EFFECT OF SUMAGIC® ON GREENHOUSE GROWN TOMATO TRANSPLANTS

By

PEGGY LOYD

Bachelor of Science in Horticulture

Oklahoma State University

Stillwater, Oklahoma

2017

Submitted to the Faculty of the
Graduate College of the
Oklahoma State University
in partial fulfillment of
the requirements for
the Degree of
MASTER OF SCIENCE
December, 2021

EFFECT OF SUMAGIC® ON GREENHOUSE GROWN TOMATO TRANSPLANTS

Thesis Approved:

Dr. Bruce Dunn

Thesis Advisor

Dr. Lynn Brandenberger

Dr. Carla Goad

ACKNOWLEDGEMENTS

I would like to acknowledge my advisor, Dr. Bruce Dunn for his direction and help in navigating my journey through the master's program. In addition, I would like to thank my thesis committee, Dr. Bruce Dunn, Dr. Lynn Brandenberger and Dr. Carla Goad for their time and assistance.

My degree completion would not have happened without Dr. Charles Fontanier, I humbly thank you for the extra time and help you provided with statistics. I would also like to thank Mr. Stephen Stanphill for his assistance with watering and data collection, it was very much appreciated.

Lastly, I'd like to thank my husband, Rodney, for his hard work in the real world that allowed me to return to the academic world and finish the education I almost missed out on.

Name: PEGGY LOYD

Date of Degree: DECEMBER, 2021

Title of Study: EFFECT OF SUMAGIC® ON GREENHOUSE GROWN TOMATO TRANSPLANTS

Major Field: HORTICULTURE

Abstract:

Commercial greenhouse vegetable transplant growers have several options available to control plant height but of those options, only one plant growth regulator, Sumagic® (Uniconazole-P), is approved for use as a chemical option on tomato, pepper, eggplant, tomatillo, pepino, and ground cherry seedlings. It has been demonstrated in research that Sumagic® is highly active in tomato and effective in retarding shoot elongation resulting in shorter more compact transplants but research has been limited to a few cultivars. In this study, twelve cultivars of tomatoes were chosen: three indeterminate, three determinate, and three container. Plants were sprayed with a one-time application of 2.5 ppm, 5 ppm, 7.5 ppm, and 10 ppm of Sumagic® during the 2-4 leaf stage to evaluate height control. Results indicated all concentrations produced lower values than the control but no significant difference between concentrations for plant height, stem caliper, and plant dry weight. Greatest SPAD values were observed with the 10 ppm treatment. Flower response in ‘Brandywine’ to a single application of 0 ppm, 2.5 ppm, and 5 ppm of Sumagic® demonstrated a greater number of flowers per plant at 5 ppm, while no significant difference was shown for number of flower clusters or number of flowers per cluster at other treatment levels. Using 2.5 ppm Sumagic® will provide transplant growers the ability to modify plant growth in four different types of greenhouse grown tomato seedlings, in addition 5 ppm was shown to increase the number of flowers in ‘Brandywine’.

TABLE OF CONTENTS

Chapter Page

LIST OF TABLES

Tables Page

CHAPTER I

INTRODUCTION

Plant growth regulators (PGRs) were a relatively small part (2.5%) of the \$56.7 billion spent in the global crop protection market in 2014 (Anonymous, 2015). Inhibitors of gibberellin (GA) biosynthesis are estimated to account for 40% of the PGR market (Rademacher, 2010). Increasing public concern regarding the safety of agrochemicals has made development and use of these products increasingly restrictive. Due to the relatively small market, above-average investments required to research, market, and produce, a PGR must concentrate on 'big crops' to be economically viable (Rademacher, 2015). Development of a new PGR for a 'minor crop,' such as vegetable transplants, is not financially attractive for a company and typically would not be pursued. To work around this obstacle, minor use labeling can be made possible by programs such as IR-4, the one prerequisite being the candidate product must have a valid registration for at least one 'major crop' (Rademacher, 2015).

In April 2009, Uniconazole-P, ((E)-1-(4-chlorophenyl)-4, -4-dimethyl-2-(1,2,4-trizol-1-yl) pentin-3-ol), acquired minor use labeling under the name Sumagic® (Valent BioSciences, Libertyville, IL), and is now available for vegetable crops, including tomato (*Solanum lycopersicum* L.), pepper *(Capsicum annuum* L.) and eggplant (*Solanum melongena* L.). Sumagic® is the first and only PGR approved that can legally be used on greenhouse grown fruiting vegetable crops (Runkle, 2009). Uniconazole has been used in commercial ornamental plug production to improve plant compactness, marketable value, and shelf life (Curry and Lopez,

2010) as compact plants have been found to be more attractive to consumers (Latimer and Scoggins, 2012). On a part per million basis uniconazole is the most active and persistent PGR used for height control of ornamentals (Runkle, 2011). According to the supplemental label the total amount of uniconazole applied to vegetable transplants may not exceed that from a single application of a 10 ppm spray application at 2 quarts/100 sq. ft. (Runkle, 2009). In addition, the final application may not occur later than 14 days after the 2 to 4 true leaf stage (Runkle 2012).

Its mode of action as a gibberellin biosynthesis inhibitor limits stem elongation between internodes and overall shoot growth (Rademacher, 2000) and is well documented for its effectiveness in many ornamental species (Blanchard and Runkle, 2007; Gibson and Whipker, 2001, 2003). As a triazole-type chemical it is translocated acropetally via the xylem of plants and is absorbed by the leaves, but not readily transported out of the leaves to other parts of the plant (Whipker and Latimer, 2013). Commercially, the primary purpose of a triazole-type growth regulator is to retard internode elongation and reduce overall stature (Bailey and Miller, 1989), with reduced stature other morphological changes can result such as: reductions in leaf area, dry weight, and number of leaves, increases and decreases in stem diameter, and increased formation of lateral shoots (Wang and Gregg, 1989). Previous studies have shown uniconazole commonly produces plants with darker leaves due to an increased chlorophyll concentration, which occurs due to an altered rate of chlorophyll degradation in plant tissue creating the appearance of higher chlorophyll levels (Wang and Gregg, 1989; Davis and Curry, 1991). At high rates uniconazole has also been shown to reduce total leaf area and dry weight in Easter lily *(Lilium longiflorum* L.) (Bailey and Miller, 1989), and the reduction of leaf area in turn reduces total dry weight (Wang and Blessington, 1990).

