EFFICACY OF PLANT GROWTH REGULATORS FOR POTTED PLANT PRODUCTION OF SUNFLOWER CULTIVARS

A Thesis

by

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ABSTRACT

While economically important as a food and oil crop, sunflowers are equally as important as a cut flower and ornamental crop. A majority of sunflowers create one large infloresence, however, new ornamental sunflower varities and hybrids recently released have improved branching and flowering habits, allowing for season-long cultivation. Due to their growth habits during greenhouse production, early vegetative stages must be controlled with plant growth regulators. A variety of non-chemical and chemical growth manipulation tools have been utilized to influence plant physiology and growth habit when ideal growth is not achieved naturally. Manual pinching remains an important tool; however, growers may not obtain the desired results, and the labor associated with pinching can be costly. The work in this thesis evalauted the efficacy of various plant growth regulators applied at commercially recommended timings and the effects of chemical pinching during early vegetative growth stages.

All plant growth regulators significantly reduced plant height and diameter on *Helianthus hybrida* ‘Sunfinity’ and ‘Suncredible’ except the paclobutrazol foliar spray to ‘Sunfinity.’ In contrast, foliar applications of paclobutrazol provided a significant reduction in plant height and diameter for ‘Suncredible.’ A tank mix application of daminozide and chlormequat chloride provided growth similar to the current production standard, a paclobutrazol drench, for both cultivars.

Applications of dikegulac sodium at 400 mg•L^{-1} at the first and third vegetative leaf stage, along with 500 mg•L^{-1} at the second vegetative leaf stage proved to be effective regarding chemically pinching. Chemical pinching did not occur when applied at 400 mg•L^{-1} at the V2 stage and 500 mg•L^{-1} at the V3 stage, but resulting growth created a well-rounded canopy. Results in this experiment show that chemical pinching of ‘Sunfinity’ is possible when applications are made at early stages of growth.

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This work was supervised by a thesis committee consisting of Professor Terri Starman of the Department of Horticultural Sciences and Professor(s) Brent Pemberton and Calvin Trostle of the Department of Horticultural Sciences and the Department of Soil and Crop Sciences.

Professor Terri Starman inspired this research project, assisted with experimental design, and the procurement of supplies. Professors Terri Starman and Brent Pemberton assisted with data analysis for Chapter 3. Ben Smesny and Chance Augsburger assisted with data collection. All other work conducted for the thesis was completed by the student independently.

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1. INTRODUCTION

1.1. Introduction

Horticultural crops are bred to have genetics that provide ideal growth characteristics. When ideal growth is not achieved naturally, a variety of nonchemical and chemical growth manipulation tools can be utilized to influence plant physiology and growth habit (Funnell, 2011). Manual pinching remains an important tool; however, growers may not obtain the desired results, and the labor associated with pinching can be costly. To help solve these issues, plant growth regulators (PGRs) can be applied at varying rates and combinations to modify plant architecture and create a uniform crop desirable to consumers (Whipker and Evans, 2012). Tank mixing of PGRs, referred to as a “bifecta” or “trifecta”, can create liners that are well branched with shortened height if applied correctly (Dabbs, 2019).

There are currently several ornamental sunflower varieties and hybrids on the commercial market with most varieties producing a single, large flower (Dole and Wilkins, 2005). Sunfinity (Syngenta Flowers, Gilroy, CA) is a new interspecific hybrid, self-branching sunflower with indeterminate growth characteristics which allow for continuous pollen-free flowering throughout the season. Due to growth habit and prolific flowering, Sunfinity is desirable in the landscape and can be utilized in bouquets (Dole et al., 2017). Suncredible (Proven Winners, Sycamore, IL) is an additional hybrid sunflower with branching growth characteristics. Suncredible has semi-determinate to determinate growth with continuous flowering that provides 10-cm flowers suitable for containers and landscapes.

The objectives of this study were to use new genetics of sunflower suitable for potted plant production to: 1) determine the efficacy of several PGRs at industry recommended rates; 2) observe treated plants for potential phytotoxic effects after PGR application, and, 3) to evaluate the effects of chemical pinching on early vegetative stages of *Helianthus hybrida* ‘Sunfinity’.

1.2. Literature Review

Sunflower was domesticated in North America with recorded uses being traced backed to American Indians (Heiser, 1951, Smith, 2013). Maxi’diwac, a Siouan woman associated with the Hidatsa, gave her account of the variety of sunflower seeds used during the 1800s. Varieties cultivated produced seed that were either black, white, red, or striped, and established one to three large heads growing to a size of 23-cm (Wilson, 1917). Sunflower seeds have been used in cooking, eaten raw from the shell, and ground into a flour-like substance (Heiser, 1951; Wilson, 1917). Sunflower literature has historically focused on the plant being used as a single stem row crop for oil content and seed production, however recent studies have been conducted on new ornamental and hybrid cultivars (Ahmad et al., 2015; Barrios and Ruter, 2019; Wien, 2016; Wien, 2017).

While economically important as a food/oil crop, sunflowers are equally as important as a cut flower and ornamental crop (Armitage and Laushman, 2003). Sales of cut sunflower (*Helianthus annuus*) stems in the USA increased to approximately 28.29 million stems sold during 2014, along with potted sunflowers accounting for 213,655 plants sold with a value of $765,000 in 2014, with a majority of the containers being 5-inches or more in diameter (USDA and NASS, 2014). In additon to the number of operations growing potted sunflowers, sales of potted sunflower increased to 466,108 plants sold in 2017 valued at $2,636,000. Along with their attractive colors, the short cropping window of 60 to 70 days (depending on the cultivar) enables sunflower to be a desirable crop. The introduction of day neutral and potted plant cultivars along with bicolor and improved branching habits has partly been responsible for the increase in popularity of sunflowers (Armitage and Laushman, 2003, Hamrick, 2003).

Manual removal of the apical growth point on a primary stem, known as pinching, is a common practice in horticulture to control growth and induce branching (Faust, 2008, Denisen, 1958). It is widely accepted that the removal of an apical meristem leads to growth of axillary buds due to the apical meristem being a major production site of auxins (Armitage and Laushman, 2003). Auxins are produced in the axillary buds soon after pinching which leads to elongation (Cline, 1978). It is believed to be the ratio of auxin to cytokinin that plays a role in axillary bud dormancy. Other methods of releasing apical dominance are achieved through applying cytokinin’s exogenously and plant parasites, such as mistletoe. Parasitic plants, along with bacteria and fungi, are thought to play a role in the physiological disorder commonly known as “witches broom” (Hopkins and Hüner, 2009).

Pinching is used by growers to create a uniform canopy of axillary branches and flowers. Whereas flower number is increased in axillary positions, flower size and stem length are reduced compared to a plant that is not pinched (Armitage and Laushman, 2003, Denisen, 1958). Whipker and Evans (2012) noted that manual pinching can potentially delay flowering, but more importantly, labor costs associated with manual pinching can become economically challenging. Studies have shown ornamental sunflower varieties that typically produce a single stem with one large primary flower grown for cut flower production may be pinched at the fourth to the tenth node (depending on the season) to produce multiple stems of marketable size flowers (Sloan and Harkness, 2010).

Pinching older plants can result in unmarketable stems with reduced stem length. Ornamental branching varieties remained productive when pinched late, however, single stem varieties produced fewer branches when pinching occurred at the tenth node stage. When pinched at the either the fourth or sixth node, ‘Procut Orange’ and ‘Sunrich Orange’ (*Helianthus annuus L.)* showed an increased in stem yield from 1 stem per plant to 2.6 and 3.5, respectively (Wien, 2016, Wien, 2017). Abbas et. al (2018) noted that pinching marigold (*Tagetes spp.)* at a height of 30.5-cm increased flower diameter, number of flowers, stem size, and number of branches.

Generally, branching cultivars which are pinched have shorter axillary stems compared to pinched single stem cultivars (Dole and Wilkins, 2005). For continual harvest of cut sunflowers, planting dates should be staggered to provide season-long growth (Armitage and Laushman, 2003). Combining staggered planting dates with pinched and unpinched plants can also be used to provide a continual harvest (Dole and Wilkins, 2005). Sloan and Harness (2010) observed that a decrease in stem length occurred as planting dates continued from May to August on both upright (single stem) and branching cultivars across all pinch treatments. For growers in the Midwest, cultivation of sunflower in a greenhouse environment has proved successful for select varieties such as ‘ProCut Bicolor’ and ‘Sunbright Supreme’ (Garfinkel and Panter, 2014).

Pot size is an important factor when growing sunflowers as potted flowering plants in greenhouse production. When potted sunflowers (*Helianthus annuus* L. cv Pacino) were grown in a greenhouse, the plants became out of proportion to the pot (Whipker and Dasoju), 1998). Plant height was elongated on the hybrids ‘Teddy Bear’, ‘Big Smile’, and ‘Sunspot’ when grown in small pots (12-cm diameter) however, growing sunflowers in larger pots (16-cm diameter) produced a more desirable plant for inflorescence size, compact growth, and flowering time. Large pots reduced the production time 1-3 days (Vernieri et al., 2003).

Photoperiod can also be a cultural consideration for growers as sunflower can exhibit short-day, long-day, and day-neutral reactions depending on the cultivar, with most cultivars exhibiting short-day or day-neutral reactions. (Wien, 2014, Schneiter, 1997). Due to the variability of photoperiod responses, it is crucial for breeders to test daylength response of new cultivars to provide growers with accurate information.

Plant growth regulators (PGRs) are synthetically produced chemicals that can modify plant shape and size in localized areas or overall plant architecture through different modes of action (Cochran and Fulcher, 2013). Phytohormones, such as auxin and cytokinin, are growth hormones which are naturally produced in the plant and are responsible for the proper growth and development of a plant. Confusion may arise between the terms plant growth regulator and phytohormone. Plant growth regulator is a term predominantly used by the agriculture chemical industry which refers to synthetic chemicals that can modify plant growth (Sajjad, 2017).

Applying plant growth regulators as foliar spray or root substrate drench is a technique often used to control growth and produce marketable plants by modifying plant architecture to promote flowering, branching, or compact growth (Sajjad, 2017). Additional benefits of applying PGRs include greener leaves, disease reduction, and less water use. Water use is reduced as a secondary effect due to the production of abscisic acid (ABA) which in turn caused stomates to close (Whipker, 2013). Disease reduction occurred during the use of either paclobutrazol, flurprimidol, ancymidol, daminozide, and chlormequat chloride through inhibiting sterol biosynthesis, a key chemical needed for fungus to grow on a leaf surface, such as powdery mildew. Starman et. al. (1990) found an application of ancymidol (A-Rest®, SePRO, Carmel, IN) on ‘Mammoth Russian’ sunflowers led to darker green foliage and an increase in chlorophyll content. This can be explained by the upregulation of chlorophyll production which is a side effect of PGRs blocking the gibberillins (GA) pathway (Whipker, 2013). Crops may display varying sensitivity to plant growth regulators depending on the physiological stage which they are applied, with late-stage applications discouraged in species such as poinsettia (Whipker and Evans, 2012).

When applying plant growth regulators, growers should consider multiple factors which affect the efficacy of the growth regulator, including which root substrate the plant is grown in, methods for applying the chemical, and environmental conditions

(Whipker and Evans, 2012). Drenching is the preferred application method since the treatment is uniform, however, this method is most labor intensive. Substrates comprised of composted bark can essentially "deactivate" plant growth regulators, therefore, chemical concentrations should be increased 25% when applying a drench (Whipker and Evans, 2012). Chemical uptake is highest when plant growth regulators are applied in the morning due to low evaporation rate (Hamrick, 2003). More importantly, pH plays a crucial role in the efficacy and absorption of certain plant growth regulators (Sajjad, 2017). Florel® shows reduced effectiveness when pH is high (Dole and Wilkins, 2005). The final solution pH should be below 4.5 to keep the chemical stable (Walters and Lopez, 2017).

