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PINCHING AND SPACING EFFECTS ON CUT SUNFLOWER (*HELIANTHUS ANNUUS*) PRODUCTION IN EAST TEXAS

By

REBECCA BURNETT, B.S. Environmental Science

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ABSTRACT

Three experiments evaluated pinching and spacing on *Helianthus annuus* in East Texas to determine their effects on growth and development. Experiment 1 was designed to determine the effects of pinching nodes 1, 2, 3, or 4 on ‘Pro Cut Gold’ sunflowers. Results from experiment 1 showed non-pinched plants produced marketable stem lengths and flower sizes, while pinched plants’ stem length, stem diameter, flower diameter, and disk diameter decreased compared to the non-pinched plants. Trial 1A produced marketable stems when pinched at nodes 1 and 2. Trial 1B did not produce any marketable stems when pinched. The objective for experiment 2 was to evaluate pinching and spacing treatments on ‘Pro Cut Gold’ sunflowers. All spacings for non-pinched plants in experiment 2 produced marketable stem lengths and flower sizes. Trial 2A from experiment 2 produced marketable stems for all pinching and spacing treatments. However, trial 2B that was planted later into the summer during mid-July, did not produce any marketable stems for any spacing treatments when pinched. All spacings for non-pinched plants in experiment 2 produced marketable stem lengths and flower sizes. Experiment 3 was designed to analyze the effects of pinching nodes 1, 2, 3, or 4 on ‘Pro Cut Gold, ‘Supreme Sunbright’, ‘Vincents Choice’, ‘Sunrich Lemon’, and ‘Superior Gold’ sunflowers. All of the non-pinched plants for all five cultivars produced marketable stem lengths and flower sizes. Pinching responses varied by cultivar but overall stem length, stem diameter, flower diameter, and disk diameter all decreased compared to the non-pinched plants. ‘Vincents Choice’ pinched at the first node was the only cultivar when pinched to produce a marketable stem length and flower size. For all three experiments pinching the plants generally led to stem lengths and flower sizes that did not meet the market minimums. Pinching increased stems per plant and days to harvest for all three experiments. Successful pinching in East Texas is dependent on the timing of planting. When sunflowers are planted early in the growing season (May), pinching appears to increase marketable stems per plant. For the East Texas region when sunflowers are planted later in the growing season the success of pinching declines. Spacing did not clearly affect sunflower growth and development; therefore, increasing planting densities of non-pinched sunflowers could increase marketable stem yield compared to pinching sunflowers at lower planting densities.

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INTRODUCTION

Cut flowers are produced for their flowers and long stems, to be used in arrangements. Cut flower products include roses, carnations, sunflowers and many others. The Industry and Trade Summary reported that the United States boasts a highly diverse market for cut flowers with shipments of cut flowers arriving from around the globe. In the United States, there was a 34% decrease in cut flower growers from about 3,000 in 1988 to roughly 2,000 in 1998 (Bonarriva, 2003). This decrease has been caused by the increasing numbers of cut flower imports.

Recently, an interest in pinching cut flowers to produce more stems per plant has risen in the cut flower community. Dr. Chris Wein of Cornell University has executed many sunflower pinching trials since 2007. His experiments have contributed a great deal in explaining how pinching sunflowers affects them. Since his research is conducted in New York in growing zone 5, his results may differ from those in other growing zones. Despite the research being done on pinching sunflowers, there is not a straightforward answer on when to pinch and how pinching affects the many different sunflower cultivars. Answers to these questions on pinching could lead to an increase in production of sunflowers in the United States. To address this issue, two different techniques were implemented to further study the effect pinching has on sunflowers. Treatments included: 1) pinching at different nodes and 2) pinching and spacing interactions. The pinching and spacing treatments studied previously by Dr. Wien will be evaluated in an East Texas climate. Data collected included stem length, stem diameter, flower diameter, disk diameter, days to harvest, and number of stems per plant.

OBJECTIVES

In this study the objectives were to:

1. Determine how pinching sunflowers at different nodes affects growth and development of sunflowers.
2. Determine how spacing affects the growth and development of sunflower flowers.
3. Develop recommendations for spacing and pinching to increase marketable sunflower production in East Texas.

LITERATURE REVIEW

Natural history of sunflowers

There are 49 species of sunflowers (*Helianthus annuus*) native to North America, 12 annual and 37 perennial species (Seilera, 1992). Sunflowers were used for food by Native Americans and some of the first settlers (Stevens et al., 1993). Before the demand of specialty flowers in the cut flower market, sunflowers were mainly grown to produce seed for food and oil. Sunflowers continue to be one of the major crops produced in the world because of their forage and oil attributes (Armitage and Laushman, 2003). When sunflower production shifted to the cut flower market, the traits desired in the agronomic sunflower crop were not conducive for cut flowers. This called for new breeding in sunflowers to create cultivars that will perform well as cut flowers (Schoellhorn et al., 2003). Cut sunflowers are now bred for many attributes including flower color, disc color, branching or non-branching, flower size, upward-facing flowers, plant height, pollenless flowers, and days to harvest. In the United States, cut sunflowers are mainly grown in New Jersey, California, and Pennsylvania (USDA, 2016).

Specialty cut flowers are in high demand around the world. Rabobank (2015) reported in 2013 that exports of flower bulbs, living plants, and cut foliage and flowers globally summed to 20.6 billion USD. The Netherlands exports 52% of the cut flowers around the world followed by Colombia with 15% (Rabobank, 2015). The United States produces less than 1% of the exported cut flowers globally (Rabobank, 2015), even though demand in the United States for cut flowers is high. According to United States Customs and Border Protection, roughly 801 million stems of cut flowers were imported into the United States in the 2014 Valentine season of 1 Jan. to 14 Feb. (U.S. Customs and Border Protection, 2016).

Growth habits

Sunflowers can grow in adverse environments, and they will thrive under optimum conditions. The ideal growing conditions for sunflowers are a soil pH of 5.7 to above 8.0, a temperature of 18−24 °C, sufficient potassium for stem stability, and full sun (Armitage and Laushman, 2003; Putnam et al., 1990; Schoellhorn et al., 2003). The sunflowers' taproot allows them to be drought tolerant, aiding in their ability to grow well in East Texas.

Sunflower cultivars consist of three different flowering types: 1) non-branching, 2) branching, and 3) spray. Non-branching cultivars like 'Pro Cut Gold' produce one single stem with one terminal head. Non-branching sunflower heads are typically larger than heads of branching or spray cultivars. Branching cultivars such as 'Floristan' develop a terminal head and multiple axillary shoots and heads (Armitage and Laushman, 2003). The axillary shoots are typically too short to be used for cut flowers. 'Moonbright' is an example of a spray cultivar (Armitage and Laushman, 2003). Spray cultivars produce an abundance of flower heads, but the flowers are generally smaller than that of non-branching and branching cultivars. Armitage and Laushman (2003) state that non-branching cultivars had the best quality terminal flower out of the three types. The interest in pinching sunflowers stems arose from growers noticing that the axillary shoots of branching cultivars were too short to be sold to florists. Pinching has been their way of experimenting with sunflowers to make them develop longer axillary shoots.

Apical Dominance

The natural development of the apical meristem in sunflowers has been studied (Palmer et al., 1982; 1984; Weberling, 1992). When the growers pinch sunflowers, they remove the plant's apical meristem and ridding the plant of its apical dominance (Wien, 2015). Two days after germination the meristem showed signs of zoning. A cone rib made up of meristem files accompanied by a mother zone in the center and two layers of tunica had been formed by day four. At this growth stage Palmer et al. (1982; 1984) noticed mitotic cells accumulating in the peripheral zone and under the leaf primordia. The meristem was flat until day six when it took on a convex nature. Block cells developed by day eight which suggested that most of the cells differentiated. Observations on day twelve showed the top of the meristem had developed a pronounced convex appearance and the mother zone and the tunica were releases separated by new cell divisions. Day fourteen observations illustrated proplastids moving towards the flowering apex. On day 16, five to seven layers of meristematic mantle were present on the surface of the convex meristem and the tunica were eight to ten cell layers above the mother zone (Palmer et al., 1982; Weberling, 1992). Palmer et al. (1982) quantitatively assessed their observations and noted that the mitotic index fluctuated in the apical, peripheral and the axial zones until day eighteen when the mitotic index stabilized in all three zones.

Apical dominance is when the apical meristem transmits hormones that are transmitted throughout the plant to control lateral branch growth. There are mixed opinions about what controls apical dominance and its release when the plants apical meristem is damaged. One theory is that auxin is the main hormone that controls apical dominance because it is produced in the apical meristem. Others believe auxin indirectly inhibits growth of lateral shoots while cytokinin induces axillary bud development (Bennett et al., 2006). Another theory is apical dominance is controlled secondarily by auxin (Morris et al., 2005). Additionally, there is a theory that a plant sends a signal to the lateral buds to grow. When the signal is sent, the auxin levels decrease for a short period of 4h and then start to flow near the lateral buds to induce growth (Morris et al., 2005).

Pinched garden peas (*Pisum sativum*) were one of the first species used to study apical dominance (Morris et al., 2005). The release of apical dominance when damaged could have evolved due to natural selection, providing a mechanism by which plants could produce lateral branches and continue their life cycles (Dun et al., 2006). The axil of each leaf contains a secondary apical meristem which aids in the initiation of secondary shoots (Bennett et al., 2006). Once the lateral buds have developed, they do not continue to grow outward. The growth is stopped to establish the cellular arrangement necessary to produce viable lateral shoots (Bennett et al., 2006).

In most apically dominant species, branching of undamaged plants is not necessary and only occurs if environmental stresses occur (Dun et al., 2006). In most branching herbaceous species, pinching does not drastically affect growth as it does with apically dominant species (Cline, 1997). *Helianthus* has strong apical dominance that is only broken with damage or pinching of the apical meristem (Cline, 1997).