Uniconazole has been observed to increase seedling survival and tolerance to transplant shock (Cha-um et al., 2009; Dunlap et al., 1991) improve environmental stress resistance (Duan et al., 2008), enhance flowering (Cochran and Fulcher, 2013), and increase fruit yield (Dunlap et al. 1991; Wang and Gregg, 1990). Corn (*Zea mays* L.) seedlings treated with uniconazole helped delay waterlogging-induced chlorosis and senescence by modification of gibberellins, zeatin, abscisic acid, and ethylene levels (Leul and Zhou, 1998). Negative effects of uniconazole in studies include: a decrease in total weight of sweet pepper fruit by 30% when uniconazole was applied at 10 $mg \cdot L^{-1}$ (Villavicencio et al., 2015) and tomato transplants showing slight growth distortions (crooked stems/horizontal leaf orientation) which increased with higher rates of 5 ppm, 7.5 ppm, and 10 ppm (Zandastra et al., 2007).

Vegetable transplants grown in commercial high-density trays can quickly outgrow their optimal size (Agehara and Leskovar, 2015). Over mature transplants generally have thinner, elongated stems and excessive leaf growth with limited root growth due to the small rooting volume of high-density plug trays (Marr and Jirak, 1990; Nishizawa and Saito, 1998). In addition, limited root growth can create an imbalance between transpiration demand and water uptake capacity resulting in severe transplant shock and poor stand establishment (Agehara and Leskovar, 2012). Producers of high-quality plants realize the need for an efficient and economic production regime to maximize productivity per unit area, make effective use of transportation capacity, minimize transportation damage loss while fulfilling market demand, and the application of low dose PGRs can provide an economical way to limit growth and achieve those goals (Sparké et al., 2021); (Whipker, 2013).

As the most widely grown vegetable in the United States, tomatoes have over 400,000 acres in production with yearly production in the U.S. exceeding 12.7 million metric tons (Kelly and Boyan, 2017). A member of the botanical family Solanaceae, and a close relative of the deadly nightshade (*Solanum dulcamara* L.), tomato fruits were once considered poisonous and initially grown only as ornamental plants (Heuvelink, 2005). It was not until the beginning of the twentieth century that tomatoes became increasingly popular and in recent years have become one of the most important vegetables produced worldwide (Yamaguchi, 1983). By the end of the 19th century in the USA, processed products such as soups, sauces, and ketchup were regularly consumed (Harvey et al., 2001). Global production of tomatoes (fresh and processed) has increased by approximately 300% in the last four decades (Heuvelink, 2005).

Research on tomato transplants is abundant since this vegetable is perhaps the most widely grown from transplants (Vavrina, 2002). An ideal transplant is young (15.24 cm to 20.32 cm tall with a stem approximately 0.635 to 0.9525 cm in diameter, with no fruits, flowers, or flower buds), does not exhibit rapid vegetative growth, and is slightly hardened off at transplanting time (Kelly and Boyhan, 2017). Commercial production goals are to produce transplants of a size that can be handled by mechanical transplanters and transplanting crews without damage and are wind tolerant (Johnson, 2020).

Tomatoes have been found to be very sensitive to uniconazole and moderate height suppression is obtained in tested cultivars with lower rates (Dunlap et al., 1991). Other PGRs tested have had to use much higher rates to achieve the same results (Wang and Gregg, 1990). Studies conducted at the University of Guelph, (Ridgetown, Ontario) demonstrated late applications of Sumagic® (after 21 days' post seeding) were less effective and minor differences occurred between 2.5 and 5.0 ppm rates (Zandastra et al., 2007).

Research conducted at the University of Florida, Gainesville, with three types of indeterminate tomato varieties, ‘Early Girl’, ‘Big Boy’, and ‘Champion II’ with application rates of Sumagic® at 0, 2.5, 5 or 10 mg·L^{-1} at 14, 21, and 28 days after sowing resulted with most varieties responding similarly in height reduction compared to the control plants and producing plants of comparable size at the market ready stage (50% of plants having seven to eight true leaves expanded) (Schnelle, 2009). Last, findings in a greenhouse trial at Michigan State concluded that a single Sumagic® spray of 2.5 or 5.0 ppm applied at the two-leaf stage was most effective in the tomato variety ‘Beefmaster’ (Runkle, et al. 2012).

Non-chemical methods for controlling height such as light quality manipulation, mechanical brushing, negative DIF (difference between day and night temperatures) and limiting water/ nutrients are some of the methods available for height control in greenhouse grown vegetable transplants (Runkle, 2010). Having a PGR alternative may significantly reduce costs by eliminating the need for specialized equipment and additional labor input used in traditional methods. With Sumagic® being highly effective in small concentrations it can be a simple, cost-effective way to address size control (Schnelle, 2009). While breeding can offer improvement to plant performance, PGRs often provide faster solutions to many growing condition problems (Rademacher, 2010).

Research to date indicates plant sensitivity varies from one cultivar to another in response to PGRs (Dunlap et al., 1991). According to Schnelle (2010), more varieties of tomatoes need to be studied for conclusive application rates to be determined. The objective of this study was to evaluate several varieties of tomatoes to different rates of Sumagic® to control plant growth and flowering.