Plant growth retardants, referred to as anti-gibberellins, are a class of PGRs which are utilized to decrease shoot length in agronomic and ornamental crops by inhibiting the biosynthesis of gibberellins (GAs) (Hopkins and Hüner, 2009). Triazole-type compounds, such as paclobutrazol (Bonzi®, Syngenta, Greensboro, NC) and uniconazole-P (Sumagic®, Valent USA, Walnut Creek, CA) affect GA synthesis by inhibiting the biological processes that occur between ent-kaurene and ent-kaurenoic acid. Other commonly applied growth retardants which inhibit the same processes are flurprimidol (Topflor®, SePRO, Carmel, IN) and ancymidol (A-Rest®); however, they are pyrimidines, not triazoles (Rademacher, 2000). Chlormequat chloride (Cycocel®, OHP, Mainland, PA) and mepiquat chloride (Pix®, BASF, Florham Park, NJ), classified as onium-type compounds, are growth retardants which stop the synthesis of GAs before ent-kaurene. Daminozide (B-Nine®, OHP, Mainland, PA) acts on late stage GA synthesis by inhibiting many of the steps after GA12-aldehyde (Rademacher, 2000). Because phytotoxic responses can occur with chlormequat chloride alone, daminozide is often mixed with chlormequat chloride to reduce the phytotoxic response and provide greater control of stem elongation (Whipker, 2013).

Unlike plant growth retardants, benzyladenine (BA) (Configure®, Fine Americas, Walnut Creek, PA) is a synthetic cytokinin which is used to stimulate branching. When BA is applied exogenously, apical dominance is interrupted due to the increase in cytokinin. The ratio of auxin to cytokinin plays a major role in apical dominance and axillary branching (Carey et al., 2009). Liners of *Agastache, Gaura*, *Lavandula*, *Leucanthemum*, and *Salvia* were all treated with foliar sprays of BA before transplant. Except for *Salvia*, all liners had increased branching. Branching habit of untreated liners developed to that of treated liners. As a result, it was recommended growers make multiple applications of BA (Grossman et al., 2012). Carey et al. (2009) noted that Configure is effective on slow growing petunia cultivars by increasing branching and reducing plant diameter. Various phytotoxic symptoms can result days to weeks after application including chlorosis, leaf cupping (with high concentrations), alteration in leaf morphology, and leaf necrosis (Carey et al., 2009).

Ethephon (Collate®, Fine Americas, Walnut Creek, PA) is a PGR that promotes the release of gaseous ethylene, a naturally occurring plant hormone. This release is explained as the pH of Ethephon becoming less acidic due to plant pH, which can cause ethephon to be converted to its gaseous state. Confined spaces, such as that during shipping, and the handling and bruising of foliage can increase a release of ethylene. The results of using ethephon include abscission of flowers and leaves and abortion of flower buds (Whipker and Evans, 2012). Ahmad et. al. (2015) hypothesized that using plant growth retardants, such as uniconazole and paclobutrazol, could reduce ethylene sensitivity of certain species during simulated shipping, however, the use of plant growth retardants did not prevent effects from ethylene. Although there can be a delay in flowering, overall plant height and width were reduced from an application of ethephon on 22 of 27 tested bedding plant varieties including *Lantana, Calibrachoa,* and *Petunia* (Starman et al., 2004).

Dikegulac sodium (Auego®, OHP, Mainland, PA) is a PGR used as a pinching agent in the greenhouse and can also control internode elongation (Whipker and Evans, 2004; Arzee et al., 1977). Once exogenously applied, dikegulac sodium is absorbed through the leaves then translocated to the apical meristem where it represses cell division. Dikegulac sodium applied to the leaves of chrysanthemum (*Chrysanthemum spp.)* at various positions was detected in one day to translocate to the apical meristem of the plant (Bocion and De Silva, 1977). Dikegulac sodium's mode of action encourages lateral branching to occur while releasing apical dominance. Arzee et. al. (1977) noted that treating 'Perdovic' (*Helianthus annuus L.)* with dikegulac sodium induced transient chlorosis and created distorted leaves. Leaf distortion was thought to occur due to chemical selectivity of localized cells which give rise to uneven growth expansion (Arzee et al., 1977). Growers need to account for added growing time due to the damaged leaves which will be covered by new growth (Whipker and Evans, 2012).

According to Whipker (2013), paclobutrazol is the most commonly used growth retardant on floriculture crops in the United States. Paclobutrazol applied as a drench at various concentrations showed a strong decrease in sunflower plant height on multiple varieties, with a 50% height decrease observed with the highest dosage (16 mg a.i.) (Vernieri et al., 2003). Paclobutrazol applied as a root substrate drench on swamp sunflowers (*Helianthus simulans*) decreased plant height and width by 27-29% at a rate of 4 mg/pot, and 34-35% at a rate of 6 mg/pot (Barrios and Ruter, 2019). It was suggested that rates for paclobutrazol drenches should be increased if applied during the warm temperature of summer (Whipker et al., 1998).

When treating 'Pacino' sunflowers (*Helianthus annuus)* with plant growth regulators, drenches of flurprimidol at 2 mg•L^{-1} showed comparable height control results to that of paclobutrazol drenches at 2 mg•L^{-1}. Foliar sprays of flurprimidol at concentrations of 30 mg•L^{-1} and greater were less effective than drenches of 2 mg•L^{-1}, however, both treatments resulted in a plant size that was significantly smaller when compared to the control. When comparing daminozide to flurprimidol, foliar sprays of flurprimidol at 30 mg•L^{-1} and greater were less effective than daminozide at 4000 mg•L^{-1} in reducing plant height. Daminozide however did not affect plant diameter (Whipker et al., 2004).

A foliar application of daminozide at rates from 4000-8000 mg•L^{-1} or uniconazole at rates from 16 to 32 mg•L^{-1} produced marketable sized plants for the sunflower variety 'Pacino'. Daminozide applied at 8000 mg•L^{-1} and uniconazole applied at 32 mg•L-^{1} delayed flowering by two to three days, however this delay was not considered detrimental. Uniconazole was comparable when applied at a drench concentration of 50% less than paclobutrazol (Whipker et al., 2004).

Current industry standard (personal communication, Syngenta Flowers) PGR guidelines for spring seeded 'Sunfinity' sunflowers call for transplanting at week 3 and pinching to four nodes two weeks later. A 3 mg•L^{-1} paclobutrazol drench is applied three separate times: 1) approximately 1-2 weeks after pinching, when lateral shoots are 3-4 cm long; 2) visible buds appear, approximately pea-sized at this point; and, 3) at the first sign of "color crack", when ray petals begin showing in the bud. Summer recommendations call for paclobutrazol concentration to increase to 5 mg•L^{-1}.

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2. EFFICACY OF PLANT GROWTH REGULATORS APPLIED AT COMMERICALLY RECOMMENDED APPLICATION TIMING

2.1. Literature Review

Plant breeding has introduced new traits *into Helianthus* varieties, such as ‘Sunfinity’, that allow for compact growth suitable for potted plant production (Beytes, 2021). A short crop time and attractive flowers makes *Helianthus* a profitable potted plant (Pallez et al., 2002). Whipker and Dasjou (1998) stated that sunflower grown as a potted plant can become disproportionate compared to the container the plant is grown in. Appropriate plant height for potted sunflower is 1.5 to 2.0 times the height of the container (Pallez et al., 2002).

Applying plant growth regulators (PGRs) as foliar sprays or root substrate drenches is a technique often used to control growth and produce marketable plants by modifying plant architecture to promote flowering, branching, or compact growth (Sajjad, 2017). Paclobutrazol is the most used growth retardant on floriculture crops in the United States (Whipker, 2013). Paclobutrazol applied as a root substrate drench at various concentrations showed a strong decrease in plant height on multiple sunflower varieties, with a 50% height decrease observed with the highest dosage (16 mg a.i.) (Vernieri et al., 2003).

Helianthus hybrida ‘Sunfinity’ and ‘Suncredible’ were subjected to five PGR rate and application method combinations to compare the efficacy of the combinations to the industry recommended PGR rate and application method. The objective was to determine the optimum chemical(s) and application method for each cultivar to give growers guidelines and options for greenhouse potted plant production protocols.

2.2. Materials and Methods

Sunflower ‘Suncredible’ liners (72 cell tray) were obtained from Four Star Greenhouse (Carleton, MI) on 3 Feb., 2021. Seeds of *Helianthus hybrida* ‘Sunfinity’ were obtained from Syngenta Flowers North America (Gilroy, CA) and were sown <0.65-cm deep in 72-cell trays, one seed per cell, containing PRO-MIX HP with mycorrhizae as a root substrate. Cells were misted by hand multiple times daily during the germination period with reverse osmosis (RO) water. Two 9W light emitting diodes (LED) (GE Lighting, East Cleveland, OH) were fixed 91-cm above the trays during propagation to provide a 4-hour night interruption (long day photoperiod) for the initial 28 days.

A root substrate drench solution of 2 mg•L^{-1} paclobutrazol (Bonzi; Syngenta, Greensboro, NC) at 5.94 mL per cell was applied when 30-50% of the plugs had cotyledons emerging through the root substrate surface, which occurred between four and six days after sowing (DAS). At seven DAS, seedlings were fertilized with each irrigation with a nutrient solution of 15N-2.2P-12.5K-5Ca-2Mg applied at 50 mg•L^{-1} (ICL-SF, Summerville, SC). Fertilizer was applied at 150 mg•L^{-1} during propagation, increased to 200 mg•L^{-1} during vegetative growth, and later increased to 250-300 mg•L^{-1} during bud set and finishing.

Trays of planted ‘Sunfinity’ sunflower seed were placed in a glass greenhouse in College Station, Texas (30.608718, -96.350350) on 18 Jan, 2021. A foliar spray consisting of thiamethoxam (Flagship 25WG; Syngenta, Greensboro, NC) was applied on 30 Jan. for systemic control of insects. A foliar spray of cyprodinil + fludioxonil (Palladium; Syngenta, Greensboro, NC) was applied on 4 Feb. as a preventative measure for powdery mildew and to control stem disease on ‘Suncredible’. All treatments were made early morning to allow for proper drying time and decrease the rate of evaporation due to heat and low humidity. For spring-seeded sunflower, industry guidelines called for transplanting at week 3 (21 DAS) and pinching to four nodes two weeks later.

On 5 Feb., uniform ‘Sunfinity’ plugs were randomly selected and transplanted into 2.50 qt thermoformed containers (The HC Companies, Twinsburg, OH), one plug per pot. On 9 Feb., uniform ‘Suncredible’ liners were randomly selected and transplanted into the same size containers, one plug per pot. PRO-MIX HP with mycorrhizae (Premier Tech Horticulture, Quakertown, PA) was used as a root substrate for both cultivars. A severe winter storm occurred 14-20 Feb. and delayed growth of plants by one week.

The experiment was to compare five plant growth regulators, each at a commercially used rate, applied three separate times. There were seven replications per treatment, and seven control plants, for a total of 42 plants per cultivar. The PGR application times were according to industry standards i.e. three separate times: 1) approximately 1-2 weeks after pinching, when lateral shoots are 3-4 cm long; 2) when visible buds appear, approximately pea-sized at this point; and, 3) at the first sign of “color crack”, when ray petals begin showing in the bud.