Auxin is synthesized and travels from the apical meristem downward, while cytokinin moves throughout the plant from the roots upward (Morris, 2005). Cline (1997) described four crucial steps in plant development to consider when discussing apical dominance disturbance. Both auxin and cytokinin play a role in shoot branching (Shimizu-Sato and Mori, 2001). Auxin hinders axillary bud growth, while cytokinin facilitates axillary bud growth (Shimizu-Sato and Mori, 2001). The first step in axillary bud development is stimulated by the hormone cytokinin. Following axillary bud development, auxin stimulates the rise of apical dominance in the plant. Once the plant is pinched, cytokinin is released into the lateral buds and growth begins. Lastly, auxin induces the lateral buds to emerge to form branches, then the auxin levels in the plant return to normal (Cline, 1997).

Apical dominance and hormone disruption

After pinching, the sunflower stem no longer has apical dominance which allows the lateral buds to develop into branches. Once the sunflower is pinched the transition from apical dominance to lateral dominance is rapid usually occurring within 24 h. Once the new lateral branches develop and elongate, each produces its own auxin (Cline, 1997).

Bennett et al. (2006) found that cytokinin applied to the buds induced shoot growth, and auxin applied directly to the buds did not inhibit growth. Therefore, when cytokinin is artificially applied, it is able to overcome the plants auxin signals, allowing the plant to laterally branch out. Physiological, environmental, and developmental variables were evaluated to determine what the plant needs to initiate bud growth (Leyser, 2009). Leyser (2009) discusses two different hypotheses dealing with hormones and branching. The first theory is called the secondary messenger hypothesis. This theory hypothesized that auxin in the main stem controls the synthesis of a secondary hormone signal that moves into axillary buds to manage their growth (Leyser, 2009). A study on peas showed when pinching occurred cytokinin synthesis in the roots increased. An increase in cytokinin synthesis in the roots did not occur when exogenous auxin was applied to the pinched location (Leyser, 2009). It is theorized that cytokinin is the secondary regulator due to the increased production of it when the plant is pinched. In *Arabidopsis* the AXR1 gene is considered to be a component of the signal pathway for auxin to control cytokinin (Leyser, 2009). This observation is supported by Chatfield et al. (2000) when they discovered AXR1 interacts with the xylem parenchyma where the central auxin movement occurs and is vital to the regulation of axillary bud growth.

The canalization hypothesis is based on auxin movement and that auxin creates channels from the axillary buds into the central stem (Leyser, 2009). Sachs (1981) proposed that auxin to moves towards an auxin sink and away from the source via a newly created pathway. With new technology scientists have been able to support Sachs' theory about canalization. With these two hypotheses in mind, Leyser (2009) researched different studies to verify which hypothesis is more accepted among scientists. Sachs and Thimann (1967) found that after a leaf was damaged on a pea seedling the axillary buds produce vascular strands which adjoin to a nearby leaf. When the leaf was undamaged the strands attached to the vascular bundle (Sachs and Thimann, 1967). Sachs and Thimann (1967) speculated that buds connect to the area that has the lowest auxin concentrations which are the largest sinks. When the apical meristem is removed from the plant the strength of the sink in the stem is high; therefore, the bud will attach to the main stem and will initiate growth.

Dun et al. (2006) discusses three different hypotheses about how apical dominance is controlled. The first is the classical hypothesis where auxin levels control branching by inhibiting lateral bud growth (Dun et al., 2006). This hypothesis is accepted because of the dozens of pinching experiments that have been conducted. In legumes pinching leads to heightened endogenously produced cytokinins and transportation of cytokinins to the lateral buds (Dun et al., 2006). The auxin transport hypothesis is the second hypothesis which states the transport of auxin controls lateral bud development (Dun et al., 2006). Species that show strong apical dominance could be created by limiting auxin transport to lateral buds (Dun et al., 2006). Dun et al. (2006) discussed that limiting auxin flow to lateral buds could be triggered by the vascular bundles being full, not allowing flow to the lateral buds. The bud transition hypothesis is the final hypothesis that Dun et al. (2006) discussed. This hypothesis states that there are three possible phases a bud can be in: latent, development, and prolonged growth (Dun et al., 2006). Nodes at different locations on the pea plant respond differently to pinching because they could be at different stages (Dun et al., 2006). Therefore, the pinching location could impact branching development (Dun et al., 2006). Pinching produces a signal that induces dormant axillary buds to start growing (Morris et al., 2005). The remaining segments of the stem after being pinched would transition from the latent stage to the development stage. Auxin levels are expected to decrease after pinching, which allows the buds to progress into the prolonged growth stage.

Morris et al. (2005) conducted an experiment where pinched pea plants were either treated with IAA or not. At hour 4 in untreated plants the highest node (node 7) on the plant had a reduction in IAA when topped, but node 6 and node 2 did not have a significant decrease in IAA when pinched. Node 6 and 7 both still had bud growth 4 - 6 h after being pinched. Node 2 had bud growth after 6 h even though IAA concentrations did not change with pinching. In the plants not treated with IAA, the axillary bud growth was activated at all nodes 4 -6 h after pinching. Morris et al (2005) found that axillary bud growth was not caused by a decreased concentration of auxin in the stem when pinched. Buds can grow without the decrease in auxin or stay dormant when auxin levels are reduced. Morris et al. (2005) claims that the signal the plant creates after being pinched is separate from auxin. This hypothesis is because the auxin levels after pinching did not correlate with bud growth in this study. IAA treatments to pinched plants did not result in different outcomes from the untreated pinched plants in the first 24 h. By h 37 the pinched plants not treated with IAA had much longer lateral buds than plants treated with IAA. In pinched plants IAA concentrations were lower than unpinched plant. IAA concentrations were lowest in the upper most nodes in the pinched plants. Morris et al. (2005) hypothesizes that there are two stages after pinching that cause bud growth; one is a novel signal sent to the axillary buds that is important to the beginning stages of growth after pinching. The second stage is a reduction of auxin concentration in the plant which sets up the axillary buds for prolonged growth (Morris et al., 2005).

Environmental factors, bud location, and bud stage all play a role in how the plant reacts to pinching and how effective its branching will be (Dun et al., 2006). Photoperiod also affects branching. Longer days decreased branching in both pinched and intact peas and *Arabidopsis*. Shorter days allowed for more branching than longer days (Dun et al., 2006). Dun et al. (2006) concluded that there is no true evidence that changing levels and movement of hormones throughout the plant aid in the process of moving the bud from the latent stage to the development stage. However, evidence has proven that auxin, cytokinin, and a novel shoot multiplication signal do play a role in the process of a bud in the development stage transition to the prolonged growth stage.

Strigolactones

Prior research and knowledge assumed that auxin was the main factor in branching control (Stirnberg et al., 2010). It was shown that auxin does not move laterally into the axillary buds (Stirnberg et al., 2010). Since auxin does not move laterally some think cytokinin helps in branching (Stirnberg et al., 2010). As expected when pea plants were pinched, cytokinin synthesis increased in the roots and in the shoots. The strigolactone family consists of a plant apocarotenoid compound that are present small amounts. Based on the research of Stirnberg et al. (2010), the following conclusions were drawn about auxin and strigolactones. Auxin can inhibit bud growth in three ways, canalization of auxin from the axillary bud is stopped, auxin controls synthesis of cytokinin, or it allows for strigolactone synthesis (Stirnberg et al., 2010). Strigolactones could possibly avert auxin canalization to the axillary buds (Stirnberg et al., 2010). Stirnberg et al. (2010), concluded for the plant to remain in homeostasis, balanced levels of auxin and strigolactones are necessary.

Shoot multiplication signals (SMS) travel from the roots to the apical meristem (Gomez-Roldan et al., 2008). Strigolactones originate from carotenoids and are believed to be the signal that stimulates seed germination in parasitic plants and are found in excretions of roots in plants such as most dicotyledons (Gomez-Roldan et al., 2008). Strigolactones serve three purposes in plants: signals parasitic plant seeds to germinate, aids in symbiosis with plants and arbuscular mycorrhizal fungi, and it inhibits branching. Gomez-Roldan et al. (2008) observed when strigolactone was provided to the stem between nodes and applied exogenously to the buds to the pea mutant *P. satium* ccd8 branching did not occur. These observations support the hypothesis that strigolactones or a hormone derived from strigolactones are the SMS hormone. This research also supports the theory that SMS travels laterally within the plant and at a great distance within the plant (Gomez-Roldan et al., 2008).

Umehara et al. (2008), refers to strigolactones as terpenoid lactones. Over 80% of plants have a symbiotic relationship with arbuscular mycorrhizal fungi, which aids in nutrient uptake in plants. Some plants that do not have a symbiotic relationship with the arbuscular mycorrhizal fungi still produce strigolactones including *Arabidopsis* (Umehara et al., 2008). Studies of mutants deficient in strigolactones demonstrated that hormones ccd8 and ccd7 are necessary for rice seedlings to produce standard levels of strigolactone (Umehara et al., 2008). Scientists are still unsure how strigolactones are synthesized (Umehara et al., 2008). A section of the strigolactone chemical structure originates from enzymatic cleavage of carotenoids present in many species of plants (Umehara et al., 2008). The research of Umehara et al. (2008) was conducted hydroponically and a synthetic strigolactone analogue (GR24) was added to the media as the treatment. Axillary bud growth in 2 week old mutant rice seedlings d10-1 and d1701 was inhibited. Branching decreased with doses as small as 10 nM GR24 and almost no branching was observed with doses of 1 μM GR24 (Umehara et al., 2008). The rice mutant d3-1 was bred with the absence of strigolactone signaling (Umehara et al., 2008). The d3-1 mutant did not respond to GR24 (Umehara et al., 2008). This discovery signifies that a signal pathway is necessary for strigolactones to prevent the axillary bud from branching. Since the d3-1 mutant did not respond to GR24 like d10-1 and d17-1; Umehara et al. (2008), concluded that strigolactones do restrict branching through a signaling pathway in rice.

Cut flower production

Spacing

Sunflower plant spacing is important in development of the plant. Sunflower seeds are normally directly sown into the field. The sunflower seeds can be sown 15 cm apart but are typically sown 23 − 30 cm apart, but planting the seeds 15 cm apart may affect air flow which could lead to a higher chance of diseases (Armitage and Laushman, 2003).