Materials and Methods

Experiment 1. A greenhouse experiment was conducted at the Horticulture and Landscape Architecture research greenhouses of Oklahoma State University in Stillwater. Seeds of ‘Mountain Pride’, ‘Mountain Fresh’, ‘Roma’, ‘Jet Star’, ‘Big Boy’, ‘Beefsteak’, ‘Cherokee Purple’, ‘Brandywine’, ‘Mortgage Lifter’, ‘Better Bush’, ‘Patio’, and ‘Bush Early Girl’ were purchased from Totally Tomatoes (Randolph, WI). Two seeds per cultivar were planted into 606 standard inserts (American Plant Products, Oklahoma City, OK) filled with soilless media (Metro-Mix 902, Sun Gro Horticulture, Bellevue, WA) on 13 Jan 2019, and 22 Jan 2021, and later thinned to one seedling per cell. Plants were placed in a heated greenhouse with mean temperature settings of 24°C day and 18°C night under natural irradiance and an average DLI of 14.1 and 18.1 $\text{mol}\cdot\text{m}^{-2}\cdot\text{d}^{-1}$ for 2019 and 2021, respectively. Plants were watered as needed and fertigated with 20N-4.4P-16.6K (Jack’s Professional® General Purpose acidic fertilizer, J.R. Peters Inc., Allentown, PA) at a rate of 200 $\text{mg}\cdot\text{L}^{-1}$ nitrogen. Treatments of 2.5, 5, 7.5, or 10 $\text{mg}\cdot\text{L}^{-1}$ Sumagic® (Valent, Walnut Creek, CA) plus a control were applied to the foliage 28 days after planting to leaves and stems once seedlings reached the two-leaf stage. Data was collected 19 March 2019, and 20 March 2021, on plant height (from top of six pack), Soil Plant Analysis Development (SPAD) (average of six leaves), stem caliper (from top of six pack), and shoot dry weight (cut at soil surface) that was dried at 80°C for 4 days.

Experiment 2. Seeds of the tomato cultivar ‘Brandywine’ were purchased from Totally Tomatoes (Randolph, WI) 1 August 2019. Seeds were planted 5 August, 2019, in 801 tray inserts (American Plant Products, Oklahoma City, OK) filled with soilless media (Fafard® Germinating Mix, Sun Gro Horticulture, Bellevue, WA) and placed under fluorescent grow lights with an average 64.8 µmol· m^{-2}· s^{-1} (Harris Seed, Rochester, NY). Trays were watered twice daily until seeds emerged. Seedlings were transplanted 19 August, 2019 into 606 deep jumbo standard inserts (American Plant Products, Oklahoma City, OK) filled with soilless growing mix (360 Metro-Mix, Sun Gro Horticulture, Bellevue, WA) and placed in the Horticulture and Landscape Architecture research greenhouses in Stillwater, OK. Plants were placed in a heated greenhouse with mean temperature settings of 24°C day and 18°C night under natural irradiance and an average DLI of 16.5 $mol{\cdot}m^{-2}{\cdot}d^{-1}$. Sumagic® was applied on 27 August 2019 when seedlings were at the two-leaf stage with rates of 0, 2.5, or 5 ppm. On 9 September 2019 seedlings were transplanted into 5-gallon fabric pots (247Garden, Montebello, CA). Each pot had three 2 gph drip emitters (Netafim, Tel Aviv, Israel) and were watered daily and fertilized with 20N-4.4P-16.6K (J.R. Peters, Allentown, PA) at a rate of 200 $mg{\cdot}L^{-1}$ nitrogen. Data collection began 3 September 2019 with plant height and stem caliper. Height was taken at two-week intervals for fourteen weeks from the soil to the shoot tip. Stem caliper was taken in week 1 and week 14. Data on flowering began 1 October 2019 and all flowers and buds were counted then removed from the plants every 2 weeks for the following 6 weeks.

Experimental Design and Data Analysis

The data analysis for this experiment was performed using SAS/STAT® software, Version 9.4 for Windows. Copyright © 2014 SAS Institute Inc. SAS and all other SAS Institute Inc. product or service names are registered trademarks or trademarks of SAS Institute, Cary, NC, USA. For experiment one, trays of 12 tomato plants were treated with prescribed rates of Sumagic®. There were seven trays of each tomato cultivar, and there were 12 tomato cultivars. Each tray was randomly assigned to one of seven Sumagic® application rates. There were two replications of the basic experiment, thus the experiment was a randomized complete block with two replications, and the treatment structure is 5 x 12 factorial. The mean response of the 12 plants for each tray was computed. The data were analyzed using linear mixed models' methods. Among the 12 tomato cultivars, there were four groups: determinate, indeterminate, heirloom, and container. There were three cultivars in each of these groups. Post hoc analyses consisted of Tukey adjusted pairwise comparisons. Contrast methods were used to analyze group effects among the twelve cultivars, and orthogonal polynomial contrasts were used to examine the Sumagic® application rates for linear and quadratic effects. All tests were conducted at the nominal 0.05 level.

Experiment two was conducted in two different but similar greenhouses. Twelve plants were treated with prescribed rates of Sumagic®. There were seven trays of each tomato cultivar, and there were 12 tomato cultivars. Each tray was randomly assigned to one of seven Sumagic® application rates. There were two replications of the basic experiment, thus the experiment was a randomized complete block with two replications, and the treatment structure was a 5 x 12 factorial. The mean responses of the 12 plants for each tray were computed. The data were analyzed using linear mixed models' methods. Among the 12 tomato cultivars, there were four groups: determinate, indeterminate, heirloom, and container. There were three cultivars in each of these groups.

Post hoc analyses consisted of Tukey adjusted pairwise comparisons. Contrast methods were used to analyze group effects among the twelve cultivars, and orthogonal polynomial contrasts were used to examine the Sumagic® application rates for linear and quadratic effects. All tests were conducted at the nominal 0.05 level. Experiment two was conducted in two different but similar greenhouses. Twelve plants were randomly assigned to each of the three treatments. The experimental design was a randomized complete block design where greenhouse was the replication factor, and there were five repeated measurements on each of the plants treated. Data was analyzed using generalized linear mixed model methods for repeated measures. Post-hoc pairwise comparisons were made using Tukey methods. All tests were conducted at the nominal 0.05 level.