The five plant growth regulators were: (1) paclobutrazol (Bonzi, Syngenta, Greensboro, NC) root substrate drench at 5 mg•L^{-1} (Sunfinity) and 2 mg•L^{-1} (Suncredible) (standard recommendations); (2) paclobutrazol foliar spray at 50 mg•L^{-1}; (3) daminozide (B-Nine WSG, OHP, Bluffton, SC) + chlormequat chloride (Cycocel, CCC, OHP, Bluffton, SC) foliar spray at 3500/1250 mg•L^{-1}; (4) uniconazole (Sumagic, Valent Biosciences, Libertyville, IL) foliar spray at 25 mg•L^{-1}; or, (5) flurprimidol (Topflor, SePRO, Carmel, IN) foliar spray at 25 mg•L^{-1}.

‘Sunfinity’ plants were harvested April 10th and ‘Suncredible’ plants were harvested May 1st 2021. Data included days to color crack (DTCC) (when ray petals were visible in the bud), days to anthesis (DTA) (when ray petals were fully expanded), total plant height (from pot rim to highest point on plant), total plant diameter (measured across the widest point of plant, and measured again at a 45 degree angle and averaged), primary flower size (diameter across ray apexes), total number of flowers (primary and secondary flowers), basal stem caliper, SPAD reading (SPAD 502, Spectrum Technologies Inc, Aurora, IL) and total plant fresh and dry weight. Observations were made on treated plants for potential phytotoxic effects after PGR application.

The statistical analysis was performed on JMP, version 16.0.0. A one-way ANOVA was conducted between cultivars. Eight of the nine variables showed significant interactions. Due to the difference in growth pattern, cultivars were analyzed separately with a one-way ANOVA to identify significant interactions for the PGR treatment. Tukeys HSD was used for a mean separation.

2.2.1. Greenhouse Climate

Ambient temperature was measured across the greenhouse with three external temperature probes (A Series, Spectrum Technologies, Aurora, IL). Light at the canopy level was measured across the greenhouse every 10 minutes with three LightScout Quantum sensors (Spectrum Technologies, Aurora, IL). Sensors were monitored and recorded by a WatchDog 100 Series Micro Station (Spectrum Technologies, Aurora, IL). Throughout production greenhouse temperatures were set at 21.1°C/18.3°C for the day and night. Actual temperatures during production averaged 22.6°C/18.7°C during the day and night. Photosynthetic photon flux density (PPFD) averaged at 280 $\mu mol \bullet m^{-2} \bullet s^{-1}$ during production and reached a maximum of 1483 $\mu mol \bullet m^{-2} \bullet s^{-1}$.

2.3. Results and Discussion

Primary flower size was not significantly different among treatments for either cultivar (‘Sunfinity’ 11.7-cm and ‘Suncredible’ 8.3-cm). DTCC and DTA were not significant for ‘Suncredible,’ 88 and 93 days, respectively. Plant height and width were reduced the greatest with daminozide + CCC compared to the control (Figure 1, Table 1). Height and width were reduced by 54% and 42%, respectively on ‘Sunfinity’, and 64% and 41%, respectively on ‘Suncredible’ after three applications of daminozide + CCC. Paclobutrazol drench had the next greatest reduction in plant height and width, 32% and 39% on ‘Sunfinity’, 45% and 46% on ‘Suncredible’ (Figure 1, Table 2).

Uniconazole and flurprimidol also reduced the height and diameter similarly, but not to of great as extent as the paclobutrazol drench. On ‘Sunfinity’, uniconazole and flurprimidol reduced plant height by 18% and 15%, and plant width by 19% and 21%

(Figure 1, Table 1). For the same treatments, 'Suncredible' plant height was reduced by 30% and 23%, and plant width was reduced by 23% and 22% (Figure 1, Table 2). Compared to the control, the paclobutrazol spray was not effective in reducing height on 'Sunfinity' (1% reduction) but was effective on 'Suncredible' (44% reduction). These findings were similar to that of Whipker and Dasjou (1998), however their study treated plants one time only whereas this experiment treated plants three times. Potted 'Pacino' sunflowers treated with uniconazole at 32 mg•L^{-1} were 17% shorter than the control, while daminozide treatments of ≥4000 mg•L^{-1} reduced height by ≥17%. Whipker and Dasjou (1998) reported that foliar treatments of paclobutrazol at 40 and 80 mg•L^{-1} resulted in plants that were 6% shorter than the control. Dasjou et al. (1998) reported that potted 'Pacino' sunflowers treated with a paclobutrazol drench at 4 mg•L^{-1} reduced plant height and diameter 36% and 25%, respectively, compared to the control.

All treatments reduced stem caliper compared to the control (Table 1 and 2), with the exception of the paclobutrazol spray on 'Sunfinity'. Daminozide + CCC resulted in the greatest reduction (14.2%) and paclobutrazol drench had the second greatest reduction (10.3%) when applied on 'Sunfinity' (Table 1). Suzuki et al. (2018) found that a paclobutrazol drench of 4 mg•L^{-1} or 6 mg•L^{-1} reduced stem diameter on *Heliathus annuus 'Florenza'* by 4.8% and 7.5% respectively. In contrast, Abdel-Moniem (2016) reported that daminozide applications of 1250 and 2450 mg•L^{-1} slightly increased stem diameter on 'Sunrich Orange' sunflower. However, daminozide treatments of 4,000-8,000 mg•L^{-1} on 'BRS-Oasis' sunflower were not different from the control (Cuquel et al., 2010). While the results in Cuquel et al. were not significant, there was a slight decrease in stem diameter when daminozide was applied to the plant three times compared to two applications.

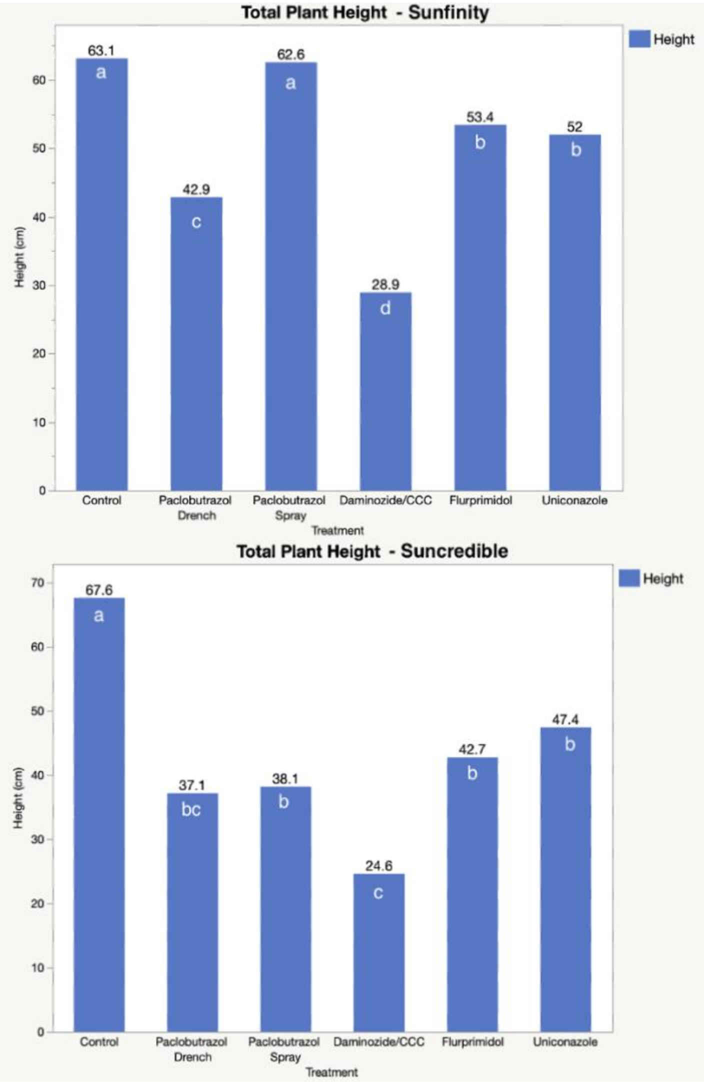
The paclobutrazol drench resulted in the least plant fresh and dry weight for ‘Sunfinity’ (30.6% and 35.2%) and was similar to the daminozide + CCC treatment (24.7% and 26.4%) (Table 1). On ‘Suncredible’, daminozide + CCC resulted in the greatest reduction in plant dry weight (58%) while the paclobutrazol drench reduced dry weight by 49% (Table 2). Barrios et al. (2019) reported that a root substrate application of paclobutrazol at 4 mg•L^{-1} on *Helianthus simulans* reduced dry weight by 17.5%.

The daminozide + CCC treatment had the least total number of flowers at harvest on both cultivars (Table 1 and 2). Compared to the control, daminozide + CCC resulted in a delay of 5 days for DTCC on ‘Sunfinity’ and 12 days for ‘Suncredible’ (Table 1 and 2). However, the daminozide + CCC treatment on ‘Sunfinity’ resulted in terminal flowers that had a tighter ray petal structure (Fig. 2-D). Whipker and McCall (2000) reported that daminozide treatments of 4,000 and 8,000 mg•L^{-1} increased inflorescence bud count, but daminozide and paclobutrazol delayed flowering by 1 to 4 days depending on the *Helianthus* cultivar. In the present study, the control treatment resulted in the greatest number of flowers while all other treatments were similar for ‘Sunfinity’ (Table 1). Uniconazole and the control treatment resulted in the greatest number of flowers for ‘Suncredible’ (Table 2).

Not surprisingly, the daminozide + CCC treatment resulted in the highest SPAD reading for both cultivars (Fig. 2-D, 3-D). SPAD levels were recorded at 57.9% on ‘Sunfinity’ and 53% on ‘Suncredible,’ while the control and paclobutrazol spray gave the lowest readings, 41.7% and 43.1% for ‘Sunfinity’, 44% and 48% for ‘Suncredible’ (Table 1 and 2). The increase in plant greenness is due to the combination of growth regulators which affect two separate stages of the GA biosynthesis pathway, chlormequat chloride (CCC) affects the early stages of GA biosynthesis pathway while daminozide affects later stages. Dole and Wilkins (2005) note that a synergistic effect occurs when using chlormequat chloride in combination with daminozide, and greater height control is achieved than by using one chemical alone.

For both cultivars, daminozide + CCC resulted in growth comparable to the industry standard and quality was increased due to darker foliage and tighter ray petals. Cultivars responded differently to the paclobutrazol foliar spray. In the future, new *Helianthus* cultivars should be tested for their response to chemical and application method. When using flurprimidol and uniconazole as a foliar spray, growers should increase rates or use a drench application for increased efficacy.

Figure 1. Effects of plant growth regulators (PGR) on total plant height and diameter for 'Sunfinity' and 'Suncredible' sunflower



Total Plant Height - Sunfinity

Total Plant Height - Suncredible

α=0.05, Tukeys HSD—connecting letters indicate no difference

Table 1. Effects of plant growth regulators (PGR) on total plant diameter, stem caliper, total plant fresh and dry weight, days to color crack (DTCC), days to anthesis (DTA), total number of flowers and SPAD reading on 'Sunfinity' sunflower.