Growth strategies for *Solidago* goldenrod in four different ecological settings were studied by Abrahamson and Gadgril (1973). They observed that completion for light affected the distribution of biomass in vegetative tissue. Goldenrods in an environment with taller plants tended to produce more leaf growth, while goldenrods competing for light with plants at a similar height allocated more biomass to stem growth. Gaines et al. (1974) observed in a study of *Helianthus* that production of a longer stem is a response to shading by plants of equivalent height. Sunflowers are grown in high density plantings in the natural environment and in production fields. In cut flower production, sunflower seeds can be sown up to 15 cm apart, which could lead to shade being an issue (Armitage and Laushman, 2003). Sunflowers generally allot more energy toward stem growth due to the high plant density (Gaines et al., 1974). Producing a longer stem than the neighboring plants allows the plant to have leaves above the competing plants, aiding in its competitiveness.

Pinching

Pinching is the act of removing the apical meristem from a sunflower seedling (Wien, 2015). Wien found by removing the apical meristem it induces lower branch production increasing stem yield. Armitage and Laushman (2003) suggest pinching when 4 − 6 pairs of leaves are present if side shoots with uniformly smaller flowers and shorter stems are desired. Wien (2015) found difficulty in pinching at the early stages of growth given that the nodes were compact.

Various sources agree that branching cultivars of sunflowers are generally better suited to be pinched than the non-branching type (Armitage and Laushman, 2003; Emino and Hamilton, 2004). Emino and Hamilton (2004) found that the greatest stem length was produced using the earliest pinching at about 3 − 4 sets of true leaves. For Emino and Hamilton (2004) pinching at 3 – 4 sets of true leaves yielded straight uniform stems about 91 cm long. Wien (2016a) urges growers who utilize the pinching method to pinch as early as possible. Pinching when the flower buds have already developed results in the stems being too short or the development of no stems at all (Wien, 2016a). When the sunflower is pinched there is roughly a week delay until flowering (Wien, 2015). This delay was not correlated to when the pinching occurred.

Cornell Trials

In 2006, Wien studied ‘Sunrich Orange’ and ‘Pro Cut Orange’ and pinched the plants at the 4th and 6th node, and observed a delay in flowering and stem length and disk diameter were half the size of the control plants. ‘Pro Cut Orange’ produced a larger amount of branches, flowered sooner, had shorter stems, and had smaller flowers compared to ‘Sunrich Orange’ (Wien, 2006). Both cultivars produced marketable sized flowers when pinched (Wien, 2006).

In 2007 a study on pinching and spacing was conducted using sunflowers ‘Pro Cut Orange’ and ‘Sunrich Orange’ (Wien, 2007). The treatments were 23 × 23 cm and 30 × 30 cm spacing with either no pinch or pinching at the 4th nodes and found that stem yield increased with pinching from 1 to 3.6 stems for each plant, flowering was delayed, flower size decreased, and stem length decreased by half when pinched. Branching and flower diameter increased with the wider spacing of 30 × 30 cm. The 30 cm spacing had larger flowers than the 23 cm spacing with a gain of 0.8 cm in flower diameter.

In 2012, Wien studied how different spacing and pinching treatments affected sunflower stem production. Wien (2012a) researched how planting at 15 × 15, 23 × 23, 30 × 30 cm spacing and either no pinch or pinching at the third node would affect the sunflower stem and flower diameter. A single stem sunflower ‘Pro Cut Amber Glow’ that was used in this study (Wien, 2012a). ‘Pro Cut Amber Glow’ produced the most stems per plant when planted in 23 × 23 cm spacing and pinched. The disk diameter for ‘Pro Cut Amber Glow’ decreased in the pinched and 23 × 23 spacing treatment. The disk diameter decreased from 6.9 cm to 4.6 cm but remained in the marketable disk diameter range of greater than 3.8 cm. The 15 × 15 cm spacing and pinched treatment increased stem yield from 4,000 stems to 10,971 stems but decreased disk diameter below the marketable size.

Wien duplicated an experiment in 2013 and 2015, using four cultivars and pinching at the 3rd or 5th node. Wien (2013, 2015) used three non-branching cultivars: ‘Pro Cut Lemon’, Pro Cut Gold’, Sunrich Orange’, and one branching cultivar ‘Goldrush’. In both experiments, there was a delay in flowering and that stem length, and flower diameter decreased. Wien (2013, 2015) observed that pinching at the 5th node for the single stem cultivars was disadvantageous for stem yield and the size of flowers produced.

Pros of pinching

The pinching method, if used correctly, can be very beneficial when it comes to producing sunflowers. A smaller uniform sunflower head with a marketable stem is the result of successful pinching (Armitage and Laushman, 2003). Smaller head sizes of sunflowers will allow florists to use them in a variety of arrangements and bouquets rather than being used only in single species arrangements, increasing the uses of sunflower for florists. After years of research, Wien found that pinching sunflowers at the correct time can boost yields 3 − 4 times greater than those of plants that were not pinched. Growers interested in pinching sunflowers to increase profits should use single stem or branched cultivars since they react positively to pinching (Wien, 2016a). Wien (2016a) also strongly suggests pinching as early as possible so that the sunflower can develop into a marketable product.

Cons of pinching

There are some disadvantages to pinching, such as a way to mechanically pinch sunflowers has not been developed (Wien, 2016a). It is timely and costly to hand pinch fields of sunflowers, and big operations could lose money trying to pinch manually. Pinching causes a reduction in head size (Wien, 2016a), pinching paired with a narrow spacing can make the head size even smaller (Wien, 2016a). Smaller head sizes can be positive or negative depending on the market. Pinching overcrowded sunflowers may lead to deformed heads, weak stems, and flowers that are too small to be marketable (Wien, 2016a).

Sunflower market standards

There are no set sunflower market standards when it comes to stem length, disk diameter, or flower diameter. The Association of Floral Importers of Florida (AFIF) and Colombian Association of Flower Exports (Asocolflores) collaborated to create a cut flower standards book that included sunflowers. They suggested the minimum stem length to be no less than 55 cm (AFIF and Asocolflores, 2009). Sloan and Harkness (2010) interviewed florists in Mississippi stated and found 60 − 90 cm long stems were preferred. A stem diameter 0.5 − 1.5 cm was also desirable (Sloan and Harkness, 2010). The sunflower head is generally measured by disk diameter. Since there is no true standard, Wien (2012a; 2012b) decided for his trials disk diameters smaller than 3.81 cm were undesirable. Mississippi florists stated sunflower diameters of 8 − 15 cm are popular (Sloan and Harkness, 2010). AFIF and Asocolflores (2009) have a graded system that states 10 cm are ‘extra’, 8 − 10 cm are ‘select’, 5 − 8 cm are ‘fancy’ and below 5 cm are ‘petite’. Wien (2016b; 2017) discovered that the Boston wholesale flower market uses two sizes to describe their flower sizes. The small disk size is 4 − 6 cm, a medium disk size is 6 − 8 cm in diameter, and the large disk size is more than 8 cm in diameter (Wien, 2016b; 2017). The standards used in various places are all similar but the lack of set standards overall makes it challenging to determine if a flower stem is marketable or not. The minimum standards used for the following three experiments were a stem length of 60 cm, flower diameter of 8 cm, and a disk diameter of 3.81 cm (Sloan and Harkness, 2010; Wien, 2012a).

Economics of cut sunflowers

After years of experiments with pinching and spacing of sunflowers, Wien (2016a) observed overall that as the sunflower head size increased, the worth of the flower head per unit area decreased (Wien, 2016a). For that reason, Wien (2016a) concluded that pinching did increase the yield of small sunflower heads and increased the grower' profits.

Wholesale sunflower costs vary depending on where they are grown and their size. Per stem the large head sunflower cultivars with disk diameters larger 8 cm and long stems cost anywhere from $1.40 − $1.75 (USDA, 2016). A medium sized flower head with a disk diameter of 6 − 8 cm and a medium stem is priced from $1.00 − $1.25 (USDA, 2016). Single stems with miniature heads and disk diameters of 4-6 cm are priced from $0.85 − $1.00 (USDA, 2016). Large head sunflower cultivars in bunches of five with long stems are priced from $5.00 − $6.50 (USDA, 2016). When large head sunflower cultivars are in a bunch of 10 stems, flowers with extra-long stems cost $16.00 a bunch and flowers with long stems cost $12.00 (USDA, 2016). Miniature sunflower cultivars are priced at $7.50 when in bunches of 10 with long stems (USDA, 2016).

EXPERIMENT 1: Trials 1A and 1B: Pinching Treatments at Nodes 1, 2, 3, and 4 Conducted on 'Pro Cut Gold' Sunflowers (*Helianthus annuus*)

Introduction

Pinching is the act of removing the apical meristem from the top of a plant to encourage development of side shoots. Removing the apical meristem from a sunflower seedling forces lower branching that would not normally occur if the apical meristem remained intact (Wien, 2015). Which hormones control branching is a debated topic. Auxin, cytokinin and strigolactones are all thought to contribute to apical dominance and the release of apical dominance. Scientists are unsure of how auxin, cytokinin and strigolactones interact and move throughout the plant to control apical dominance (Leyser, 2009; Morris et al., 2005; Sachs and Thimann, 1967; Stirnberg et al., 2010; Weberling, 1992).

Branching produces more sunflowers per plant, and is advantageous to growers who want to produce more sunflowers per square meter. When the plant allocates the carbohydrates for one large flower into multiple flowers, the flower size decreases (Wien, 2016a). There is an overall decrease in size of flower and stem length due to the reallocation of limited carbohydrates. Sunflower cultivars react differently to pinching. Thus far, no guidelines for pinching to provide the highest economic return in the southeastern United States have been established.

Positive outcomes of pinching include the production of a crop of smaller uniform heads with marketable stem lengths when pinched early (Armitage and Laushman, 2003). The minimum market standards used for the following experiment were a stem length of 60 cm, flower diameter of 8 cm, and a disk diameter of 3.81 cm (Sloan and Harkness, 2010; Wien, 2012a). Yields can increase up to four times with pinching, increasing economic profit for the grower (Wien, 2016a). A disadvantage of pinching is that it increases labor since the technology to mechanically pinch sunflowers has not been developed. When the plants are overcrowded, pinching can lead to deformities in the sunflower heads, causing them to be unmarketable (Wien, 2016a). Depending on the growers market, a decrease in flower head size could be a positive or a negative (Wein, 2016a). Even with some negatives, Wien (2016a) found that in zone 5a pinching can be beneficial when producing sunflowers as the positive factors outweigh the negative factors. The objective of these two trials is to assess the efficiency of pinching the sunflower cultivar 'Pro Cut Gold' at different nodes in East Texas (Zone 8b).