RESULTS

Experiment 1. Main effects for plant height, SPAD, and shoot dry weight were significant among application rates (Table 1). For plant height, 2.5 ppm produced plants with the smallest height but was not different than any other application rate except the control. Lack of significant height difference among spray concentrations is consistent with data reported by Schnelle (2009), from a study using cultivars ‘Champion II’, ‘Big Boy’ and ‘Early Girl’ (Schnelle and Barrett, 2009; Schnelle and Ruberg, 2010). A 25% to 35% height suppression in the ornamental plant market is considered ideal, plants more than 35% shorter than untreated plants may make plants appear stunted (Hamrick, 2003). Sprays at 2.5 ppm in our study provided an approximately 35% height reduction compared to the untreated tomato plants. For stem caliper and dry weight, the 0 ppm treatment was the greatest. In contrast, data from a study using tomato ‘Mountain Fresh’ transplants did find stem diameter to be greater with Sumagic® treatment, but they also used a fertilization program in conjunction with the foliar spray to provide an inch growth per week that may have influenced the difference (Zandastra, 2007). Additionally, dry weight of ‘Summer Flavor’ tomato, was found to progressively decline in dry weight with increasing rates of uniconazole (Wang and Gregg, 1990) as did all the cultivars in our study. Height and stem caliper showed quadratic curves, while SPAD showed a cubic trend and dry weight was quadratic. SPAD value was greatest at 10 ppm with no difference among other rates except for 0 ppm (Table 2). A 1997 nutrient solution strength (NSS) study was performed with the objective of characterizing SPAD readings for five tomato cultivars, and SPAD reading response to a combination of two nutrient solutions strength (NSS). Chlorophyll readings for the variety ‘Max’ were significantly higher than the rest of the varieties and no differences were detected among ‘Caruso', 'Jumbo’, ‘Match’, and ‘Trust’. Results concluded SPAD readings were useful for monitoring the supply of nitrogen in tomatoes and cultivar could influence chlorophyll concentration (Sandoval-Villa, et. al, 2006). A recent study on the effects of uniconazole on leaf photosynethesis in mung bean (*Vigna radiate* L.) saw increased stomatal conductance, transpiration rate, net photosynthesis rate and SPAD value. Different cultivars sprayed with 30 mg·L^{-1} at the V_3 (3rd trifoliolate leaf unfolded at node 5) stage saw an increased SPAD value (Zhou, et. al, 2021).

Main effects for cultivars were significant for height, SPAD, and shoot dry weight (Table 2). 'Beefsteak' and 'Mortgage Lifter' were greater in height from 'Patio' but was not significantly different from remaining cultivars. 'Big Boy' had the greatest stem caliper but varied only from 'Patio'. 'Patio' is a container tomato bred for compactness and averaged a 42% reduction in height compared to 'Beefsteak'. Genetics likely played a role in having the smallest height, stem caliper, and dry weight of the varieties tested. SPAD was lower for 'Beefsteak' than the cultivar 'Better Bush', all other cultivars did not differ significantly. For shoot dry weight, 'Beefsteak' had the greatest weight but was only different from 'Patio'.

The effect of tomato type on height was greatest for the indeterminant category but was not different than all others except container types (Table 3). Stem caliper was greatest for indeterminant types and significantly different from determinant and container types. Container tomatoes had significantly higher SPAD readings compared to heirlooms and indeterminants. Dry weight was highest for the indeterminant types and only different from determinant and container types.

Experiment 2. There was a significant rate by DAT interaction for plant height and stem caliper (Table 4). Smallest plant height was 7 DAT with 2.5 ppm Sumagic® and was not different than 5 ppm Sumagic® at 7 DAT. At 21 DAT, plant height was still restricted for the 2.5 ppm treatment but on all future dates no difference was reported among treatments within a day. This indicates that plants outgrew the treatment by day 35. A 2004 study on the bedding plants, (*Celosia plumosa* L). 'Apricot Brandy', (*Salvia splendens* L). 'Vista Red', (*Petunia multiflora* L.) 'Wave Rose', and (*Tagetes erecta* L.) 'Inca II Orange' demonstrated a single 1-2.5 ppm application of Sumagic® 8 DAT produced moderate height control. The effect of treatment for height was still seen 27 DAT in '*Salvia splendens'*, 22 DAT in *'Petunia multiflora'*, and 35 DAT in '*Tagetes erecta'*. Depending on rate, plant and growing conditions the effects of Sumagic® on stem elongation may last 3-5 weeks (Whitman, et. al, 2005).

Stem caliper means were similarly small at 7 DAT with either 2.5 ppm or 5 ppm Sumagic®. No rate differences were observed 106 DAT for stem caliper. Rate effects for number of flower clusters and number of flowers per plant was significant (Table 5). The highest number of flower clusters occurred in the 5 ppm treatment but was not different than at 0 ppm. The number of flowers per plant was greatest for the 5 ppm treatment. The main effect of DAT was significant for number of flower clusters, number of flowers per cluster, and number of flowers per plant (Table 6). The number of flowers per plant maximized at 49 DAT and 69 DAT. Number of flowers per cluster was greatest for 35 DAT but not different than 69 and 82 DAT. Number of flowers per cluster was greatest 69 DAT, but not different than 49 DAT. In contrast, a 1989 study found soil drenches of uniconazole at 0.025 to 0.2 mg/pot applied to young 'Jane Cowl' hibiscus (*Hibiscus rosa-sinensis* L.) plants resulted in fewer flowers with smaller diameter and shorter pedicels (Wang and Gregg, 1990).

Conclusion

The objective of this study was to observe the effect of different rates of Sumagic® applied to several cultivars of greenhouse grown tomatoes. As a high value crop, research may offer recommendations for growers to improve transplant quality and provide an increase in the impact of using Sumagic® as a part of their production plan. Internode stretching is a common plant growth response to low irradiance that creates elongated low-quality plants. Based on the results concerning height control, the 2.5 ppm foliar applications were not significantly different from higher applications and no one tomato variety responded significantly different. This information may prove helpful for future research; an experimental design that includes the same varieties but using smaller incremental rates could confirm whether 2.5ppm is the lowest rate that can maintain height control.