PGR Treatments	Total plant diameter (cm) *	Stem caliper (mm)	Total plant fresh weight (g)	Total plant dry weight (g)	DTCC	DTA	Total number of flowers (no.)	SPAD reading (%)
Control	66.6 a[z]	15.5 a	286.0 a	45.7 a	70 b	74 b	33.3 a	41.7 c
Paclobutrazol drench 5mg•L^{-1}	40.4 c	13.9 bc	198.4 c	29.6 c	71 b	74 b	24.9 bc	51.8 b
Paclobutrazol spray 50mg•L^{-1}	62.1 a	14.7 a	267.6 a	42.6 a	70 b	74 b	26.1 bc	43.1 c
Daminozide/CCC 3500/1250mg•L^{-1}	38.7 d	13.3 c	215.5 bc	33.6 bc	75 a	79 a	23.1 c	57.9 a
Flurprimidol 25mg•L^{-1}	52.8 b	14.0 bc	233.3 b	35.6 b	71 b	74 b	28.3 b	48.2 b
Uniconazole 25mg•L^{-1}	53.9 b	14.1 bc	231.4 b	35.4 b	71 b	74 b	27.3 bc	49.5 b

*: α=0.05,

[Z]: Tukeys HSD—connecting letters indicate no difference

Table 2. Effects of plant growth regulators (PGR) on total plant diameter, stem caliper, total plant fresh and dry weight, days to color crack (DTCC), days to anthesis (DTA), total number of flowers and SPAD reading on 'Suncredible' sunflower.

PGR Treatments	Total plant diameter (cm) *	Stem caliper (mm)	Total plant fresh weight (g)	Total plant dry weight (g)	Total number of flowers (no.)	SPAD reading (%)
Control	67.9 a	16.0 a	313.1 a	51.21 a	27 a	44.0 c
Paclobutrazol drench 5mg•L^{-1}	45.1 bc	13.7 b	186.5 b	26.1 bc	14 ab	50.5 ab
Paclobutrazol spray 50mg•L^{-1}	54.2 b	13.1 b	181.2 b	22.8 bc	15 ab	48.0 b
Daminozide/CCC 3500/1250mg•L^{-1}	40.0 c	13.0 b	166.0 b	21.6 c	5 b	53.0 a
Flurprimidol 25mg•L^{-1}	53.1 b	13.5 b	206.6 b	24.1 bc	22 ab	51.0 ab
Uniconazole 25mg•L^{-1}	52.6 b	13.1 b	242.9 ab	34.21 b	27 a	50.2 b

*: α=0.05

[z] : Tukeys HSD—connecting letters indicate no differences

Figure 2. Visual comparison of the effects of PGRs applied to 'Sunfinity' sunflower. A) control (0mg•L^{-1}), B) paclobutrazol spray (50mg•L^{-1}), C) paclobutrazol drench (5mg•L^{-1}, industry standard), D) daminozide+CCC spray (3500+1250 mg•L^{-1}), E) uniconazole spray (25mg•L^{-1}), and F) flurprimidol spray (25mg•L^{-1})

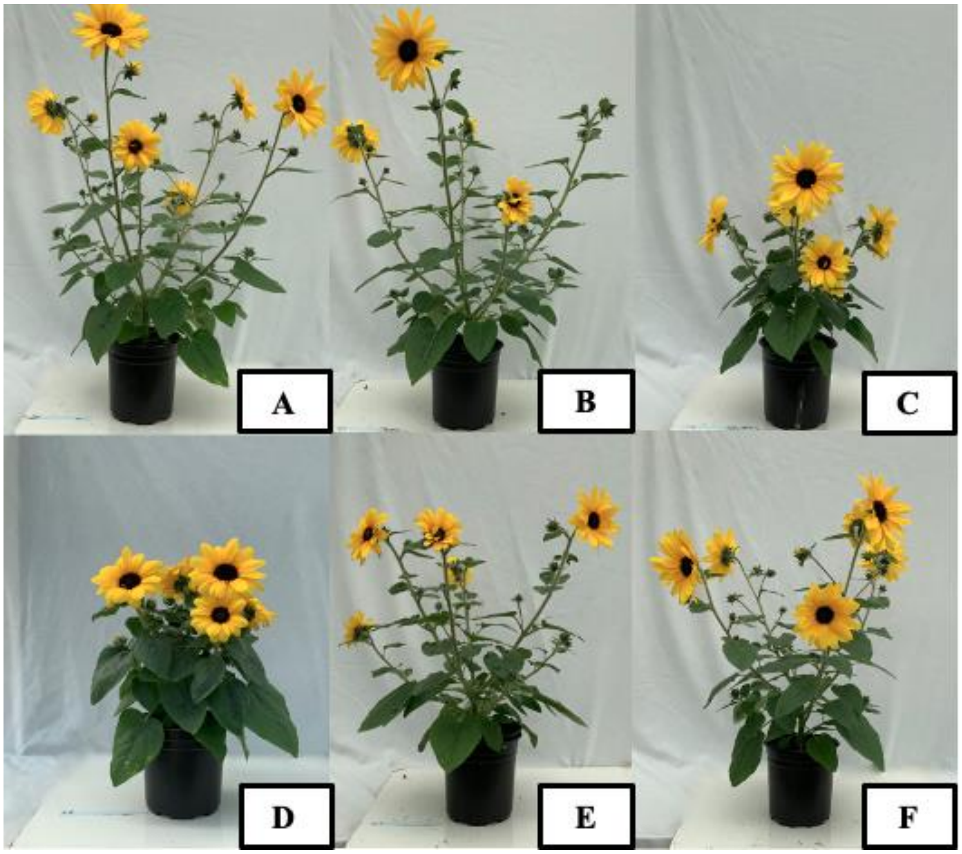
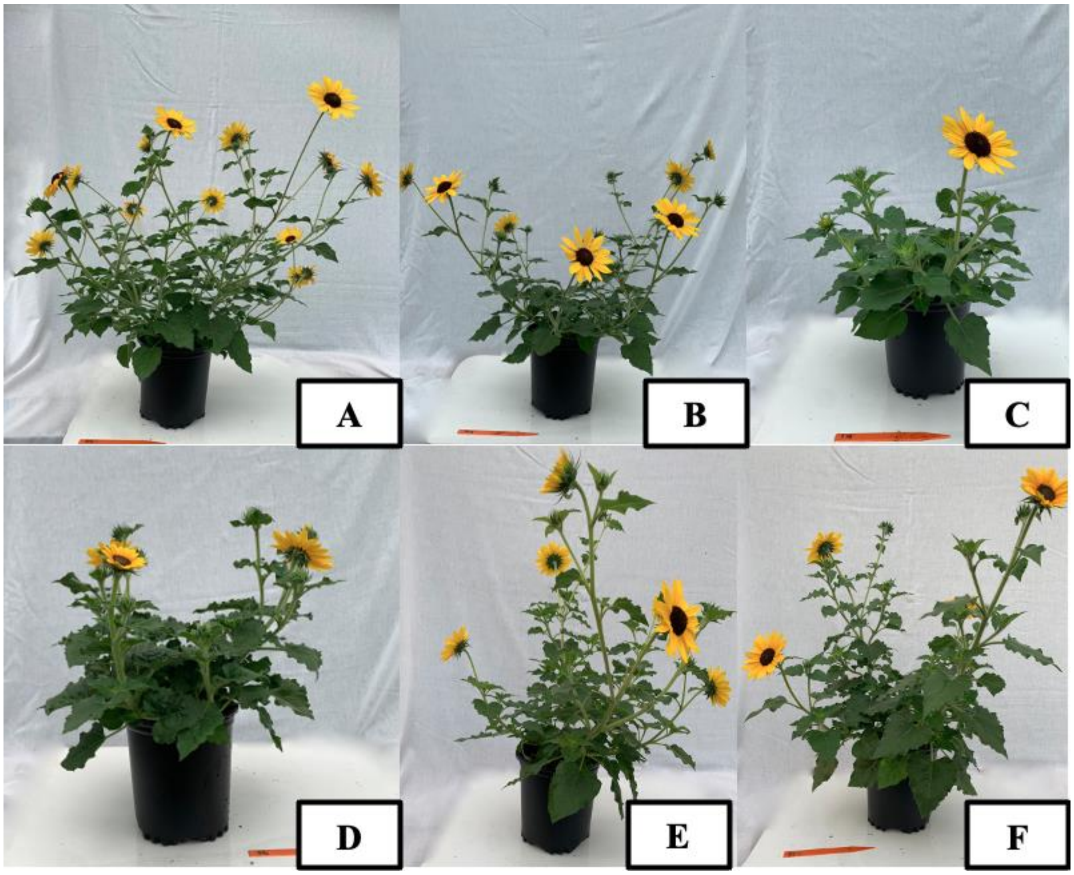


Figure 3. Visual comparison of the effects of PGRs applied to 'Suncredible' sunflower. A) control (0mg•L^{-1}), B) paclobutrazol spray (50mg•L^{-1}), C) paclobutrazol drench (2mg•L^{-1}, industry standard), D) daminozide+CCC spray (3500+1250mg•L^{-1}), E) uniconazole spray (25mg•L^{-1}), and F) flurprimidol spray (25mg•L^{-1})



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3. EVALUATING EFFECTS OF CHEMICAL PINCHING DURING EARLY VEGETATIVE STAGES ON ‘SUNFINITY’ SUNFLOWER FOR POTTED PLANT PRODUCTION

3.1. Literature Review

Manual pinching of apical meristems in horticultural crops removes apical dominance and promotes branching, increased flowers, and a rounded, uniform plant canopy. However, manual pinching is a time-consuming and labor-intensive practice that can become costly for growers (Cheema, 2018; Starman, 1991). Meijón et al. (2009) noted that chemical pinching agents can reduce the cost associated with manual pinching, but plant growth response is variable. Previous research classifies sunflower *(Helianthus sp.)* as having strong apical dominance that can only be broken with the removal or manual pinching of the apical meristem (Bhattacharjee and Gupta, 1984; Cline 1978). More recently, some basal branching sunflower cultivars, referred to as multifloras, generally are not pinched, however pinching single-stem sunflower cultivars promoted multiple axillary stems with smaller flowers (Armitage and Laushman, 2003). *Helianthus hybrida* ‘Sunfinity’, a relatively new ornamental hybrid of sunflower has a continuous branching habit. Manual pinching above the fourth node is recommended commercially to encourage continuous lateral branching and create a uniform and rounded plant canopy.

Dikegulac sodium is a plant growth regulator (PGR) that chemically prevents apical dominance by inhibiting cell division in the apical meristem, therefore allowing lateral branching to occur (Arzee et al., 1977; Rezazadeh, 2015). Dikegulac sodium has been shown to be effective at increasing branching of several horticultural crops such as *Sedum*, *Hydrangea*, *Phlox* and *Nepeta* (Banko and Stefani, 1995; Grossman et al., 2013; Sun et al., 2015; Cline, 1978). Within one day, dikegulac sodium was detected in the apical meristem after being applied to the basal foliage of *Chrysanthemum morifolium*. However, foliar application to the apical leaves provided maximum effect in preventing apical dominance (Bocion and DeSilva, 1977). While published literature has examined the effects of dikegulac sodium on *Helianthus* physiology and enzyme activities (Arzee et al., 1977; Purohit, 1980; Bhattacharjee and Gupta, 1981 and 1984). We are not aware of reports on dikegulac sodium's ability to chemically pinch sunflower.