Material and Methods

This experiment was conducted in raised beds at SFASU. *Helianthus annuus* 'Pro Cut Gold' sunflower seeds were directly sown into 3.7 × 1.2 × 0.61 m raised beds. The seeds were sown in five rows of 23 × 23 cm spacing on 7 June 2016 (Trial 1A) and 19 July 2016 (Trial 1B). Soil in the raised beds was a top soil mixed with mushroom compost. The soil pH was 7.98 which is in the range of 5.7 to above 8.0 that sunflowers are generally grown in (Putnam et al., 1990). Nitrate-N was the only

Table 1.1. Nutrient levels present in raised beds and their sufficiency ranges.

Nutrients	Raised bed (ppm)	Sufficiency range (ppm)
NO_3	23.31	100-199[z]
P	196.36	21-60[y]
K	324.38	120-300
Ca	4474.60	460-749
Mg	170.99	100-150
S	53.25	16-25
B	0.38	N/A
Fe	30.99	2.5-4.5
Mn	4.06	1-1.5
Zn	4.79	0.3-0.8
Cu	2.53	0.1-0.3

[z]Sufficiency range of a saturated media from Greenhouse Operation and Management (2013).

[y]Sufficiency ranges of soil from Stephen F. Austin State University Soils Lab.

nutrient that was not at or above the sufficiency range before fertilizer was applied (Table 1.1). The plots were fertilized on 10 June and 22 July with Lone Star Super Lawn and Turf Builder, 15N-2.2P-8.3K, at a rate of 51.6 g per 1 m^2 (Texas Farm Products Co, Nacogdoches, Texas). Additional nutrients include S (13.4%), B (0.02%), Cu (0.05%), Fe (1.0%), Mn (0.05%), Mo (0.0005%) and Zn (0.05%). The plants were watered via drip irrigation every other day for the duration of the trials. The sunflowers were pinched on the same day at either the 1st, 2nd, 3rd, or 4th node of the stem. Control plants were not pinched. Each trial had 100 plants total and each treatment contained 20 plants each.

The experimental design was a randomized block design and contained four replications for both trials. The data was analyzed using SAS 9.2 (Cary, NC) via a Two-Way ANOVA. Tukey's Studentized Range Test was run to determine significant differences between means at a 5% probability level. Sunflowers were harvested when heads were fully developed and open. The measurements taken per stem harvested were: stem length measured from the soil line to the base of the head for control plants or from where the stem was cut from the main stem to the base of the head for pinched plants, stem diameter (5.1 cm below base of the head), flower diameter, disk diameter, and the harvest date were recorded.

Results

Trial 1A: Pinching Treatments at Nodes 1, 2, 3, and 4 Conducted on 'Pro Cut Gold' Sunflowers (*Helianthus annuus*)

Stem length was significantly affected by pinching, but location of the pinching (node number) was not statistically significant (Table 1.2). The marketable length for a cut sunflower stem is 60 cm (Sloan and Harkness, 2010). The length of non-pinched stems was double the marketable range. Although pinching at nodes 3 and 4 were not statistically different from nodes 1 and 2, pinching at nodes 1 and 2 produced marketable

Table 1.2. Effects of pinching on sunflowers 'Pro Cut Gold' stem length, stem diameter, flower diameter, disk diameter, days to harvest and stems per plant trial 1A.

Pinch location	Stem length (cm)	Stem diameter (mm)	Flower diameter (cm)	Disk diameter (cm)	Days to harvest (d)	Stems/ plant (no.)
0	122.81 a[z]	14.21 a[z]	15.36 a[z]	8.43 a[z]	45.60 c[z]	1.00 a[z]
1	61.21 b	6.00 bc	8.90 b	3.96 b	48.76 b	4.15 b
2	62.62 b	7.32 bc	9.47 b	4.56 b	49.55 ab	3.56 b
3	58.61 b	5.93 bc	8.73 b	3.85 b	50.10 ab	4.33 b
4	57.98 b	5.34 c	8.70 b	3.76 b	50.59 a	3.85 b
P-value	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

[z] Means within column followed by the same letter are not significantly different at the 5% probability level by Tukey's Studentized Range Test.

lengths while pinching nodes 3 and 4 did not. Non-pinched plants had a statistically larger stem diameter than pinched plants. All of the plants that were pinched had significantly lower flower diameters as compared to the non-pinched treatment. A marketable flower diameter is 8 cm or larger (Sloan and Harkness, 2010). Although flower diameter decreased with pinching, all of the treatments had flower diameters greater than the marketable minimum. Similarly to flower diameter, disk diameters for all pinched treatments were statistically the same. Disk diameter for non-pinched plants was significantly larger than pinching treatments. A marketable disk diameter is 3.81 cm (Wien, 2012a; 2012b). Except for pinching at node 4, all other treatments met the disk diameter requirement. Pinching significantly increased days to harvest. Days to harvest followed a trend with pinched plants required significantly longer days to harvest compared to the non-pinched plants; increasing the number of days to harvest increased with the node pinched (1 – 4). Pinching significantly increased stems per plant for all pinched treatments compared to the non-pinched plants (Table 1.2).

Trial 1B: Pinching Treatments at Nodes 1, 2, 3, and 4 Conducted on 'Pro Cut Gold' Sunflowers (*Helianthus annuus*)

The non-pinched treatment stem length was significantly longer than the pinching treatments; more than 2.5 times greater than the pinching treatments. Stem length for all pinching treatments was below the marketable minimum. Stem diameter was significantly larger in the non-pinched treatment (Table 1.3). Non-pinched plants had

Table 1.3. Effects of pinching on sunflowers 'Pro Cut Gold' stem length, stem diameter, flower diameter, disk diameter, days to harvest and stems per plant trial 1B.

Pinch location	Stem length (cm)	Stem diameter (mm)	Flower diameter (cm)	Disk diameter (cm)	Days to harvest (d)	Stems/ plant (no.)
0	132.84 a[z]	14.21 a[z]	15.33 a[z]	9.20 a[z]	46.40 b[z]	1.00 a[z]
1	45.68 b	5.14 b	7.23 b	4.39 b	56.61 a	3.15 b
2	45.29 b	5.59 b	7.58 b	3.99 b	56.03 a	3.60 b
3	40.76 b	5.66 b	7.12 b	3.70 b	57.05 a	3.20 b
4	48.80 b	6.04 b	7.85 b	3.77 b	56.66 a	2.90 b
P-value	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

[z] Means within column followed by the same letter are not significantly different at the 5% probability level by Tukey's Studentized Range Test.

a significantly greater flower diameter that was double the pinched treatments (Table 1.3). All pinching treatments failed to produce a marketable flower diameter for this trial. Non-pinched plants had significantly larger disk diameters than pinched plants. Disk diameter decreased significantly when pinching occurred (Table 1.3). Pinching at nodes 1 and 2 led to marketable disk diameters while pinching at nodes 3 and 4 did not, although the treatment were not significantly different. Pinching treatments significantly increased days to harvest compared to the non-pinched treatment (≥10 d). Similar to days to harvest, pinching treatments significantly increased stems per plant.

Discussion

There are two main factors that determine marketability of sunflowers; 1) stem length, and 2) flower/disk diameter. For non-pinched treatments, stem length and flower size reached marketable values for both trials 1A and 1B. Trial 1A produced adequate stem lengths when pinched at nodes 1 and 2 while trial 1B did not produce adequate stem lengths at any pinched node. In trial 1A stem length was on average 10 cm longer than trial 1B for pinched treatments (Tables 1.2 and 1.3). Trial 1A produced marketable flower diameters for all pinching treatments while trial 1B, did not produce any marketable flower diameters. Trial 1A had disk diameters above the standard of 3.81 cm for pinching at nodes 1, 2, and 3. Trial 1B had marketable disk diameters at node 1 and 2. The only marketable stem produced were pinched at nodes 1 and 2 for trial 1A. As expected, stem diameter and flower diameter were also decreased for pinched plants. It is well documented that a larger number of flowers leads to decreased overall growth per flower stem (Wardlaw, 1990). Stem diameter was larger in trial 1A compared to 1B; this observation could be a result of overall longer stem lengths in trial 1A compared to trial 1B. Wien (2013; 2015) trialed ‘Pro Cut Gold’ sunflower and also found a decrease in stem length and disk diameter for pinched plants compared to non-pinched plants. However, all flowers from pinched plants produced marketable stem length and disk diameter. Trials 1A and 1B disk diameters varied by pinching location, similar to previous research (Wien, 2013).

Previous research has shown that temperature might play a role in sunflower growth and development that could be causing the differences between the results of Wien (2013) and trials 1A and 1B (Goyne and Schneiter, 1988; Haba et al., 2014; Lokhande et al., 2003).

Lokhande et al. (2003) observed that under higher temperatures *Arabidopsis thaliana* flowered faster compared to cooler temperatures which delayed flowering. The delayed flowering in cooler weather allowed the stems to elongate while the plants quicker to flower initiation had a shorter time frame for stem elongation and flower development. Goyne and Schneiter (1988) conducted a growth chamber experiment to see how photoperiod and temperature affected sunflower development. They found that increased day and night temperatures of 28°C and 22°C respectively, decreased days to flower initiation. Goyne and Schneiter (1988) noted that plants grew taller under higher temperatures and produced more leaves. The optimum temperature range for sunflower growth is 18 − 24°C (Armitage and Laushman, 2003). Growth declines significantly when the plants are started in the summer and grown into the fall when temperatures are decreasing (Armitage and Laushman, 2003). Average daily temperatures over 28°C may stress the plant, leading to less growth. Haba et al. (2014) conducted an experiment growing sunflowers in day/night temperatures at 33°C and 29°C, respectively. They found that high temperatures caused a reduction in photosynthesis, leading to decreased growth (Haba et al., 2014).