Dry weight and stem caliper results were all lower than the control which is likely related to the treated plants smaller size. Results for SPAD readings indicated all treated plants had higher readings than the control, possibly due to a smaller leaf size creating a more concentrated area of chlorophyll. Future research might include documentation of leaf size which would confirm that lower dry weights and higher SPAD readings are related. The study was able to conclude that the number of flowers per ‘Brandywine’ plant was significantly higher at the 5 ppm rate. Heirloom tomatoes such as ‘Brandywine’, that produce lower yields per plant but command high value in the marketplace, warrant further research to establish that higher flower numbers correlate with higher fruiting (yield).

REFERENCES

Agehara, S. and D.I. Leskovar. 2015. Growth suppression by exogenous abscisic acid and uniconazole for prolonged marketability of bell pepper transplants in commercial conditions. Sci. Hort. 194:118-125.

Anonymous. 2015. Global Crop Protection Market 2014, Phillips McDougall, Crop Protection & Biotechnology Consultants, Edinburgh (quoted in: Annual Report 2014/2015, German Crop Protection Association, Frankfurt).

Arteca, R.N. 1996. Gibberellins. In Plant growth substances: Principles and applications. essay, Springer.

Bailey, D.A. and W.B. Miller. 1989. Whole-Plant response of easter lilies to ancymidol and uniconazole. J. Amer. Soc. Hort. Sci. 114(3):393-396.

Browning, S., 2011. Growing Heirloom Tomatoes? (Heirloom Tomato). Nebraska Extension in Lancaster County. [online] Lancaster.unl.edu. Available at: <https://lancaster.unl.edu/hort/articles/2011/HeirloomTomato.shtml>.

Bumgarner, N. and A. Carver. 2016. The Tennessee Vegetable Garden Growing Tomatoes. [online] Extension.tennessee.edu. Available at: <https://extension.tennessee.edu/publications/documents/w346-h.pdf>.

Cochran, D.R. and A. Fulcher. 2013. Type and rate of plant regulator influence vegetative, floral growth, and quality of Little Lime™ hydrangea. Hort Technology, 23:306-311.

Currey, C.J. and R.G. Lopez. 2010. Applying plant growth retardants for height control. Purdue Ext. HO-248-W.

Davies, P. 2010. The Plant Hormones: Their Nature, Occurrence, and Functions. doi 0.1007/978-1-4020-2686-7_1.

Davies, P.J. 1995. Plant Hormones: Physiology, Biochemistry and Molecular Biology. Dordrecht: Kluwer.

Davis, T.D. and E.A. Curry. 1991. Chemical regulation of vegetative growth. Crit. Rev. Plant Sci. 10(2):151-188.

Duman, I. and E. Duzyaman. 2003. Growth control in processing tomato seedlings. Acta Hort. 613:95-102.

Dunlap, J.R., Y. Wang, J.L. Carson, and C.E. Meacham. 1991. Improving the performance of vegetable transplants with a triazole growth retardant. Subtrop. Plant Sci. J. 44:7-10.

Gane, R. 1934. Production of ethylene by some ripening fruits. Nature 134:1008.

Garner L.C. and T. Bjorkman. 1996. Mechanical conditioning for controlling excessive elongation in tomato transplants: Sensitivity to dose, frequency, and timing of brushing. J. Am. Soc. Hort. Sci. 121:894-900.

Hamrick, D. ed. 2003. Ball Red Book, Volume 2: Crop Production: 17th edition. Ball Publishing. West Chicago, IL

Harvey, M., S. Quilley, and H. Beynon. 2002. Exploring the Tomato. Transformations of Nature, Society and Economy. Edgar Publishing. 304.

Hickman, G.W., E.J. Perry, R.J. Mullen, and R. Smith. 1989. Growth regulator controls tomato transplant height. Calif. Agr. 43:19-20.

Heuvelink, E. 2005. Tomatoes. Crop production science in horticulture. CABI Publishing. https://doi.org/10.1079/9780851993966.0000

Kelly, T.K. and G. Boyhan. 2017. Commercial Tomato Production Handbook. Atlanta, GA: University of Georgia. 3, 9-10.

Johnson, Gordon. 2020. Vegetable Growers News. https://vegetablegrowersnews.com/article/controlling-the-height-of-vegetable-transplants/

Klingaman, G., 2004. Tomato, Brandywine. [online] Tomato, Brandywine. Available at: https://www.uaex.uada.edu/yard-garden/resource-library/plant-week/tomato-brandywine.aspx

Latimer, J.G. and H. Scoggins. 2012. Using plant growth regulators on containerized herbaceous perennials. Virginia Coop. Ext. Publ., 430.

Liu, J., W., R. Leatherwood, and N.S. Mattson. 2012. Irrigation method and fertilizer concentration differentially alter growth of vegetable transplants. HortTechnology 1:56-63.

Leul, M. and W. Zhou. 1998. Alleviation of waterlogging damage in winter rape by application of uniconazole effects on morphological characteristics, hormones, and photosynthesis. Field Crops Res. 59:121-127.

Nishizawa, T. and K. Saito. 1998. Effects of rooting volume restriction on the growth and carbohydrate concentration in tomato plants. J. Amer. Soc. Hort. Sci. 123:581-585.

Marr, C.W. and M. Jirak. 1990. Holding tomato transplants in plug trays HortScience 25:173-176.

Mauseth, J.D. 1991. Botany: An introduction to plant biology. Philadelphia: Saunders. 854 pp.

Mckeon T.A., L.C. Fernandez-Maculet, and S.F. Yang. 1995. Biosynthesis and metabolism of ethylene. In: Plant hormones. P.J. Davies (ed.) Dordrecht, NL: Kluwer Academic Press 1995:118–139.

Orzolek, M.D., S.M. Bogash, R.M. Harsh, L.F. Kime, and J.K. Harper. 2006. Tomato Production. University Park, PA; The Pennsylvania State University.

Raven, P.H., R.F. Evert, and S.E. Eichhorn. 2005. Biology of Plants 7th edition. New York: W.H. Freeman and Company.