In vitro studies involving *Solanum nigrum* showed that dikegulac sodium did not inhibit stationary or dormant cells, but phytotoxicity did occur on actively dividing cells (Zilkah and Gressel, 1978). Further research by Zilkah and Gressel (1979) showed that cell leakage is quickly induced after application. Latimer and Whipker (2001) recommended to test several rates of dikegulac sodium on new species because responses to the chemical were species-specific. Preliminary research we conducted in the Spring of 2022 with the objective of substituting manually pinching 'Sunfinity' above the fourth node as commercially recommended with applications of dikegulac sodium at the five to seven node vegetative stages of unpinched plants resulted in total plant senescence three weeks after application.

The objective of this experiment was to treat 'Sunfinity' seedlings with increasing rates of dikegulac sodium (200, 300, 400, or 500 $mg \cdot L^{-1}$) at three early vegetative stages (two, three or four nodes) to determine if the PGR was effective in producing a well-branched plant comparable to manually pinching. The overall goal was to determine which treatment resulted in growth similar to the manually pinched control and if chemical pinching proved to be an effective alternative to manually pinching for the purpose of saving labor and costs. Applications to dormant axillary stem nodes at early vegetative stages were chosen to prevent phytotoxic effects that were found to occur on actively growing axillary stems. Observations were made on treated plants for potential phytotoxic effects after application.

3.2. Materials and Methods

Seeds of *Helianthus hybrida* ‘Sunfinity’ were obtained from Syngenta Flowers North America (Gilroy, CA) and were sown <0.65cm deep in 72-cell trays, one seed per cell, containing PRO-MIX HP with mycorrhizae as a root substrate. Trays were placed in a glass greenhouse in College Station, Texas (30.608718, -96.350350) on 28 May, 2021. Cells were misted by hand multiple times daily during the germination period with reverse osmosis (RO) water. All seeds received an industry standard initial paclobutrazol drench at 2 $mg{\bullet}L^{-1}$ on day 5 to prevent stretching. Later industry standard PGR applications were withheld.

Dikegulac sodium (Atrimmec) (PBI/Gordon Corp., Kansas City, MO) was applied as a foliar spray at four rates and three vegetative growth stages. Chemical rates applied were 200, 300, 400, and 500 $mg{\cdot}L^{-1}$. Vegetative growth stages were defined as V1, V2 or V3 and received their PGR applications on June 7, 12, or 18, corresponding to

10, 15, or 21 days after sowing and one, two, or three nodes above the cotyledons, respectively. The timing of applications that corresponded with V1, V2, and V3 were determined by the number of true leaves longer than 2cm. V1 had one node and one pair of true leaves, V2 had two nodes and two pairs of true leaves, and V3 had three nodes and three pairs of true leaves. There were seven replications per treatment, and two control groups (manually pinched and no pinch) of seven plants each for a total of 98 plants. The experiment was arranged in a completely randomized design. On 21 June., all plants were transplanted into 2.50 qt thermoformed containers, one plug per pot. A nutrient solution of 200 mg•L^{-1} 15N-2.2P-12.5K-5Ca-2Mg was applied during the vegetative growth stage until harvest.

All plants were harvested on 24 July. Data included total plant height (from pot rim to highest point on plant), total plant diameter (measured across the widest point of plant), total plant fresh and dry weight, number of nodes on the main stem, number of secondary (axillary) branches on the main stem, and length of the two lowest secondary branches on the main stem and averaged. The lowest branches were selected for measurement because they were the longest and instrumental in determining the overall plant architecture.

The statistical analysis was performed on JMP, version 16.0.0. First, the manually pinched and no-pinch control treatments were compared with Student’s t-test. Second, a two-way ANOVA was applied including the manually pinched control data to identify significant interactions between the vegetative stage and PGR rate. Next, Dunnett’s test was used to compare each treatment to the manually pinched control.

Lastly, treatment comparison was made within the vegetative stage, excluding the control, using Tukey’s HSD.

3.3. Results and Discussion

3.3.1. Comparison of control treatments

Manually pinching the plant reduced total plant height by 31.9 cm and increased the total plant diameter by 4.4 cm compared to not pinching (Table 3). The total plant fresh weight was similar in both treatments, however the pinched treatment resulted in less total plant dry weight compared to the no pinch treatment. Manual pinching occurred above the fourth node which resulted in a total of four nodes for the pinched treatment, while the no pinch treatment developed 18 nodes (Table 4). Plants with more nodes produce more stems per plant (Sloan and Harkness, 2010). The pinched treatment resulted in 8 secondary stems while the no pinch treatment had 21. This stem count was due to ‘Sunfinity’ having opposite nodes up to the fifth or sixth node and alternate nodes above.

Secondary branch length was increased by 28 cm with manual pinching. The difference in secondary branch length can be explained by the release of apical dominance that occurred after manual pinching. Axillary branching due to the release of apical dominance explains the larger plant diameter for the manually pinched plant. (Table 3, Fig. 4).

If plants were not manually pinched, apical dominance ensued. Plants grew tall due to increased node numbers and internode elongation. Each node produced one secondary stem on average and those stems were 10.5 cm long giving the plant a “clubby” architecture which was prone to lodging when grown in a container. In contrast, manually pinched plants had analogous height and width dimensions (53 and 59 cm) and each of the four nodes that remained on the main stem produced two secondary stems that elongated to 38.5 cm. These results produced a rounded canopy that was suitable for potted plant production.

Figure 4. Visual comparison of the effects of manual pinching on the morphology of 'Sunfinity' sunflower, A) no pinched, and B) manually pinched to four nodes.

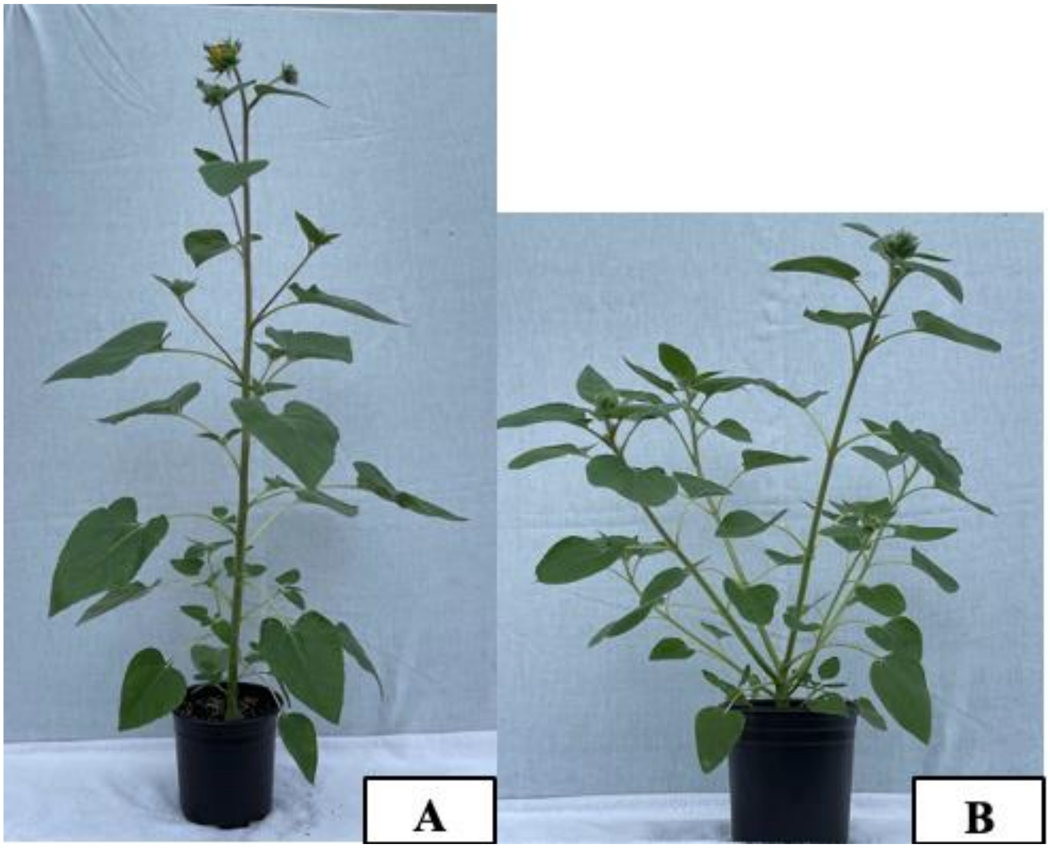


Table 3. Effect of manual and no pinching on plant height, diameter, fresh and dry weight for 'Sunfinity' sunflower.

Pinch treatment	**Plant height (cm)**	**Plant diameter (cm)**	**Plant fresh weight (g)**	**Plant dry weight (g)**
Manual	53.29 b[z]	59.29 b	147.40 a	15.57 b
None	85.14 a	54.86 a	175.23 a	20.13 a

[Z]= Comparison of means by student t-test

Table 4. Effect of manual and no pinching on number of nodes, number of secondary stems, and secondary branch length for 'Sunfinity'.

Pinch treatment	**Number of nodes (#)**	**Secondary stems (#)**	**Secondary branch length (cm)**
Manual	4 b	8 b	38.50 a
None	18 a	21 a	10.50 b

[Z]=Comparison of means by student t-test

Table 5. ANOVA for interaction between treatment stage and chemical concentration for height, diameter, fresh weight, and dry weight on 'Sunfinity' sunflower.

Source	**Total plant height (cm)**	**Total plant diameter (cm)**	**Total plant fresh weight (g)**	**Total plant dry weight (g)**
Stage	0.0006*	0.0001*	0.0001*	0.0001*
mg $\cdot L^{-1}$	0.0001*	0.0003*	0.0001*	0.0001*
Stage*mg $\cdot L^{-1}$	0.0001*	0.0001*	0.0001*	0.0001*

NS = Not Significant
***** = $P \leq 0.05$

Table 6. ANOVA for interaction between treatment stage and chemical concentration for number of nodes, number of secondary stems, and secondary branch length on 'Sunfinity' sunflower.

Source	**Total number of nodes (#)**	**Secondary stems (#)**	**Secondary branch length (cm)**
Stage	0.0001*	0.0001*	0.0001*
mg $\cdot L^{-1}$	0.0001*	0.0001*	0.0001*
Stage* mg $\cdot L^{-1}$	0.0001*	0.0001*	0.0001*

NS = Not Significant
***** = $P \leq 0.05$

3.3.2. Comparison of treatments to the control

A two-way ANOVA showed significant interaction between vegetative stage and PGR rate for total plant height, total plant diameter, total plant fresh and dry weight, number of nodes, secondary stems, and secondary branch length (Table 5, 6). The manually pinched treatment was used for the control group comparison for the Dunnett's test (Table 7, 8). Compared to the control, total plant height for V1 500, V2 500, and V3 400 were reduced (Table 7). At V1 and V3, all rates reduced total plant diameter, however, at the V2 stage, only 500 mg·L^{-1} reduced plant diameter compared to the control (Table 7). All treatments decreased total plant fresh weight compared to the control with the exception of 200 and 300 mg·L^{-1} at the V2 stage (Table 7). Excluding 200-400 mg·L^{-1} at the V2 stage, all treatments reduced total plant dry weight compared to the control (Table 7).

The 500 mg·L^{-1} at all stages, 400 mg·L^{-1} at V1 and V3 and 300 mg·L^{-1} at V1 exhibited total number of nodes that was similar to that of the control, resulting in a chemical removal or temporary inhibition of apical dominance (Table 8). All rates except 200 mg·L^{-1} at the V1 stage reduced the total number of secondary stems, along with 500 mg·L^{-1} at the V2 stage and 400 mg·L^{-1} at the V3 stage. Applications of 200 mg·L^{-1} at the V1 and V3 stage, and 500 mg·L^{-1} at the V2 stage resulted in reduced secondary branch length when compared to the control (Table 8).

