanting is delayed because of inclement weather at the time of field establishment. Overmature transplants generally have spindly stems and excessive leaf growth, whereas their root growth is limited because of the small rooting volume of high-density plug trays (Marr and Jirak, 1990; Nishizawa and Saito, 1998). Such transplants are susceptible not only to damage during shipping and transplanting (Shaw, 1993; Garner and Björkman, 1996) but also to wind lodging after transplanting (Latimer and Mitchell, 1988; Garner and Björkman, 1999). In addition, the imbalance between transpiration demand and water uptake capacity can result in severe transplant shock and poor stand establishment (Agehara and Leskovar, 2012).

Plant growth retardants, such as daminozide, paclobutrazol, and uniconazole, are used in ornamental plug production to improve plant compactness, marketable value, and shelf life (Currey and Lopez, 2010). These chemicals limit stem elongation and overall

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shoot growth by inhibiting gibberellin biosynthesis (Rademacher, 2000), and their effectiveness is well documented in many ornamental species (Blanchard and Runkle, 2007; Currey et al., 2012; Gibson and Whipker, 2001; Gibson and Whipker, 2003). However, regulations for their use are rather restrictive for vegetable crops. At present, the only approved chemical is uniconazole registered as Sumagic (Valent BioSciences, Libertyville, IL) for solanaceous crops including pepper, tomato (*Solanum lycopersicum* L.), and eggplant (*Solanum melongena* L.). This product is used primarily for height control and must be applied during early development, no later than 14 days after two to four true leaf stage. How and how long uniconazole applied at late development stages affects growth and quality of vegetable transplants is unknown.

Abscisic acid is a plant hormone, which triggers adaptive growth responses to water stress (Davies and Jones, 1991). The immediate physiological response is stomatal closure, which in turn inhibits photosynthesis and transpiration-driven mass flow of nutrients (Taiz and Zeiger, 2010; Umezawa, 2011), whereas the morphological response is inhibition of leaf expansion (Bacon et al., 1998; Van Volkenburgh, 1999). Thus, the overall effect of ABA is shoot growth suppression. The potential of ABA as a growth retardant has been studied for some vegetable transplants. For example, cucumber (*Cucumis sativus* L.) and tomato seedlings sprayed with 0.38 or 1.89 mM ABA had reduced transpirational water loss and stem elongation during dark storage, thereby maintaining the overall quality and optimal size for transplanting (Yamazaki et al., 1995). In bell pepper, Leskovar and Cantliffe (1992) reported that the concentration effect of ABA on stem elongation was quadratic, with height suppression occurring above 10 μM. The efficacy of ABA is mostly age-dependent, and growth suppression is normally maximized when ABA is applied at the cotyledon stage (Biai et al., 2011; Agehara and Leskovar, 2014a,b). However, these studies have not determined the duration and, more importantly, reversibility of growth suppression by ABA in overmaturing transplants. Such information is critical to evaluate the effectiveness of ABA in prolonging transplant marketability.

For vegetable transplants, growth retardants should be applied shortly before the maturity stage to suppress excessive shoot growth to a predictable and manageable extent. It is also important that this growth suppression is followed by a complete recovery with no negative side effects on plant appearance. The objective of this study was to examine the magnitude, duration, and reversibility of growth suppression by ABA and uniconazole in bell pepper seedlings.

2. Materials and methods

2.1. Plant material and growth conditions

Two experiments were conducted at commercial nursery (Speedling Inc.) greenhouses located in Alamo, TX (Expt. 1) and Ruskin, FL (Expt. 2) from Aug. to Oct. 2009. At each location, seeds of two bell pepper cultivars, 'Aristotle' (Seminis Vegetable Seeds, St. Louis, MO) and 'Revolution' (Harris Moran Seed Company, Modesto, CA), were sown in a polystyrene tray with 200 inverted pyramid cells each containing 23 ml of peat-lite mix (Speedling Peat-lite; Speedling, Ruskin, FL). Seedlings were grown following commercial transplant production practices throughout the two experiments.

2.2. Treatments

In Expt. 1 (Texas location), treatments were factorial combinations of two ABA concentrations [0 and 3.8 mM (1000 mg L^{-1})] and four application timings (7, 5, 3, and 1 DBM). In Expt. 2 (Florida location), there were six treatments: no spray control, four application timings of 3.8 mM ABA (7, 5, 3, and 1 DBM), and one treatment of 34 μM (10 mg L^{-1}) uniconazole applied at 4 DBM. The maturity date was when seedlings were anticipated to reach the optimal size (10.2–11.4 cm) for shipping and transplanting according to the commercial nursery.

The formulation of ABA stock solution was VBC-30151 (Valent BioSciences, Libertyville, IL) containing 10% of S-ABA, a naturally occurring active form in plants. Uniconazole was formulated as Sumagic. Test solutions were prepared immediately before each treatment by diluting the stock solutions with irrigation water at the nursery. All test solutions including the control were mixed with a non-ionic surfactant (CapSil; Aquatrols, Paulsboro, NJ) at 0.05% (v/v), which showed no significant effect on transplant growth in our preliminary experiment.

A CO_2-pressurized backpack sprayer (Model T; Bellspray, Opelousas, LA) was used to spray the test 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) and a CO_2 cylinder with pressure maintained at 276 kPa. Spray volume was 0.61 L m^{-2} (0.71 ml/plant), which wetted the leaves thoroughly to the dripping point. The spray concentration and volume were determined based on manufacturer recommendations.

2.3. Transplant growth measurements

In Expt. 1, stem height, cotyledon number, and leaf chlorophyll index were measured non-destructively at 8, 6, 4, 2, and 0 DBM and 7 and 14 DAM, whereas shoot and root dry weight were measured destructively at 8 and 0 DBM and 7 and 14 DAM. Five plants per replication were randomly selected before the first measurement. All non-destructive measurements were made repeatedly on the selected plants between 08:00 and 10:00 am on each measurement day. Stem height (cm) was measured from the medium surface to the shoot apex. Relative stem elongation rate (RSER, mm cm^{-1} d^{-1}) was calculated as follows:

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

where $\ln H_1$ and $\ln H_2$ are the natural logarithm of stem height 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 washed to remove the growth medium. Shoots and roots were separated and dried at 65 °C for 72 h to determine dry weight.

In Expt. 2, stem height was measured non-destructively at 8, 6, 4, 2 and 0 DBM and 8, 16, and 29 DAM, whereas shoot and root dry weight were measured destructively at 8 and 0 DBM and 8 and 16 DAM. These measurements were made using the method described for Expt. 1.

2.4. Statistical design and analysis

In Expt. 1, there were four replicates for each treatment arranged in a split-plot design with application timing as the main plot and ABA concentration as the subplot. One half of each seedling tray was sprayed with the control solution, whereas the other half was sprayed with 3.8 mM ABA solution. In Expt. 2, there were four replicates for each treatment arranged in a split-plot design with cultivar as the main plot and spray treatment as the subplot. Each spray treatment was assigned randomly to an individual tray.

All data analyses were run in SAS (version 9.2; SAS Institute, Cary, NC), and P values less than 0.05 were considered statis-

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