Rademacher, W. 2000. Growth retardants: Effects on gibberellin biosynthesis and other metabolic pathways. Annu. Rev. Plant Biol. 51:501-531.

Rademacher, W. 2015. Plant growth regulators: Backgrounds and uses in plant production. J Plant Growth Regul. (34):845–872.

Runkle, E. 2009. Sumagic plant growth regulator now registered for use on several vegetable transplants. https://www.canr.msu.edu/news/sumagic_plant_growth_regulator_now_registered_for use_on_several_vegetable.

Runkle, E. 2011, April. Tips on Using Uniconazole. Greenhouse Product News. https://gpnmag.com/article/tips-using-uniconazole/

Runkle, E. and M. Blanchard. 2012. Sumagic® on vegetable transplants. <http://gpnmag.com/sumagic-vegetable-transplants>.

Schnelle, R.A. and M. Ruberg. 2010. Sumagic foliar spray effect on fruit quality of greenhouse grown tomato. University of Kentucky College of Agriculture, 2010 Fruit and Vegetable Research Report. 48-49.

Schnelle, R.A. and J.E. Barrett. 2009. Sumagic® and tomato transplants. http://www.gpnmag.com/sumagic-and-tomato-transplants

Schnelle, R. 2009. Sumagic sprays for height control of greenhouse grown tomato and pepper transplants. (http://ir4.rutgers.edu/FoodUse/PerfData/2932.pdf).

Schwarz, D., A.J. Thompson, and H.P. Klarring. 2014. Guidelines to use tomato in experiments with a controlled environment: https://www.frontiersin.org/article/10.3389/fpls.2014.00625

Sandoval-Villa, M., C.W Wood, and E.A. Guertal. 2002. Tomato leaf chlorophyll meter readings as affected by variety, nitrogen form, and nighttime nutrient solution strength. J. Plant Nutr. 25: 2129–2142.

Sparké, M., A. Wegscheider, P. Winterhagen, U. Ruttensperger, M. Hegele, and J.N. Wünsche. 2021. Air-based mechanical stimulation controls plant height of ornamental plants and vegetable crops under greenhouse conditions. HortTechnology 31(4):405-416.

Valent, U.S.A. Corporation 2008. Sumagic plant growth regulator for use on fruiting vegetable transplants. Supplemental label. http://www.valent.com/Data/Labels/2008-SUM-011%20Sumagic%20for%20use%20on%20Fruiting%20Veg%20Transplants.pdf

Vavrina, C.S. 2002. An introduction to the production of containerized vegetable transplants. Fla. https://ufdc.ufl.edu/IR00004229/00001

Villavicencio, L.E., J. Bethke, and L. Corkidi. 2015. The effect of uniconazole on the control of plant height and fruit yield of potted tomato, pepper, and eggplant. HortTechnology 25(4):522-527.

Walton D.C. and L.Yi. 1995 Abscisic Acid Biosynthesis and Metabolism. In: Davies P.J. (eds) Plant Hormones. Springer, Dordrecht. https://doi.org/10.1007/978-94-011-0473-97.

Wang, Y.T. and T. Blessington. 1990. Growth of four tropical foliage species treated with paclobutrazol or uniconazole. HortScience 25(2):202-204.

Wang, Y.T. and L.L. Gregg. 1989. Uniconazole affects vegetative growth, flowering, and stem anatomy of hibiscus. J. Amer. Soc. Hort. Sci. 114(6):27-932.

Wang, Y.T. and L.L. Gregg. 1990. Uniconazole controls growth and yield of greenhouse tomato. Sci. Hort. 43:55-62.

Wang, Y.H. and H.R. Irving. 2011. Developing a model of plant hormone interactions. Plant Signaling Behavior 6(4):494–500. https://doi.org/10.4161/psb.6.4.14558

Whipker, B.E. and J. Latimer. 2013. Plant Growth Regulator Guide. https://www.ballpublishing.com/pdf/PGR_GUIDE_2013

Whipker, B.E., J.L. Gibson, T.J. Cavins, I. McCall, and P.Konjoian. 2003. D. Hamrick (ed.). Growth Regulators. In: Ball RedBook, vol. 2: Crop Production, 17th ed. Ball Publishing, Batavia, IL.

Whitman, C., M. Olrich, and E. Runkle, (2005). Sumagic on bedding plants. *Greenhouse Product News*.

Yamaguchi, M. 1983. Solanaceous fruits: tomato, eggplant, pepper and others, In World Vegetables, ed M. Yamaguchi New York, NY: AVI Books. 291–312. doi: 10.1007/978-94-011-7907-2_22.

Zandastra J., R. Squire, and G. Watt. 2007. Managing transplant size and advancing field maturity of fresh tomatoes and peppers. CORD IV Project #9022 Final Report.

Zhou, H., D. Zheng, N. Feng, and X. Shen. 2021. Effects of uniconazole on leaves photosynthesis, root distribution and yield of mung bean (*Vigna radiata*). J. Plant Growth Regul. https://doi.org/10.1007/s00344-021-10455-7

1. Main effects and contrasts of five different foliar Sumagic® application rates applied at the two to four leaf stage on 12 different tomato seedling varieties.

Rates (ppm)	Height (cm)***[z]	Stem caliper (cm)	SPAD (unitless)***	Dry wt. (g)***
0	20.56a[y]	5.13a	37.60c	2.56a
2.5	13.06b	4.31b	42.89a	2.13b
5	12.07b	4.36b	42.26ab	2.05b
7.5	11.27b	4.36b	42.21ab	1.91b
10	11.25b	4.24b	43.85a	1.92b
Linear	***	***	***	**
Quadratic	***	***	**	***
Cubic	NS	NS	*	*
Quartic	NS	NS	NS	**

[z] Main effects are significant at $P \leq 0.05$ (*), $P \leq 0.01$ (**), or $P \leq 0.001$ (***).

[y] Means within a column followed by the same letter are not significantly different based upon (Tukey-Kramer method, α = 0.05).