Trial 1A had average temperatures of 27°C, 29°C, and 28°C in June, July, and August, respectively (US Climate Data, 2016). Trial 1B started with an average temperature of 29°C decreasing to 26°C in July and September, respectively (US Climate Data, 2016). In 2013 Ithaca, New York experienced average temperatures of 13°C, 22°C, and 18°C in May, July, and August, respectfully (Wien, 2013). In 2015 the average temperatures for Ithaca, New York was 16°C in May and increased to 18°C in August, respectively (Wien, 2015). The largest temperature difference between Ithaca, New York and Nacogdoches, Texas was 10°C in August. The smallest temperature difference of 5.5°C occurred in May.

Trials 1A and 1B temperatures lead to faster flowering like Lohandle et al., (2003) observed in their experiment. A possible reason that the results of trials 1A and 1B did not support Goyne and Schneiters (1988) findings is that the trials were conducted at 29°C average temperatures, which is higher than Goyne and Schneiters' high temperature. Wein grew 'Pro Cut Gold' in cooler temperatures compared to trials 1A and 1B which allowed the plants to develop slower producing marketable stem lengths, and disk and flower diameters. The high average temperatures in trials 1A and 1B, may have stressed the plant which reduced stem length and flower size similar to the findings of Haba et al. (2014).

Days to harvest significantly increased with the pinching treatments for trials 1A and 1B, similar to Wien (2012a). Days to harvest for the non-pinched treatments in trials 1A and

1B only differed by of one day. The average days to harvest for trial 1B was 6 days longer than trial 1A for pinched plants. Trial 1A had an increase of 3 − 5 d between the non-pinched and pinched treatments. Trial 1B had a 10 − 11 d increase for days to harvest between the non-pinched and pinched treatments. Wien also saw an increase in days to harvest the higher the pinch occurred (Wien, 2013).

Non-pinched plants in trials 1A and 1B produced one stem per plant. Trial 1A 'Pro Cut Gold' produced 3 − 4 stems per plant for pinched plants (Table 1.2). During trial 1B 'Pro Cut Gold' produced about 2 − 3 stems per plant for pinched plants (Table 1.3). Similarly to trials 1A and 1B, Wien found that stems per plant did not follow a positive trend coinciding with nodes pinched (Wien, 2013). Wien (2013; 2015) observed an increase from 1 stem per plant to 2 − 3 stems per plant with pinching. Trial 1A produced more stems per plant than the trials Wien conducted, which could have led to the smaller flowers and shorter stems observed in trial 1A. Plants had a higher number of stems to allocate carbohydrates, which led to smaller flowers and shorter stems overall (Wardlaw, 1990).

Conclusion

The non-pinched plants produced marketable stem lengths and flower sizes. Pinching led to a decrease in stem length, stem diameter, flower diameter, and disk diameter. Generally, pinching treatments produced unmarketable stem length and flower size. Flower diameter decreased with a pinching treatment but remained above the marketable range for trial 1A, when temperature averages were lower than in trial 1B. Pinching decreased disk diameters but marketability varied by node pinched. Stems per plant increased when the plant was pinched. Although pinching did increase the amount of stems produced per plant, the overall stem length and flower size did not reach a marketable size. High temperatures in East Texas during the summer sped up the stages of plant growth. This did not allow pinched plants time to develop sunflowers with adequate stem length and disk diameter. The fact that trial 1A producing marketable stems for pinched nodes 1 and 2 while trial 1B did not produce any marketable stems when pinched; perhaps due to the timing of the plantings. Planting earlier in the spring could lead to increased marketability of the pinched plants. Considering the variability in the pinched plants stem length and flower size for trials 1A and 1B, pinching in East Texas does not appear to be a viable option for sunflower production for ‘Pro Cut Gold’ in the summer.

EXPERIMENT 2: Trials 2A and 2B: Pinching and Spacing Effects on Sunflower (*Helianthus annuus*) 'Pro Cut Gold' Growth and Development

Introduction

Pinching the removal of the apical meristem of a plant. When pinching occurs it forces the lower axillary buds to branch out producing multiple branches instead of one single stem. Which hormones control branching once the apical meristem is removed is still under debate. The three hormones that are thought to contribute to branching are auxin, cytokinin, and strigolactones (Leyser, 2009; Morris et al., 2005; Sachs and Thimann, 1967; Stirnberg et al., 2010; Weberling, 1992).

Guidelines for pinching to consistently provide the highest yield have not been created, because sunflower cultivars react differently to pinching. Growers generally pinch when the plant has 4 − 6 leaves but this has not been consistently supported by research (Armitage and Laushman, 2003). Pinching in sunflower production increases yield while maintaining the same bed space. Pinching decreases stem length and flower size and increases labor costs (Wien, 2016a; 2012b). The benefits of pinching are producing a smaller uniform crop and increasing yields up to four times (Wien, 2016a; 2012b). The minimum market standards used for the following experiment were a stem length of 60 cm, flower diameter of 8 cm, and a disk diameter of 3.81 cm (Sloan and Harkness, 2010; Wien, 2012a). Wien (2016a; 2012b) recommends pinching to increase the grower's profit.

Plant spacing is an important factor when producing sunflowers. Growers strive to pick a spacing that will optimize their bed space while producing marketable sized flowers and stems. Generally sunflower seeds are directly sown into the beds in 23 × 23 cm or 30 × 30 cm spacings (Armitage and Laushman, 2003). Sowing the seeds in denser spacings could limit, airflow leading to diseases and could lead to the production of smaller flowers heads (Armitage and Laushman, 2003). Planting densities less than 15 × 15 cm also leads to high amounts of shading. Gaines et al. (1974) observed in a study of *Helianthus* that producing a longer stem is a response to shading by plants of equivalent height. This could be beneficial to growers who want to plant at higher densities and pinch the plants. Pinching and spacing used together could yield a superior crop while maximizing bed space allowing the grower to make a greater profit. The objective of this experiment is to compare quality and productivity of three spacing treatments and a pinching treatment on ‘Pro Cut Gold’ sunflowers, a non-branching cultivar.

Material and Methods

This experiment was conducted in raised beds at SFASU. The sunflower seeds were directly sown into 3.7 × 1.2 × 0.61 m raised beds on 11 May 2016 and 26 June 2016 for trials 2A and 2B, respectively. Sunflower seeds *Helianthus annuus* 'Pro Cut Gold' were sowed in spacing treatments of 15 × 15 cm, 23 × 23 cm, and 30 × 30 cm creating four rows of 7, 5, and 4 plants, respectively. On 8 June 2016 (Trial 2A) and 14 July 2016 (Trial 2B) the plants were pinched with small clippers. The pinching

Table 2.1. Nutrient levels present in raised beds and their sufficiency ranges.

Nutrients	Raised bed (ppm)	Sufficiency range (ppm)
NO_3	23.31	100-199^{z}
P	196.36	21-60^{y}
K	324.38	120-300
Ca	4474.60	460-749
Mg	170.99	100-150
S	53.25	16-25
B	0.38	N/A
Fe	30.99	2.5-4.5
Mn	4.06	1-1.5
Zn	4.79	0.3-0.8
Cu	2.53	0.1-0.3

^{z}Sufficiency range of a saturated media from Greenhouse Operation and Management (2013).

^{y}Sufficiency ranges of soil from Stephen F. Austin State University Soils Lab.

treatments were a manual pinch above the third node and the control was not pinched. Each trial had had a total of 512 plants: 15 × 15 cm spacing had 224 plants, 23 × 23 cm spacing had 160 plants and 30 ×30 cm spacing had 128 plants. Soil in the raised beds was a top soil mixed with mushroom compost. The soil pH was 7.98 which is in the range of 5.7 to above 8.0 that sunflowers are generally grown in (Putnam et al., 1990). Nitrate-N was the only nutrient that was not at or above the sufficiency range before fertilizer was applied (Table 2.1). The plots were fertilized on 10 June (Trial 2A) and 22 July (Trial 2B) with Lone Star Super Lawn and Turf Builder of 15N-2.2P-8.3K at a rate of 51.6 g per 1 m^2 (Texas Farm Products Co, Nacogdoches, Texas). Additional nutrients include S (13.4%), B (0.02%), Cu (0.05%), Fe (1.0%), Mn (0.05%), Mo (0.0005%) and Zn (0.05%). The plants were watered via drip irrigation every other day for the duration of the experiment.

Trials 2A and 2B were randomized split plot designs, with pinching as the main plot and spacing as sub-plots. The experiment was repeated twice and each trial (2A and 2B) had four replications. The data was analyzed by SAS 9.2 (Cary, NC) via a Two-Way ANOVA. Tukey's Studentized Range Test was used to find significant differences between means at a 5% probability level. Sunflowers were harvested when heads were fully developed and open. The measurements taken per stem harvested were: stem length measured from the soil line to the base of the head for control plants or from where the stem was cut from the main stem to the base of the head for pinched plants, stem diameter (5.1 cm below base of the head), flower diameter, disk diameter, and the harvest date were recorded.

Results

Trial 2A: Pinching and Spacing Effects on Sunflower (*Helianthus annuus*) 'Pro Cut Gold' Growth and Development

Stem length of pinched plants was significantly shorter than the non-pinched plants; however, all treatments had marketable stem lengths of 60 cm or greater (Table 2.2; Sloan and Harkness, 2010). For stem diameter, there was a significant interaction between spacing and pinching (Table 2.2). Stem diameter for non-pinched plants was

Table 2.2. Effects of pinching and spacing on sunflowers 'Pro Cut Gold' stem length, stem diameter, flower diameter, days to harvest and stems per plant Trial 2A.