3.3.3. Comparison of treatments without the control

Treatments of 400 mg·L^{-1} at V1 and V3 and 500 mg·L^{-1} at V1 and V2 resulted in more than 50% of each group becoming chemically pinched (Table 9). However, the majority of plants treated at the V1 stage with 500 mg·L^{-1} were small and unmarketable (Fig 13). While 400 mg·L^{-1} at V2 and 500 mg·L^{-1} at V3 did not result in chemical pinching, the secondary stems were consistently equal in length which resulted in a round canopy (Fig. 14, 15).

When comparing PGR concentration within the vegetative stage without the control, V1 at 500 mg·L^{-1} had the greatest reduction in height compared to all other treatments (Fig. 7). Bhattacharjee and Gupta (1984) showed that dikegulac sodium applied to dwarf sunflower (*Helianthus annuus* cv. Modern) at 500 mg·L^{-1} and 750 mg·L^{-1} reduced leaf area and plant height more than 100 mg·L^{-1}. When treatments were compared without the control, all treatments resulted in the same diameter with the exception of 500 mg·L^{-1} at the V1 and V2 stage which reduced diameter compared to the other treatments (Fig. 8)

Treatments of 500 mg·L^{-1} at V1 and V2, and 400 mg·L^{-1} at V3 reduced fresh and dry weight compared to the other treatments (Fig. 9) Results from Bhattacharjee and Gupta (1981) show that dry weight continues to decrease as dikegulac sodium rates increase when applied to *Helianthus annuus* L. cv. EC68414. In their study, all plants were treated at 26 days old, while this experiment treated plant based on vegetative stages (10, 15, and 21 days after sowing).

Spraying with higher concentrations at the V1 stage reduced number of secondary stems compared to the other treatments (Fig. 11). The 200 mg·L^{-1} concentration at the V1 and V3 stages and 500 mg·L^{-1} at the V1 and V2 stage decreased secondary branch length compared to the other treatments (Fig. 12).

With few exceptions, 500 mg·L^{-1} exhibited a linear and 400 mg·L^{-1} a quadratic response across all measured variables (Figs. 7-12).

Phytotoxic effects appeared approximately five to seven days after foliar application for each treatment. Initial symptoms of phytotoxicity were chlorosis on the upper leaves and apical meristem, followed by upwards leaf curling and the eventual death of the apical meristem, which occurred 18-21 days after application (Fig. 14). Arzee et. al (1977) recorded similar results on the distorted foliage of *Helianthus annuus* ‘Peredovic’ when applying dikegulac sodium at 100-750 mg·L^{-1} and noted that the effect was transient. While all treatments displayed extensive chlorosis and eventually greened, several plants exhibited a change in leaf morphology from cordate-ovate leaf structure to a linear shape.

Understanding the overall morphology in regard to the number of nodes and their relationship to other plant growth parameters was important when concluding which treatment resulted in growth similar to the manually pinched control and if chemical pinching proved to be an effective alternative to manually pinching. Vegetative stages (V1, V2, and V3) corresponded to the number of nodes present on the plant at the time of application. An ideal plant should not be taller than the control and have a low number of nodes with secondary stems setting the height and width.

More than half of the treatment group was chemically pinched when dikegulac sodium was applied at 400 and 500 $mg{\cdot}L^{-1}$ at the V1 stage, 500 $mg{\cdot}L^{-1}$ at the V2 stage, and 400 $mg{\cdot}L^{-1}$ at the V3 stage (Table 9). However, plants treated with 500 $mg{\cdot}L^{-1}$ at the V1 stage did not grow after application and remained stunted. While 400 $mg{\cdot}L^{-1}$ at the V2 stage and 500 $mg{\cdot}L^{-1}$ at the V3 stage did chemically pinch, resulting growth from secondary branches created a well-rounded canopy (Figs. 14, 15). Apart from the paclobutrazol drench during the seedling stage, only dikegulac sodium was applied in this experiment. Based on visual observations of plant quality during harvest, combining a PGR with dikegulac sodium applied at 400 $mg{\cdot}L^{-1}$ at all stages and 500 $mg{\cdot}L^{-1}$ at stages V2 and V3 would result in a plant of marketable size that is chemically pinched and well-branched.

Figure 5. Effects of dikegulac sodium after foliar application to 'Sunfinity' sunflower, A) leaf chlorosis appearing three to five days after foliar application, and B) evidence of chemical pinching and axillary growth 21 days after foliar application.

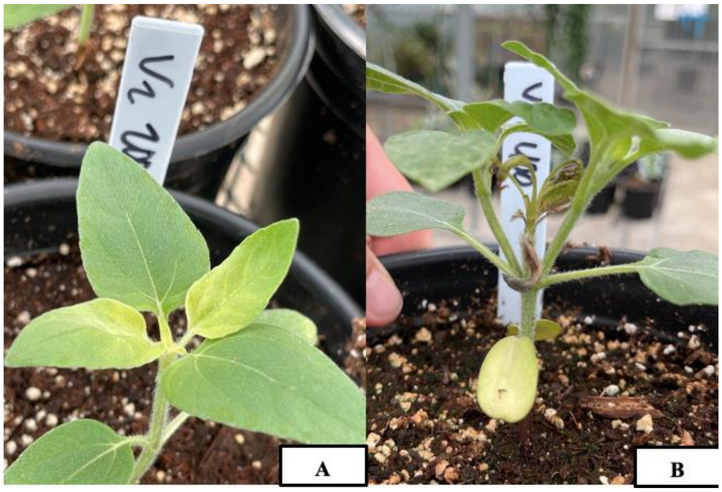


Figure 6. Phytotoxic effects of dikegulac sodium on leaf morphology of ‘Sunfinity’ sunflower. Normal leaf shape is cordate-ovate, affected plants had one to two linear shaped leaves.

Table 7. Dunnett's test for comparing means of dikegulac sodium treatments on 'Sunfinity' sunflower to the manually pinched control.

Stage	**mg ·L^{-1}**	**Plant height (cm)**	**Plant diameter (cm)**	**Plant fresh weight (g)**	**Plant dry weight (g)**
Control	0	53.29	59.29	147.40	15.58
V1 Stage	200	66.43^{NS}	42.93*	95.99*	10.25*
	300	45.00^{NS}	41.71*	68.87*	7.24*
	400	40.14^{NS}	39.43*	66.71*	7.62*
	500	18.14*	19.86*	19.79*	2.09*
V2 Stage	200	62.00^{NS}	49.50^{NS}	117.18^{NS}	11.77^{NS}
	300	66.29^{NS}	56.50^{NS}	137.79^{NS}	13.61^{NS}
	400	53.71^{NS}	50.57^{NS}	109.84*	12.24^{NS}
	500	31.14*	35.50*	49.49*	5.20*
V3 Stage	200	64.71^{NS}	43.00*	90.22*	9.65*
	300	60.29^{NS}	44.86*	89.69*	9.76*
	400	31.29*	40.93*	52.51*	5.86*
	500	41.29^{NS}	50.57*	84.62*	9.30*

***** = $P \leq 0.05$
NS=Not Significant

Table 8. Dunnett’s test for comparing means of dikegulac sodium treatments on ‘Sunfinity’ sunflower to the manually pinched control.

Stage	**mg ·L^{-1}**	**Number of nodes (#)**	**Secondary stems (#)**	**Secondary branch length (cm)**
Control	0	4.00	8.00	38.50
V1 Stage	200	20.00*	7.86^{NS}	8.93*
	300	8.71^{NS}	2.29*	29.64^{NS}
	400	5.14^{NS}	2.57*	33.93^{NS}
	500	5.14^{NS}	0.00*	0.00*
V2 Stage	200	17.00*	5.57^{NS}	35.50^{NS}
	300	18.57*	7.00^{NS}	37.00^{NS}
	400	17.57*	5.57^{NS}	37.43^{NS}
	500	6.14^{NS}	3.29*	19.21*
V3 Stage	200	17.43*	5.43^{NS}	15.64*
	300	16.86*	6.57^{NS}	26.50^{NS}
	400	6.14^{NS}	4.29*	27.21^{NS}
	500	9.14^{NS}	5.71^{NS}	34.43^{NS}

***** = $P \leq 0.05$
NS=Not Significant

Table 9. Effect of vegetative stage and rate on percentage of plants chemically pinched after foliar application of dikegulac sodium on 'Sunfinity' sunflower.

Stage	**mg ·L^{-1}**	**Plants chemically pinched**
V1 Stage	200	0 %
	300	43 %
	400	71 %
	500	57 %
V2 Stage	200	0 %
	300	0 %
	400	0 %
	500	71 %
V3 Stage	200	0 %
	300	0 %
	400	71 %
	500	29 %

Figure 7. Interaction of vegetative stage by rate (mg·L^{-1}) on total plant height of ‘Sunfinity’ sunflower.

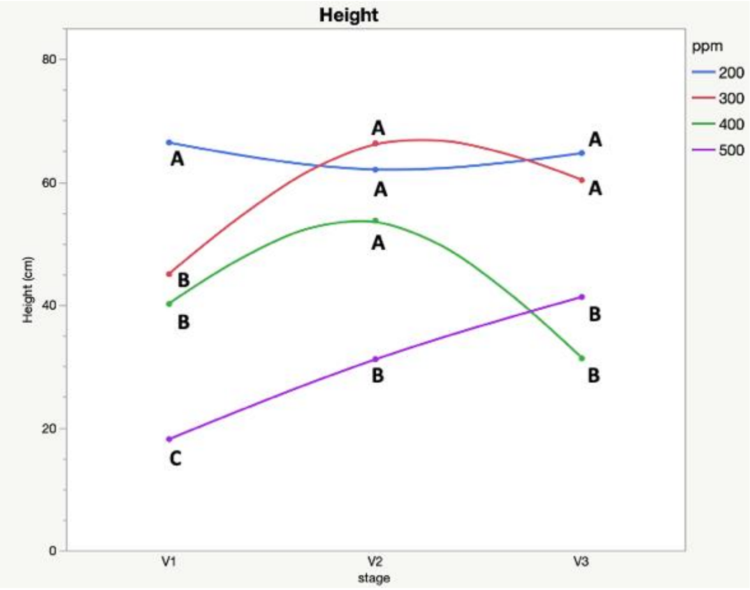


Figure 8. Interaction of stage by rate (mg·L^{-1}) on total plant diameter of ‘Sunfinity’ sunflower.

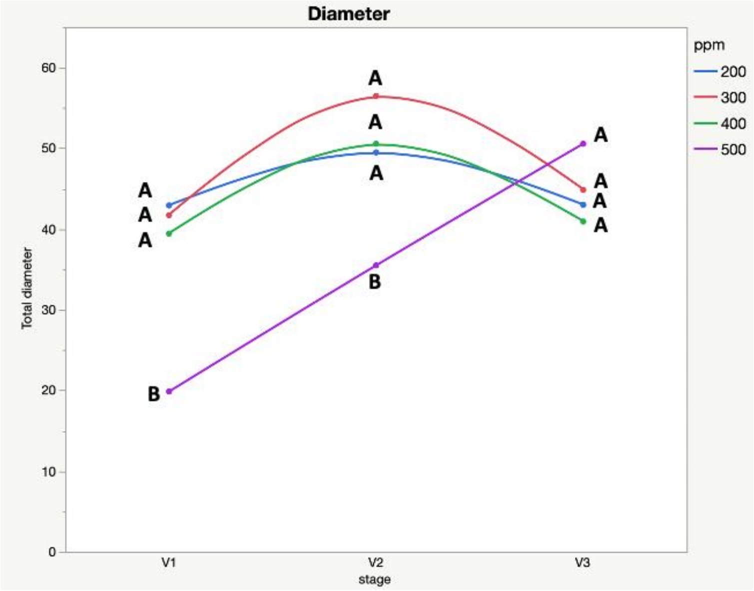


Figure 9**.** Interaction of stage by rate (mg·L^{-1}) on total plant fresh and dry weight of ‘Sunfinity’ sunflower.