Table 2. Main effects of tomato cultivars on plant growth and quality after five different rates of foliar Sumagic® applications applied to seedlings at the two to four leaf stage.

Cultivar	Height (cm)*	Stem caliper (cm)	SPAD*	Dry wt. (g)**
Beefsteak	15.63a[y]	4.48ab	39.23b	2.35a
Mortgage Lifter	15.02a	4.44ab	39.87ab	2.27a
Big Boy	14.18ab	4.96a	39.99ab	2.23a
Jet Star	13.59ab	4.62ab	39.72ab	2.18a
Brandywine	14.08ab	4.53ab	41.17ab	2.17a
Bush Early Girl	13.45ab	4.39ab	43.40ab	2.03a
Better Bush	13.43ab	4.51ab	43.50a	2.00ab
Roma	13.11ab	4.45ab	40.02ab	2.00ab
Mt. Pride	12.41ab	4.38ab	41.16ab	1.97ab
Cherokee Purple	13.62ab	4.39ab	41.36ab	1.96ab
Mt. Fresh	12.35ab	4.24ab	42.85ab	1.94ab
Patio	8.92b	4.13b	41.13ab	1.44b

[z] Main effects are significant at $P \leq 0.05$ (*), $P \leq 0.001$ (**), or $P \leq 0.0001$ (***).

[y] Means within a column followed by the same letter are not significantly different based upon (Tukey-Kramer method, $\alpha = 0.05$).

Table 3. Group effects of tomato types on plant growth and quality after five different rates (0, 2.5, 5, 7.5, and 10 ppm) of foliar Sumagic® applications applied to seedlings at the two to four leaf stage.

Types^y	Height (cm)*^{y}	Stem caliper (cm)*	SPAD**	Dry wt. (g)***
Indeterminant	14.47a^x	4.69a	39.65b	2.25a
Determinant	12.62ab	4.36b	41.34ab	1.97bc
Heirloom	14.24a	4.45ab	40.80b	2.14ab
Container	11.93b	4.34b	42.67a	1.83bc

[z] Indeterminant (Mountain Fresh, Mountain Pride, Roma), determinate (Big Boy, Beefsteak, Jet Star), heirloom Brandywine, Mortgage Lifter, Cherokee Purple), and container (Patio, Bush Early Girl, Better Bush).

[y] Significant at $P \leq 0.05$ (*), $P \leq 0.01$ (**), or $P \leq 0.001$ (***).

[x] Means within a column followed by the same letter are not significantly different.

(Tukey-Kramer method, α = 0.05).

Table 4. Height and caliper response to different rates of foliar Sumagic® application to ‘Brandywine’ tomato grown in a greenhouse in Stillwater, OK.

DAT^z	Rate (ppm)	Height (cm)***^{y}	Stem caliper (cm)*
7	0	3.90f^x	2.77b
7	2.5	3.30g	2.53c
7	5	3.60gf	2.61bc
21	0	7.09d	-----
21	2.5	5.79e	-----
21	5	6.56d	-----
35	0	24.59c	-----
35	2.5	24.78c	-----
35	5	25.05c	-----
69	0	52.26b	-----
69	2.5	50.20b	-----
69	5	51.81b	-----
106	0	72.55a	7.97a

106	2.5	70.18a	8.32a
106	5	73.11a	8.25a

[z] Days after initial treatment.

[y] Main effects not significant (NS) or significant at $P \leq 0.05$ (*).

[x] The average means (n = 12) are presented. Mean separation within columns using Tukey protected least significant difference at $P \leq 0.05$. Means within a column with the same letter are not significantly different from one another.

Table 5. Main effects of flower response to three different rates of foliar Sumagic application to ‘Brandywine’ tomato.

Treatment	No. of flower clusters*^{z}	No. of flowers per cluster^{NS}	No. of flowers per plant*
0	2.17ab^{y}	5.85a	13.64b
2.5	2.05b	6.21a	13.19b
5	2.34a	6.59a	16.31a

^{z}Main effects not significant (NS) or significant at $P \leq 0.05$ (*).

^{y}Means (n = 12) within a column followed by the same letter are not significantly different according to Tukey-Kramer LSDs.

^{y}Means (n = 12) within a column followed by the same letter are not significantly different based upon (Tukey-Kramer method, α = 0.05).

Table 6. Main effects of flower response over five different dates to foliar Sumagic® application to 'Brandywine' tomato.

DAT[z]	No. of flower clusters***[y]	No. of flowers per cluster***	No. of flowers per plant***
35	1.62bc[x]	7.39a	11.24b
49	3.39a	5.76b	19.70a
69	3.46a	6.49ab	22.73a
82	1.45c	6.74a	10.12bc
106	1.80b	4.72c	8.10c

[z] Days after initial treatment.

[y] Main effects are significant at $P \leq 0.001$ (***).

[x] Means (n = 12) within a column followed by the same letter are not significantly different based upon (Tukey-Kramer method, α= 0.05)

CHAPTER 2

SUMAGIC® USE ON VEGETABLE TRANSPLANTS

Plants produce hormones to control normal plant functions, such as root growth, fruit set and drop and other developmental actions. Plant growth regulators, known as PGRs, are defined as any substance or mixture of substances that through physiological action accelerate or slow the rate of growth or alter the behavior of a plant. PGRs can be thought of as two classes: growth inhibitors and growth retardants. Sumagic®, active ingredient uniconazole-P is a PGR that uses the biosynthetic pathway of a natural hormone, gibberellins, to inhibit growth. Simply put a system exists inside the plant cell that is much like a highway, and we can apply a PGR to slow the delivery of gibberellins which slows the growth between nodes on the stem giving us shorter, stockier plants.

In 2008 Sumagic® was given supplemental approval by the Environmental Protection Agency to be used by greenhouse growers on specific *Solanaceae* fruiting vegetable transplants: tomato, pepper, eggplant, groundcherry, pepino and tomatillo. Being able to control plant height is an important consideration for greenhouse transplant growers. For more information about vegetable transplant production see: HLA6020 Growing vegetable transplants: https://extension.okstate.edu/fact-sheets/growing-vegetable-transplants.html.