Treatments		Stem length (cm)	Stem diameter (mm)	Flower diameter (cm)	Days to harvest (d)	Stems/ plant (no.)
Pinching	Spacing (cm)					
none	15x15	165.42 a[z]	9.12 b[z]	14.84 a[z]	46.21 a[z]	1.00 a[z]
none	23x23	161.74 a	10.73 a	15.99 a	49.81 a	1.00 a
none	30x30	185.73 a	11.25 a	16.16 a	49.84 a	1.00 a
pinched	15x15	65.90 b	6.75 c	10.64 c	61.37 b	1.84 b
pinched	23x23	68.62 b	6.91 c	11.03 b	59.18 b	2.35 bc
pinched	30x30	65.14 b	7.68 c	11.42 b	58.24 b	2.48 c
Statistical signif.	Pinching	<.0001	<.0001	<.0001	<.0001	<.0001
	Spacing	0.5910	0.0011	0.0369	0.8638	0.0024
	Interaction	0.1351	0.0136	0.2824	0.0885	0.0031

[z] Means within column followed by the same letter are not significantly different at the 5% probability level by Tukey's Studentized Range Test.

significantly larger than the pinched plants. Stem diameter increased as the spacing increased for both non-pinched and pinched plants (Table 2.2). Flower diameter was significantly larger in the non-pinched plants compared to the pinched plants. Flower diameters were significantly affected by spacing and pinching treatments (Table 2.2). Flower diameters for both non-pinched and pinched plants followed a trend of increasing flower diameter as spacing increased (Table 2.2). Non-pinched plants had a significantly greater flower diameter (Table 2.2). A marketable flower diameter is 8 cm or larger (Sloan and Harkness, 2010). Although pinched flower diameter was significantly different from non-pinched plants, all pinching treatments were above the market minimum. Non-pinched plants had significantly shorter days to harvest compared to pinched plants. Days to harvest significantly increased with the pinching treatment. An interaction between spacing and pinching occurred for stems per plant with the pinching treatments significantly increasing the number of stems per plant; stems per pinched plant increased with larger spacings.

Trial 2B: Pinching and Spacing Effects on Sunflower (*Helianthus annuus*) 'Pro Cut Gold' Growth and Development

Stem length significantly decreased with pinching (Table 2.3). Pinching treatments had stem lengths below the market minimum. Similar to trial 2A, stem diameter had a statistically significant interaction with pinching and spacing (Table 2.3).

Table 2.3. Effects of pinching and spacing on sunflowers 'Pro Cut Gold' stem length, stem diameter, flower diameter, days to harvest and stems per plant Trial 2B.

Treatments		Stem length (cm)	Stem diameter (mm)	Flower diameter (cm)	Days to harvest (d)	Stems/ plant (no.)
Pinching	Spacing (cm)					
none	15x15	128.16 a[z]	8.41 b[z]	12.09 b[z]	45.02 a[z]	1.00 a[z]
none	23x23	126.96 a	10.61 a	13.24 a	43.97 a	1.00 a
none	30x30	124.21 a	11.51 a	14.19 a	44.60 a	1.00 a
pinched	15x15	51.84 b	5.17 d	7.87 c	53.97 b	2.76 b
pinched	23x23	50.03 b	5.54 d	7.84 c	53.19 bc	3.13 bc
pinched	30x30	54.17 b	7.03 c	8.51 c	51.87 c	3.47 c
Statistical signif.	Pinching	<.0001	<.0001	<.0001	<.0001	<.0001
	Spacing	0.1663	<.0001	<.0001	<.0001	0.0003
	Interaction	0.3971	0.0019	0.0030	0.0396	0.3144

[z] Means within column followed by the same letter are not significantly different at the 5% probability level by Tukey's Studentized Range Test.

As the spacing increased, the stem diameter increased for both non-pinched and pinched treatments. The diameter of the stem significantly decreased with pinching. Flower diameter had a significant interaction with pinching and spacing (Table 2.3). Flower diameter significantly decreased when the plants were pinched. All the non-pinched treatments and 30 × 30 cm pinching treatment were above the market standard. Flower diameter was statistically different between spacing treatments that were not pinched. The flower diameter for non-pinched plants was significantly smaller for the 15 × 15 cm spacing as compared to 23 × 23 cm and 30 × 30 cm spacings. However, when the plants were pinched, the flower diameter was not affected by the spacing treatment. There was a significant interaction between pinching and spacing and days to harvest, days to harvest of pinched plants was reduced as spacing increased (Table 2.3). Days to harvest significantly increased with the pinching treatment. The smaller spacing treatment caused longer days to harvest. Pinching significantly increased stems per plant as compared to non-pinched plants. There was a significantly increased number stems per pinched plant as the spacing treatment increased (Table 2.3).

Discussion

Stem length, pinched vs. not pinched, were significantly different while spacing had no significant effect on stem length (Tables 2.2 and 2.3). Stem length decreased significantly when pinched (Tables 2.2 and 2.3). In trial 2A all three pinching and spacing treatments produced marketable stem lengths and flower diameters while pinching with 15 × 15 cm and 23 × 23 cm spacing treatments for trial 2B did not produce marketable stem lengths. Stem diameter and flower diameter decreased with the pinching treatments in both trials. Days to harvest increased with pinching for both trials 2A and 2B. Stems per plant increased in the trials (2A and 2B) when pinching occurred.

Non-pinched plants produced marketable stem lengths and flower diameters for all spacing treatments. A decrease in stem length after pinching has been observed in other studies (Wien, 2012b). There was a 10 cm decrease in stem length between trials 2A and 2B. Trial 2A produced marketable stem lengths when pinched, while trial 2B did not. When pinched, ‘Pro Cut Amber Glow’ in the Wiens trial 2012 produced stem lengths that were 18 cm and 32 cm longer than ‘Pro Cut Gold’ in trials 2A and 2B, respectively. Stem diameter for trials 2A and 2B were similar with trial 2B being just slightly smaller than trial 2A. This observation could be a result of trial 2A having a longer development time, therefore produced thicker stems. All spacings and pinching and non-pinching treatments had flower diameters above the marketable standard in trial 2A. Trial 2B had significantly smaller flower diameters for all three spacing treatments whether pinched or not compared to trial 2A and only produced a marketable flower diameter for the non-pinched treatments and the 30 × 30 cm spacing with a pinching treatment. Overall in both trials 2A and 2B, spacing treatments did not influence the sunflower growth and development. Data on flower diameters for trials 2A and 2B was collected by measuring as the disk and the rays. Wien (2012a; 2012b) measured only the disk; therefore, the two measurements cannot be directly compared. Pinching and spacing treatments 23 × 23 cm and 30 × 30 cm produced marketable disk diameters of 3.81 cm or greater for Wien (2012b). Wien observed unmarketable disk diameters for the 15 × 15 cm spacing with a pinching treatment. Differences in temperature could be the reason for the differences in results of trials 2A and 2B. Previous studies have shown that temperature could play a role in sunflower development (Goyne and Schneiter, 1988; Haba et al., 2014; Lohandle et al., 2003).

Lokhande et al. (2003) found that higher temperatures led to faster flowering in *Arabidopsis thaliana* with delayed flowering in cooler temperatures. Faster flower initiation does not allow the flower to develop at a normal pace leading to smaller flowers (Lokhande et al., 2003). Goyne and Schneiter (1988) carried out a growth chamber experiment to observe how temperature affected sunflower development. Their experimental day/night temperatures were 28/22°C and 18/15°C. Goyne and Schneiter (1988) observed that higher temperatures decreased the days to flower initiation and led to taller plants with more leaves. The optimum temperature range for sunflower growth is 18 − 24°C (Armitage and Laushman, 2003). Plant growth declines when planting occurs in the summer and the plants are grown into the fall with decreasing temperatures

(Armitage and Laushman, 2003). Haba et al. (2014) conducted an experiment growing sunflowers in day/night temperatures of 33/29°C, respectively. A reduction in photosynthesis led to decreased growth under the high temperature treatment (Haba et al., 2014). Average temperatures reached 29°C in trials 2A and 2B; this observation could have stressed the plants, reducing overall growth.

Trial 2A had average temperatures of 20°C, 27°C, and 29°C in May, June, and July, respectively (US Climate Data, 2016). Trial 2B had average daily temperatures of 27°C, 29°C, and 28°C in June, July, and August, respectively (US Climate Data, 2016). The starting temperature in Ithaca, New York where Wien held his 2012 trial was 15°C, increasing to 22°C in May and July, respectively (Wien, 2012b). In Ithaca and Nacogdoches the differences in temperature were 8°C, 7°C, and 8°C in June, July, and August, respectively.

In trial 2A, when the plants had cooler temperatures during the initial growth stages, stem lengths and flower size for control and pinched plants were above the marketable standard and the shortest control stem was 161 cm (Table 2.2). Trial 2B was 7°C warmer than trial 2A when the initial growth stages occurred and the longest non-pinched stem was 128 cm long, 33 cm shorter than trial 2A (Table 2.3). For pinched plants there was a difference of 11 cm between the shortest stem length in trial 2A and the longest in trial 2B. Wien (2012b) produced marketable stems with both non-pinched and pinched plants at the 3rd and 5th nodes, but under had cooler growing temperatures than trials 2A and

2B. Trial 2A had cooler growing days compared to trial 2B, which led to longer stems and larger flowers. Lower starting temperatures in the trial 2A could have contributed to its success. A difference in starting temperatures could be the cause of the different results observed in trial 2A and 2B.

Days to harvest increased when the pinching treatment was applied for trial 2A and 2B, consistent with other studies (Wien, 2013). Trial 2A had a difference of 11 d between pinching and non-pinching treatments. Trial 2B had an 8 d difference between the pinching and non-pinching treatments. Trial 2B had higher temperatures compared to trial 2A. Higher temperatures cause earlier flower initiation which leads to quicker days to harvest (Goyne and Schneiter, 1988; Lohandle et al., 2003). The increase in days to harvest was not large enough to be a negative factor of pinching. Growers need to consider the increasing days to harvest when scheduling sunflower production.

Non-pinched plants in trials 2A and 2B produced 1 stem per plant for all three spacing treatments. Trial 2A averaged 2.2 stems per plant for all three spacing treatments and 3.1 stems per plant in trial 2B (Wien, 2012b).

Trial 2A and Wien (2012b) had cooler starting temperatures than trial 2B. Trial 2A produced marketable stem lengths and flower diameters for all spacing and pinching treatments. Wien produced marketable stem lengths and flower diameters for spacings of 23 × 23 cm and 30 × 30 cm with a pinching treatment. The similar starting temperatures of trial 2A and Wiens 2012 trial could be a reason for the comparable results. Trial 2B had warmer starting temperatures than trial 2A and the trial Wien conducted. Results of trial 2B support conclusions from prior studies that high temperatures cause flower initiation sooner, which decreases stem length and flower size (Blacquiere et al., 2002).