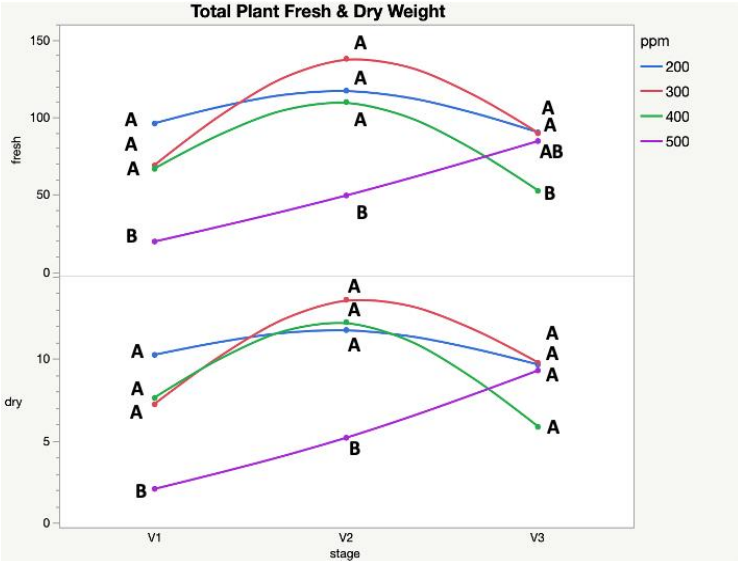


Figure 10. Interaction of stage by rate (mg·L^{-1}) on total number of nodes of ‘Sunfinity’ sunflower**.**

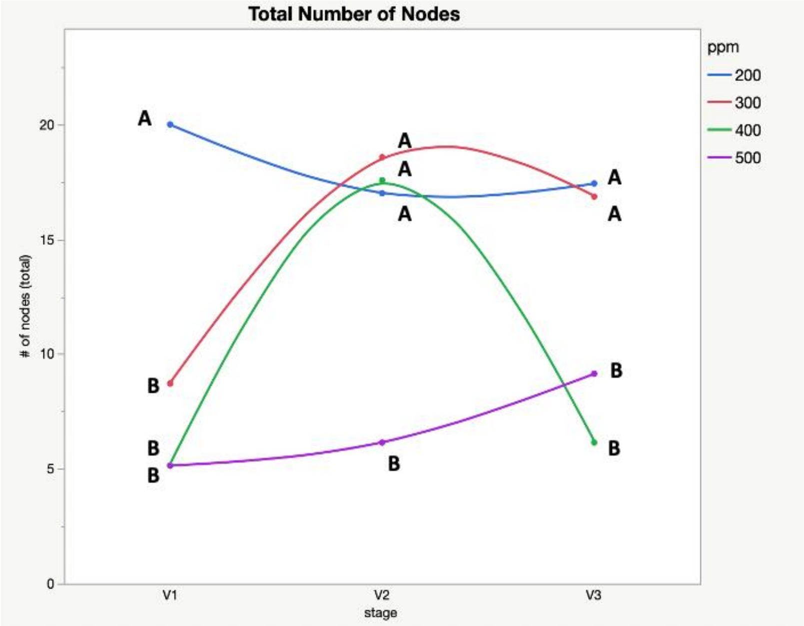


Figure 11. Interaction of stage by rate (mg·L^{-1}) on total number of secondary stems of ‘Sunfinity’ sunflower

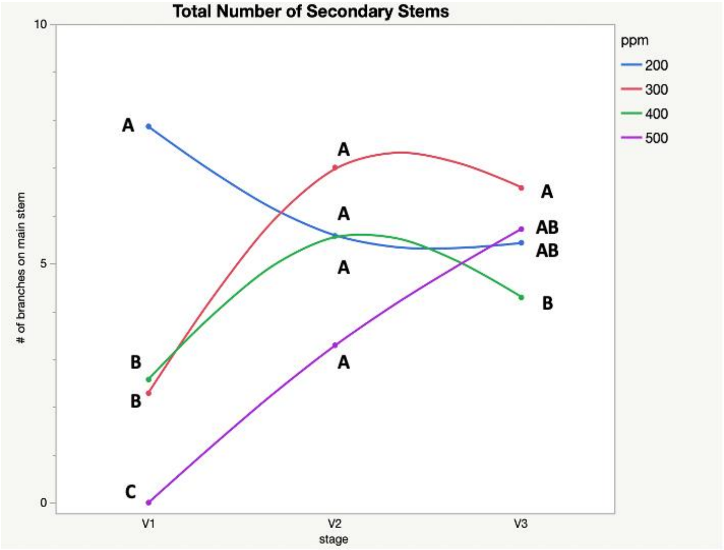


Figure 12. Interaction of stage by rate (mg·L^{-1}) on secondary branch length of ‘Sunfinity’ sunflower.

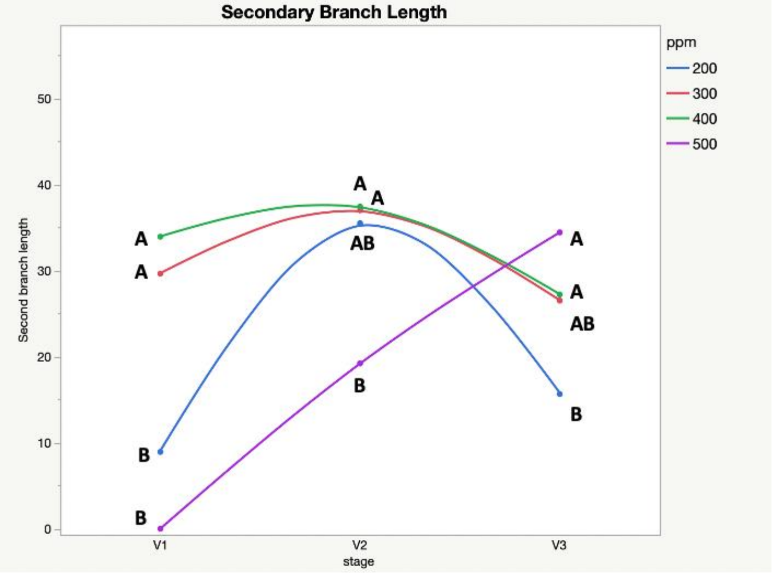


Figure 13. Visual comparison of the effects of dikegulac sodium applied at the V1 stage on 'Sunfinity' sunflower at A) 200 mg·L^{-1}, B) 300 mg·L^{-1}, C) 400 mg·L^{-1}, and D) 500 mg·L^{-1}.

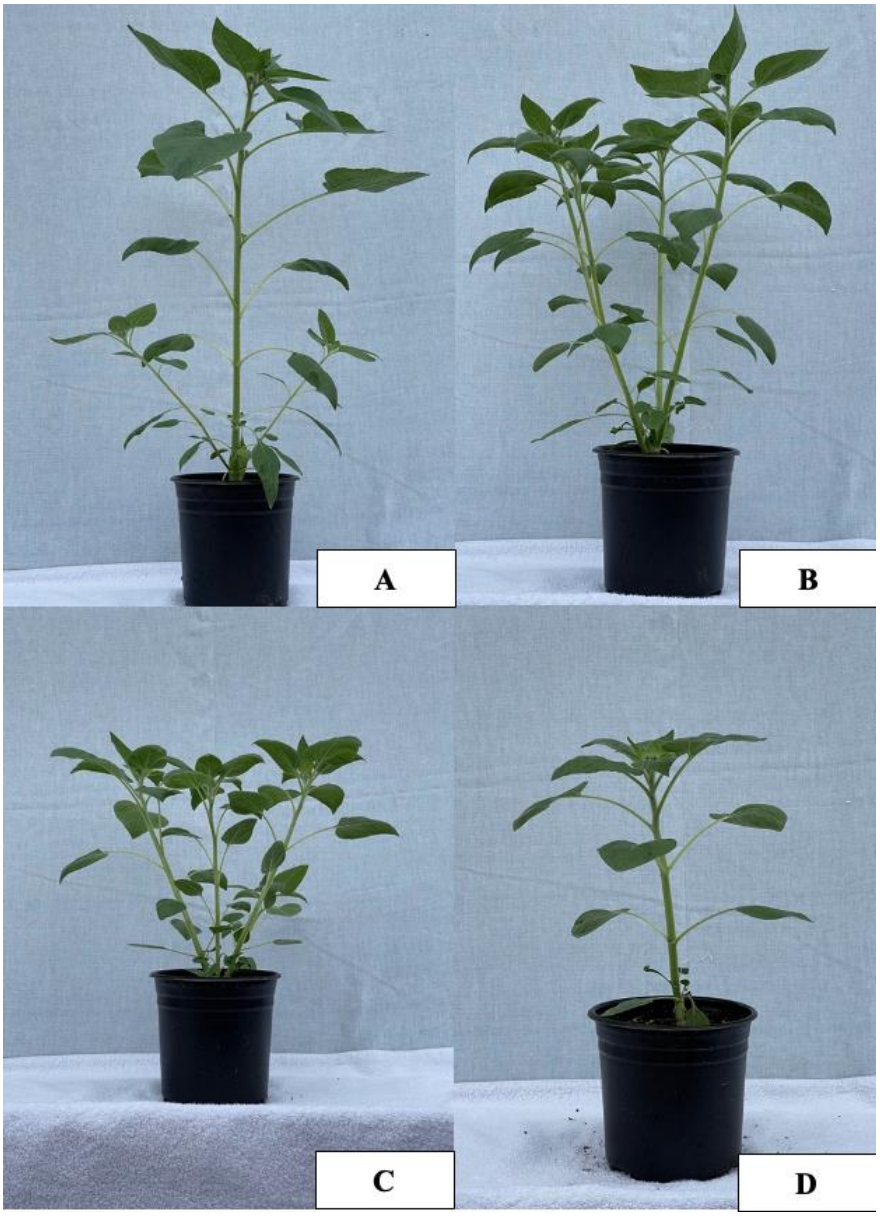


Figure 14. Visual comparison of the effects of dikegulac sodium applied at the V2 stage on 'Sunfinity' sunflower at A) 200 mg·L^{-1}, B) 300 mg·L^{-1}, C) 400 mg·L^{-1}, and D) 500 mg·L^{-1}.