While a product like Sumagic® would not have practical benefits to a home gardener, small to large commercial greenhouse operations may benefit financially. The more plants that can fit into your high tunnel, shade house, or greenhouse translates into profit. Shorter, stockier plants can be spaced closer allowing more transplants per bench. Shorter plants are less likely to shade their neighbors, preventing the plants from stretching which can result in a poor-quality plant. During handling, shorter plants are less likely to tangle and break and can be stacked more closely in trucks for transport. For the consumer, these shorter, stockier plants transplant with less shock but will grow and develop normally as the effect of Sumagic® is outgrown.

Possible drawbacks to Sumagic

Sumagic® can have varying degrees of effectiveness dependent on its method of application, time of year (temperature), and variation in response within different cultivars.

Application Method

Sumagic® belongs to a class of chemicals known as triazoles. In the triazoles, Sumagic® is one of the most effective plant growth retardants on a part per million basis. While it can be applied as a drench or a spray, labelling for vegetable transplants specifies spraying as the only approved method of application. Drench application though is 2 to 4 times as effective as a spray and this important information explains why applications earlier in the crop's growth are more effective due to less foliage cover and more spray hitting the soil surface. Sumagic® is not absorbed by leaves but through the stem and roots of the plant. This to some extent is why later sprays, when plants have more foliage cover and it is harder to reach stems, sprays can be less effective. The spray uniformity can greatly affect results. Applicators want to avoid spray volume that results in runoff and avoid drift onto non-target plants.

Personal Protective Equipment (PPE)

Applicators and other handlers must wear: long-sleeved shirt and long pants, waterproof gloves, and shoes plus socks.

Recommended label rates

The recommended label rate is 2 to 10 ppm at a volume of 2 quarts per 100 sq. ft. of crop. The first application can be made when transplants have 2-4 true leaves. In addition, the cumulative amount of Sumagic® cannot exceed 10 ppm with the final application having to be sprayed no later than 14 days after the 4-leaf stage. Research to date has shown that a single lower rate (2.5 ppm) controls height as good as higher rates for several tomato cultivars and growth types.

Time of Year

Due to increased plant growth during warmer temperatures and higher light intensity a higher application rate may be required to reduce increased growth.

Variation in Cultivars Response

Studies on the use of Sumagic® in vegetable plug transplants have shown that different cultivars of the same species can react differently to the same spray concentration. Taller, more vigorous varieties generally require more chemical. Local environmental conditions will affect recommended rates too. First time users should perform small test groups on various cultivars they are growing before spraying at one uniform rate for all cultivars.

PGR Calculator: Calculators and formulas can be found online to help with application amounts.

Cost Calculations/Sumagic® $80 per quart

Concentration PPM	Amount of Sumagic® needed for 5 gal. spray	Cost of 1000 ft^2 of bench area sprayed
2	2.56 fl oz.	$ 6.40
5	6.40 fl oz.	$16.00
7.5	9.60 fl oz.	$24.00
10	12.80 fl oz.	$32.00

https://extension.unh.edu/resource/greenhouse-production-calculators

Preparing Diluted Solutions PGR recommendations typically come with a dilution table for each PGR. The dilution tables list the parts per million (ppm) of active ingredients and the corresponding amount of PGRs (in fluid ounces or milliliters) required to prepare 1 gal. (or liter) of diluted solution. The following method for calculating diluted solutions does not require dilution tables but instead uses a single formula applicable for all PGRs. All the grower needs to do is plug in the desired concentration (in ppm) and the final volume of diluted solution and calculate the amount of PGR:Amount of PGR = Desired concentration (ppm) x Final volume (gallons) divided by a conversion constant. The conversion constant for Sumagic® when calculating fluid ounces per gallon is 3.91, when calculating milliliters per gallon the conversion constant is 0.132.

EXAMPLE: Amount of PGR = .5 ppm x 50 gal. ÷ 3.91

25 ÷ 3.91 = 6.4 fl.oz. of Sumagic needed to prepare 50 gal. of diluted solution

Calculating Spray Volume

The Sumagic® label states one gallon will treat 200 sq. ft. The following formula can be used to calculate the total volume of diluted PGR solution needed for sprays:

 # gallons needed = <u>Total # of square feet to be treated</u>
Coverage (square feet treated per gallon)

***Example**: <u>(5) 5 ft. x 60 ft. benches (area to be treated)</u>*

200 sq. ft. per gallon (sq. feet Sumagic® will treat)

5 x 5 x 60= 1500 ÷ 200 = 7.5 gallons Sumagic®

References

https://www.greenhousegrower.com/production/plant-culture/non-chemical-height-control/

http://gpnmag.com/wp-content/uploads/grower101calculatingcostss.pdf

https://hortscans.ces.ncsu.edu/uploads/s/u/sumagic__5266b428c76cf.pdf

https://www.hort.vt.edu/floriculture/documents/VCEPGR.pdf

https://irrec.ifas.ufl.edu/flcitrus/pdfs/short_course_and_workshop/factors_fruit_quality/Davies-Jackson-Plant_Growth_Regulators.pdf

https://www.valent.com/professional/products/sumagic/loader.cfm?csModule=security/getfile&pageid=41937

VITA

PEGGY LOYD

Candidate for the Degree of

Master of Science

Thesis: EFFECT OF SUMAGIC® ON GREENHOUSE GROWN TOMATO TRANSPLANTS

Major Field: Horticulture

Biographical:

Education:

Completed the requirements for the Master of Science in Horticulture at Oklahoma State University, Stillwater, Oklahoma in December, 2021.

Completed the requirements for the Bachelor of Agricultural Science in Public Horticulture at Oklahoma State University, Stillwater, Oklahoma in 2017.

Completed the requirements for the Associate in Applied Science in Horticulture at Tulsa Community College, Tulsa, Oklahoma in 2014.

Completed the requirements for the Associate of Arts in Journalism at Claremore Junior College, Claremore, Oklahoma in 1978.