Conclusion

Both pinched and non-pinched plants in all spacing treatments produced marketable stem lengths and flower diameters in trial 2A. Non-pinched plants produced 1 stem per plant for both trials 2A and 2B. However, pinched stems per plant increased for trial 2A, which led to a higher marketable yield compared to the non-pinched treatments. Trial 2B resulted in unmarketable stem lengths and smaller flower sizes that may be related to higher temperatures compared to trial 2A. Even though the amount of stems per plant increased in trial 2B the stems produced did not meet the market minimum. The spacing treatments for trials 2A and 2B did not have a large effect on sunflower growth and development. Pinching results might be dependent on time of planting. Pinching may be acceptable early in East Texas but is not recommended for mid-to-late summer based on the limited observations from trials 2A and 2B.

EXPERIMENT 3: Pinching Treatments at Nodes 1, 2, 3, and 4 Conducted on Various Sunflower Cultivars (*Helianthus annuus*)

Introduction

Pinching is the removal of the apical meristem a plant, done to force the lower axillary buds to branch out and create multiple uniform stems (Wien, 2015). Single stem sunflowers are apically dominant, therefore branching does not occur unless the apical meristem is damaged or removed (Cline, 1997). Hormones that control apical dominance and axillary branching are still being researched. Scientists think that auxin, cytokinin and a novel hormone, possibly strigolactone, play a role in controlling branching and apical dominance (Leyser, 2009; Morris et al., 2005; Sachs and Thimann, 1967; Stirnberg et al., 2010; Weberling, 1992).

Pinching is used in cut sunflower production to increase stems per plant. The pinching method has been studied but no clear guidelines have been set that consistently provide the highest yield, due to the fact that various sunflower cultivars that react differently to being pinched. The general agreement is that pinching should occur when the plant has 4-6 leaves, but this method has not shown consistent results (Armitage and Laushman, 2003). Pinching generally leads to a larger yield of smaller uniform flowers with shorter stems (Armitage and Laushman, 2003). Pinching sunflowers normally raises yield by four times (Wien, 2016a). Growers who use high planting densities should use caution with pinching. Pinching high density plantings could lead to misshapen heads and weaker stems (Wien, 2016a). Pinching also increases labor costs. Wein (2016a) encourages growers to pinch sunflowers because the economic gain is greater with pinching. Since the flower sizes and stem lengths decreased with pinching minimum market standards were used for the following experiment: stem length of 60 cm, flower diameter of 8 cm, and a disk diameter of 3.81 cm (Sloan and Harkness, 2010; Wien, 2012a).

Some sunflower cultivars are sensitive to photoperiod; different sensitivities include short day cultivars, facultative short day, and day neutral cultivars. Short day cultivars produce better stems and flower sizes when grown under short day conditions (Fred C. Gloeckner and Company, Incorporated, 2014). Stem lengths and flower sizes of facultative short day cultivars are reduced when grown under short day conditions while day neutral cultivars are not affected by day length (Wien, 2014a). The objective of experiment 3 was to assess the efficiency of pinching five different sunflower cultivars at different nodes.

Material and Methods

This experiment was conducted at SFA Gardens in Nacogdoches, Texas. Raised beds located in an open area between La Nana Creek and the SFASU soccer field were used. The sunflower seeds were directly sown on 26 Aug 2016 into 3.7 × 1.2 × 0.61 m raised beds in five rows of 23 × 23 cm spacing. Soil in the raised beds was a top soil mixed with mushroom compost. The soil pH was 7.98, which is within the range of 5.7 to above 8.0 that sunflowers are generally grown in (Putnam et al., 1990). Nitrate-N was the only

Table 3.1. Nutrient levels present in raised beds and their sufficiency ranges.

Nutrients	Raised bed (ppm)	Sufficiency range (ppm)
NO_3	23.31	100-199[z]
P	196.36	21-60[y]
K	324.38	120-300
Ca	4474.60	460-749
Mg	170.99	100-150
S	53.25	16-25
B	0.38	N/A
Fe	30.99	2.5-4.5
Mn	4.06	1-1.5
Zn	4.79	0.3-0.8
Cu	2.53	0.1-0.3

[z]Sufficiency range of a saturated media from Greenhouse Operation and Management (2013).

[y]Sufficiency ranges of soil from Stephen F. Austin State University Soils Lab.

nutrient that was not at or above the sufficiency range before fertilizer was applied (Table 3.1). The plots were fertilized on 28 Aug 2016 with Lone Star Super Lawn and Turf Builder, 15N-2.2P-8.3K, at a rate of 51.6 g per 1 m^2 (Texas Farm Products Co, Nacogdoches, Texas). Additional nutrients include S (13.4%), B (0.02%), Cu (0.05%), Fe (1.0%), Mn (0.05%), Mo (0.0005%) and Zn (0.05%). The plants were watered via drip

Table 3.2. Information from Glockner Seed 2016-2017 Catalog.

Cultivar	Comments	Photoperiodic response^z	Flower color	Stems	Days to harvest (d)	Plant height (m)	Flower diameter (cm)^y
'Pro Cut Gold'	Spring, summer, fall	Day neutral	Golden orange	Single	60	1.2-1.8	10-15
'Superior Gold'	Fall and shorter days	Short day	Golden yellow	Single	60	1.5-1.8	15-20
'Supreme Sunbright '	Year round	Facultative short day	Golden yellow	Single	55	1.2-1.5	15-20
'Vincents Choice'	Day length neutral, all seasons	Day neutral	Golden yellow	Single	55	1.2-1.5	10-15
'Sunrich Lemon'	Spring, summer, fall	Facultative short day	Lemon yellow	Single	55-70	0.9-1.5	10-15

^{z}Data from Wien, 2014a; 2015

^{y}Flower size from Glockner Seed 2014-2015 Catalog

irrigation every other day for the duration of the experiment. Five different sunflower cultivars, *Helianthus annuus* ‘Pro Cut Gold’, ‘Supreme Sunbright’, ‘Vincents Choice’, ‘Sunrich Lemon’, and ‘Superior Gold’ were used in this experiment (Table 3.2). Each cultivar was selected based on growing season and plant height. The plants were pinched at the 1st, 2nd, 3rd, or 4th nodes of the stem. The control plants were not pinched. Each cultivar had 100 total plants and 20 plants per treatment.

Experiment 3 was a randomized block design and contained four replications within each cultivar. The data was analyzed by SAS 9.2 (Cary, NC) via a Two-Way ANOVA. Tukey’s Studentized Range Test was run to find significant differences between means at a 5% probability level. Sunflower heads were harvested when fully developed and open. The measurements taken per stem harvested were: stem length measured from the soil line to the base of the head for control plants or from where the stem was cut from the main stem to the base of the head for pinched plants, stem diameter (5.1 cm below base of the head), flower diameter, disk diameter, and the harvest date were recorded.

Results

Stems of non-pinched plants 'Pro Cut Gold' were significantly longer than all pinched treatments (Table 3.3). Only the non-pinched plants produced a stem longer than the market standard of 60 cm (Sloan and Harkness, 2010). Pinching significantly reduced the stem diameter by at least one half compared to the non-pinched treatment (Table 3.3).

Table 3.3. Effects of pinching at various nodes on sunflower 'Pro Cut Gold' stem length, stem diameter, flower diameter, disk diameter, days to harvest, and stems per plant.

Node pinched	Stem length (cm)	Stem diameter (mm)	Flower diameter (cm)	Disk diameter (cm)	Days to harvest (d)	Stems/ plant (no.)
0	133.77 a[z]	12.4 a[z]	16.31 a[z]	7.50 a[z]	46.89 a[z]	1.00 a[z]
1	58.37 b	5.99 b	8.56 bc	3.20 b	51.50 a	2.00 b
2	48.45 bc	4.30 c	7.98 c	2.75 b	51.08 a	3.20 c
3	55.52 b	4.90 bc	9.25 b	3.15 b	62.41 a	3.70 c
4	44.29 c	5.42 bc	7.70 c	2.86 b	55.20 a	3.20 c
P-value	<0.0001	<0.0001	<0.0001	<0.0001	0.51840	<0.0001

[z] Means within column followed by the same letter are not significantly different at the 5% probability level by Tukey's Studentized Range Test.

Of the pinching treatments, pinching at the first node resulted in the thickest stems but they were not significantly different from pinching at nodes 3 and 4. The non-pinched treatment had a significantly larger flower diameter of 16.31 cm than all the pinched treatments (Table 3.3). A marketable flower diameter is 8 cm or larger (Sloan and Harkness, 2010). Pinching decreased flower diameter, but flowers of plants pinched at nodes 1 and 3 were above the market standard. Pinching at node 3 had largest flower diameter of the pinching treatments but was not significantly different from pinching node 1. Although there were significant differences between pinching treatments for flower diameter there was no trend in the data. Disk diameter was significantly larger in the non-pinched treatment, producing disks with a diameter two times the disk diameter of all pinched treatments. Disk diameters for all pinching treatments were below the market standard of 3.81 cm (Wien, 2012a). The non-pinched plants had the shortest days to harvest but this was not significantly different from the pinching treatments. Pinching significantly increased the number of stems per plant. Pinching at nodes 2, 3, and 4 produced significantly more stems than pinching at node 1.

For ‘Superior Gold’ sunflowers there is no data for pinching at node 1 because none of the plants survived the pinching treatment. Non-pinched plants had significantly longer stem lengths than pinched plants. Pinching significantly decreased the stem length by over half (Table 3.4). Non-pinched plants produced stem lengths above the market standard (Table 3.4). Stem diameter of non-pinched plants was significantly larger than pinched plants. For the pinching treatments stem diameter increased as the pinched node

Table 3.4. Effects of pinching at various nodes on sunflower ‘Superior Gold’ stem length, stem diameter, flower diameter, disk diameter, days to harvest, and stems per plant.