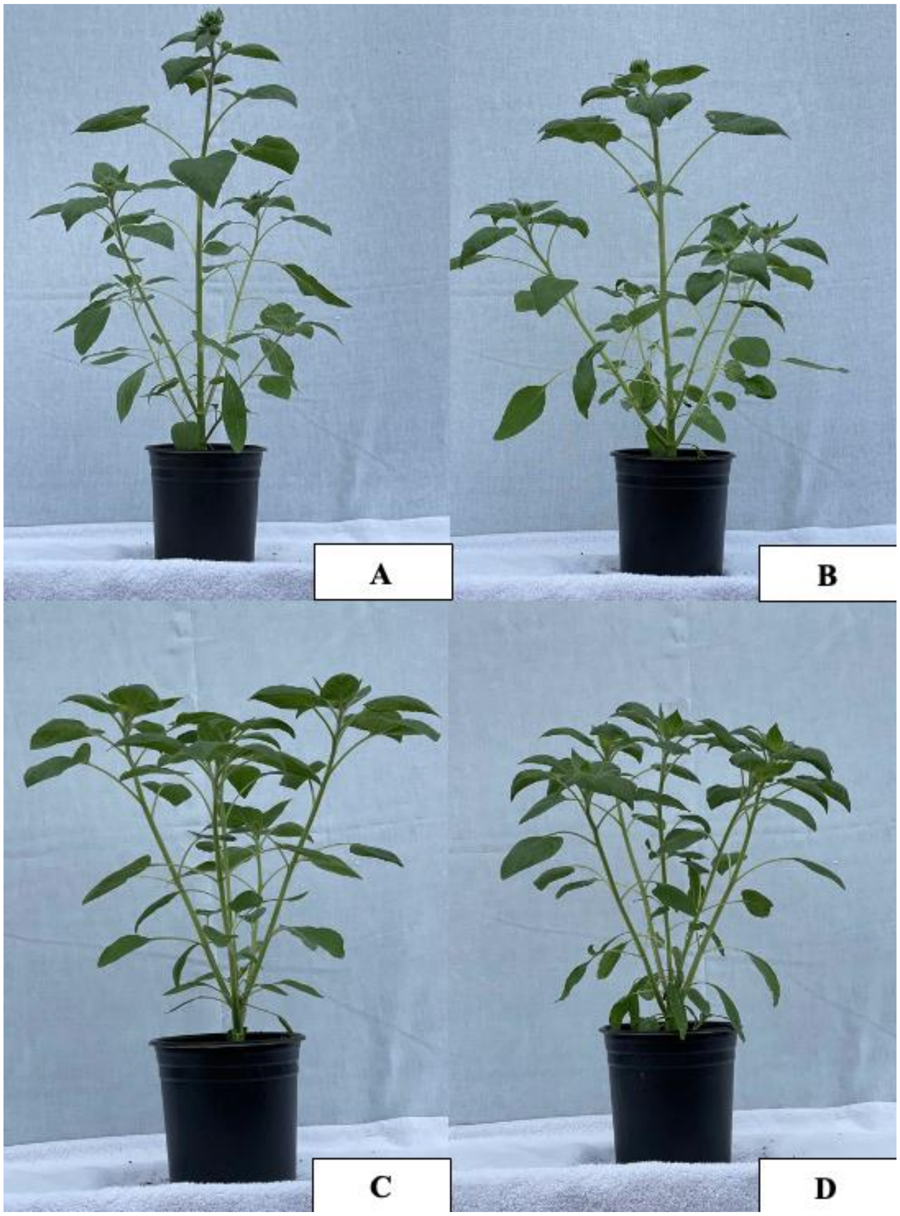
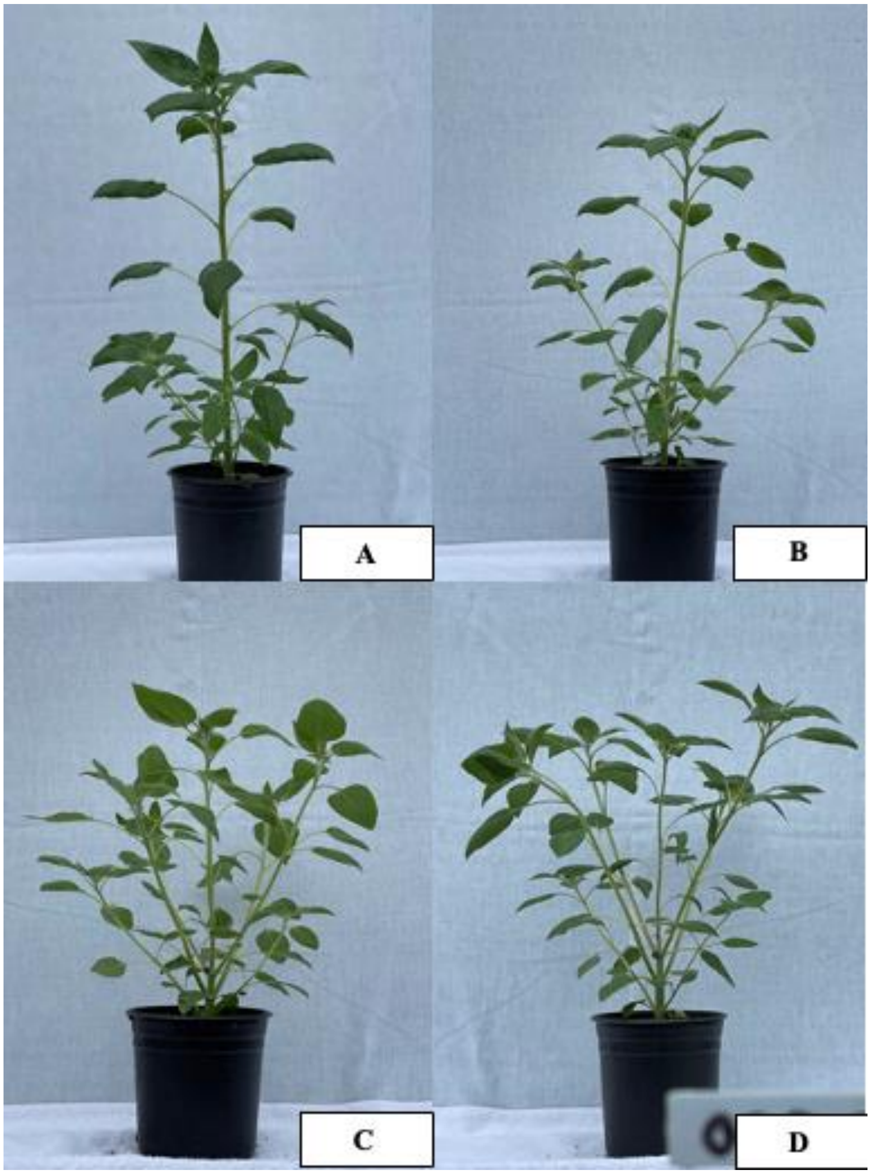


Figure 15. Visual comparison of the effects of dikegulac sodium applied at the V3 stage on ‘Sunfinity’ sunflower at A) 200 mg·L^{-1}, B) 300 mg·L^{-1}, C) 400 mg·L^{-1}, and D) 500 mg·L^{-1}.



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4. CONCLUSIONS

4.1. Chapter 2

- Daminozide + CCC (3500/1250 mg•L^{-1}) foliar spray resulted in growth comparable to the industry standard, paclobutrazol substrate drench (5 mg•L^{-1}), for total plant height, total plant diameter, number of flowers, and total fresh and dry weight.
- Plant quality was improved visually due to darker foliage and tighter ray petals with Daminozide + CCC.
- Cultivars responded differently to the paclobutrazol foliar spray. Applications of 50 mg•L^{-1} to ‘Suncredible’ reduced total plant height and diameter while ‘Sunfinty’ was unaffected.
- Flurprimidol (25 mg•L^{-1}) and uniconazole (25 mg•L^{-1}) foliar sprays were not effective in controlling plant growth compared to the control. Higher rates (> 30 mg•L^{-1}) could be applied in the future, or root substrate drenches may be more effective.

4.2. Chapter 3

- Vegetative stage and rate influenced the resulting plant morphology.
- Applications of 400 mg•L^{-1} at the first and third vegetative stage, along with 500 mg•L^{-1} at the second vegetative stage proved to be effective regarding chemical pinching.

- Apical dominance was temporarily inhibited when 400mg•L^{-1} was applied at the second vegetative stage and 500mg•L^{-1} at the third vegetative stage, resulting in growth that formed a well-rounded canopy.
- Further research should be conducted before replacing manual pinching with dikegulac sodium chemical pinching on ‘Sunfinity’ sunflower.

APPENDIX A

CHAPTER 3 SUPPLEMENTARY TABLES

Table 10. Tukey's test comparing the treatment mean of rate within the vegetative stage on 'Sunfinity' sunflower

Stage	**mg ·L^{-1}**	**Total plant height (cm)**	**Total plant diameter (cm)**	**Total plant fresh weight (g)**	**Total plant dry weight (g)**
V1 Stage	200	66.4 **a**^{z}	42.9 **a**	96.0 **a**	10.2 **a**
	300	45.0 **b**	41.7 **a**	68.9 **a**	7.2 **a**
	400	40.1 **b**	39.4 **a**	66.7 **a**	7.6 **a**
	500	18.1 **c**	19.9 **b**	19.8 **b**	2.1 **b**
V2 Stage	200	62.0 **a**	49.5 **a**	117.2 **a**	11.8 **a**
	300	66.3 **a**	56.5 **a**	138.8 **a**	13.6 **a**
	400	53.7 **a**	50.6 **a**	117.2 **a**	12.2 **a**
	500	31.1 **b**	35.5 **b**	49.5 **b**	5.2 **b**
V3 Stage	200	64.7 **a**	43.0 **a**	90.2 **a**	9.7 **a**
	300	60.3 **a**	44.9 **a**	89.7 **a**	9.8 **a**
	400	41.3 **b**	40.9 **a**	52.5 **b**	5.9 **a**
	500	31.3 **b**	50.6 **a**	84.6 **ab**	9.3 **a**

^{Z}= comparison of treatments within stage

Table 11. Tukey's test comparing the treatment mean of rate within vegetative stage on 'Sunfinity' sunflower

Stage	**mg ·L^{-1}**	**Total number of nodes (#)**	**Secondary stems (#)**	**Second branch length (cm)**
V1 Stage	200	20.0 **a**	7.90 **a**	8.9 **b**
	300	8.7 **b**	2.30 **b**	29.6 **a**
	400	6.1 **b**	2.60 **b**	33.9 **a**
	500	6.1 **b**	0 **c**	19.2 **b**
V2 Stage	200	17.0 **a**	5.6 **a**	35.0 **ab**
	300	18.6 **a**	7.0 **a**	37.0 **a**
	400	17.6 **a**	5.6 **a**	37.4 **a**
	500	6.1 **b**	3.3 **a**	0.0 **b**
V3 Stage	200	17.4 **a**	5.4 **ab**	15.64 **b**
	300	16.9 **a**	6.6 **a**	26.5 **ab**
	400	6.1 **b**	4.3 **b**	27.2 **a**
	500	9.1 **b**	5.7 **ab**	34.4 **a**

^{Z}= comparison of treatments within stage

Table 12. ANOVA F-ratio for the significant interaction between stage and mg ·L^{-1} for plant height, plant diameter, plant fresh weight, and plant dry weight

Source	**Plant height (cm)**	**Plant diameter (cm)**	**Plant fresh weight (g)**	**Plant dry weight (g)**
Stage	6.31*^{z}	39.08*	70.67*	51.82*
mg ·L^{-1}	32.01*	6.81*	15.89*	10.71*
Stage*mg ·L^{-1}	7.12*	5.25*	6.74*	5.24*

^{Z} = F-value,
* = P≤0.05

Table 13. ANOVA F-ratio for the significant interactions between stage and mg ·L-1 for total number of nodes, number of secondary stems, and secondary branch length

Source	**Number of nodes (#)**	**Secondary stems (#)**	**Secondary branch length (cm)**
Stage	40.27*	29.92*	23.37*
mg ·L^{-1}	27.02*	8.74*	9.96*
Stage*mg ·L^{-1}	8.87*	6.26*	6.96*

^{Z} = F-value,
* = P≤0.05