Node pinched	Stem length (cm)	Stem diameter (mm)	Flower diameter (cm)	Disk diameter (cm)	Days to harvest (d)	Stems/ plant (no.)
0	196.09 a[z]	14.66 a[z]	19.99 a[z]	10.22 a[z]	59.25 a[z]	1.00 a[z]
1	- -	- -	- -	- -	- -	- -
2	63.68 bc	3.45 c	8.73 c	3.24 b	61.61 a	3.80 b
3	60.82 c	3.58 c	9.18 bc	3.28 b	65.39 b	3.80 b
4	71.07 b	4.68 b	10.06 b	3.49 b	67.82 c	5.20 c
P-value	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

[z] Means within column followed by the same letter are not significantly different at the 5% probability level by Tukey's Studentized Range Test.

increased (Table 3.4). Flower diameter of non-pinched plants was significantly larger than all the pinching treatments. Flower diameter remained above the market standard for all pinching treatments (Table 3.4). The non-pinched plants produced a significantly larger disk diameter than the pinched plants (Table 3.4). Disk diameter was not significantly different in any of the pinching treatments. None of the pinching treatments met the market standard of 3.81 cm for disk diameter (Table 3.4; Wien, 2012a). For days to harvest the non-pinched treatment and pinching at node 2 could not be separated but pinching at nodes 3 and 4 significantly increased days to harvest (Table 3.4). Pinching significantly increased the number of stems per plant. Pinching at node 4 produced significantly more stems per plant than pinching at nodes 2 and 3 (Table 3.4).

‘Supreme Sunbright’ sunflowers had a significant decrease in stem length when pinching occurred (Table 3.5). The non-pinched plants and those pinched at node 3 were the only two treatments to produce stem lengths above the market standard. The non-pinched treatment had a significantly greater stem diameter than the pinching treatments. There were significant differences between pinching treatments but there was no trend in stem

Table 3.5. Effects of pinching at various nodes on sunflower 'Supreme Sunbright' stem length, stem diameter, flower diameter, disk diameter, days to harvest, and stems per plant.

Node pinched	Stem length (cm)	Stem diameter (mm)	Flower diameter (cm)	Disk diameter (cm)	Days to harvest (d)	Stems/ plant (no.)
0	118.39 a[z]	13.08 a[z]	15.49 a[z]	8.26 a[z]	52.54 a[z]	1.00 a[z]
1	59.47 b	4.29 c	7.94 bc	4.15 b	54.49 bc	3.00 b
2	57.99 bc	4.67 bc	7.69 c	3.07 c	55.36 b	3.00 b
3	62.62 b	5.38 b	8.76 b	3.66 bc	53.65 bc	4.20 c
4	50.13 c	4.12 c	7.76 bc	3.30 c	58.85 c	4.30 c
P-value	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

[z] Means within column followed by the same letter are not significantly different at the 5% probability level by Tukey's Studentized Range Test.

diameter. Flower diameter was significantly larger for the non-pinched plants compared to the pinching treatments. The non-pinching treatment and pinching at the 3 node met the market standard for flower diameter (Table 3.5). Significant differences were observed between pinching treatments but there was no trend in flower diameter. The non-pinched plants had significantly larger disk diameters than the pinched plants. Disk diameter significantly decreased by almost half when pinching occurred (Table 3.5). Pinching at node 1 and the non-pinched treatment were the only treatments to produce a disk diameter above the market standard. Pinching at node 1 could not be was statistically separated from pinching at node 3, which did not produce a marketable disk diameter. Days to harvest significantly increased when the plants were pinched. The number of days to harvest was the longest when plants were pinched at node 4 (Table 3.5). Pinching significantly increased the number of stems compared to the non-pinched plants. Pinching at nodes 1 and 2 were significantly different from pinching at nodes 3 and 4 in terms of number of stems per plant.

Stem length of 'Vincents Choice' sunflower significantly decreased when a pinching treatment occurred. The non-pinched plants and pinching at node 1 produced a marketable stem length and were significantly different from pinching at nodes 2, 3, and 4. The non-pinched plants produced significantly larger stem diameters. Stem diameter pinching treatments could not be statistically separated. Flower diameter was significantly larger for non-pinched plants. Flower diameter decreased significantly when pinching took place (Table 3.6). The non-pinched plants and all pinching treatments

Table 3.6. Effects of pinching at various nodes on sunflower 'Vincents Choice' stem length, stem diameter, flower diameter, disk diameter, days to harvest, and stems per plant.

Node pinched	Stem length (cm)	Stem diameter (mm)	Flower diameter (cm)	Disk diameter (cm)	Days to harvest (d)	Stems/ plant (no.)
0	120.85 a[z]	12.85 a[z]	15.57 a[z]	7.69 a[z]	50.58 a[z]	1.00 a[z]
1	67.24 b	5.51 b	9.37 bc	3.97 b	53.74 bc	1.90 a
2	42.01 d	4.56 b	8.19 c	2.90 d	52.62 b	3.50 b
3	55.67 c	5.01 b	9.47 bc	3.67 bc	52.41 ab	4.10 bc
4	52.45 c	4.56 b	8.43 c	3.17 cd	54.31 c	4.90 c
P-value	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

[z] Means within column followed by the same letter are not significantly different at the 5% probability level by Tukey's Studentized Range Test.

produced marketable flower diameters (Table 3.6). Disk diameter was significantly reduced with the pinching treatments (Table 3.6). Only the non-pinched plants and the plants pinched at node 1 produced marketable disk diameters (Table 3.6). Days to harvest increased significantly for pinching treatments 1, 2, and 4 compared to the non-pinched plants. Days to harvest for non-pinched plants and pinching at node 3 could not be statistically separated. Pinching increased days to harvest by 2 to 4 days compared to non-pinched plants. Stems per plants followed the trend of increasing the number of stems per plant with increasing node pinched. There were no consistent trends related to pinching observed in this experiment for ‘Vincents Choice’ sunflowers.

Stem length for 'Sunrich Lemon' sunflowers significantly decreased with the pinching treatments. Although there were significant differences between pinching treatments, all pinching treatments produced unmarketable stem lengths. Stem diameter significantly decreased with pinching (Table 3.7). Flower diameter for the non-pinched plants was significantly larger than pinched plants. Flower diameter significantly decreased with

Table 3.7. Effects of pinching at various nodes on sunflower 'Sunrich Lemon' stem length, stem diameter, flower diameter, disk diameter, days to harvest, and stems per plant.

Node pinched	Stem length (cm)	Stem diameter (mm)	Flower diameter (cm)	Disk diameter (cm)	Days to harvest (d)	Stems/ plant (no.)
0	102.47 a[z]	11.18 a[z]	15.63 a[z]	8.24 a[z]	52.93 a[z]	1.00 a[z]
1	47.41 c	4.20 c	7.24 c	3.44 c	55.08 ab	3.50 b
2	58.65 b	4.96 b	9.91 b	4.70 b	55.48 b	3.50 b
3	38.99 d	4.69 bc	7.87 c	3.45 c	54.77 ab	3.10 b
4	31.66 e	4.18 c	6.88 c	2.50 d	59.28 c	3.00 b
P-value	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

[z] Means within column followed by the same letter are not significantly different at the 5% probability level by Tukey's Studentized Range Test.

pinching, but there was no trend observed. Flowers of plants pinched at node 2 were significantly larger in diameter and of marketable size compared to pinching at nodes 1, 3, and 4. Disk diameter of non-pinched plants was significantly larger than all pinching treatments. Disk diameter was reduced below marketable sizes for all pinching treatments except for pinching at node 2. Days to harvest was increased significantly for pinching at nodes 2 and 4 compared to non-pinched plants. Pinching increased the number of stems per plant (Table 3.7); means for all four pinching treatments could not be statistically separated.

Discussion

The cultivars have various responses to day length with some being short day, ('Superior Gold'), day neutral, ('Pro Cut Gold' and 'Vincents Choice'), or facultative short day, ('Supreme Sunbright' and 'Sunrich Lemon') (Ha, 2014; Hayata and Imaizumi, 2000; Wien 2014a; 2014b). Short day cultivars produce long stems and larger flower sizes under short day conditions. Day neutral cultivars are not affected by photoperiod (Wien, 2014a; 2014b). Facultative short day cultivars respond to short day lengths by flowering sooner and when pinched having shorter stem lengths with smaller daisy sized flowers (Wien, 2015; Blacquière et al., 2002). Short days are considered 12 h or less and long days are 16 h or more (Blacquière et al., 2002).

In experiment 3 non-pinched plants followed the expected trend of the short day cultivar 'Superior Gold', having the longest stems followed by day neutral cultivars 'Pro Cut Gold' and 'Vincents Choice', and facultative short day cultivars 'Supreme Sunbright' and 'Sunrich Lemon' with the shortest stems. Stem length for all cultivars and pinching treatments decreased compared to the non-pinched sunflowers similar to previous research (Wien, 2015). Only 'Superior Gold' (short day) produced marketable stem lengths for all pinched nodes. Flower diameter was the largest for the non-pinched treatments of all the cultivars. All pinching treatments for 'Superior Gold' met the market standard for flower diameter. Flower diameter marketability varied by cultivar and pinching treatment. The control plants for the other cultivars followed the expected trend with the day neutral cultivars 'Pro Cut Gold' and 'Vincents Choice' having larger flower diameters than the facultative short day cultivars ‘Supreme Sunbright’ and ‘Sunrich Lemon’.

Disk diameter varied by cultivar and pinching location. Most pinching treatments led to unmarketable disk diameters which Wien (2015) found that all pinching lead to marketable stem lengths and disk diameters. Stem diameter decreased significantly after pinching. The average stem diameter for non-pinched plants in experiment 3 was 12.9 mm while pinched plants averaged 4.7 mm (Tables 3.3-3.7).

Wien (2015) found that responses to pinching varied by cultivar but overall stem length and disk diameter decreased with pinching at the 3rd node and decreased further with pinching at the 5th node. While the disk diameter averages were above marketable size, Wien does not suggest pinching at the 5th node. Results of experiment 3 are similar to Wiens’ (2015) observations that pinching significantly reduces stem length and disk diameter, but differ in respect to marketable stem lengths or disk diameters produced by the pinched plants. Day length or temperature could be causing different results in the trials Wien conducted and experiment 3.

Wien (2015) found facultative short day plants under short day conditions flower earlier which led to plants being 59% as tall as plants grown in long day conditions. This observation could be due to fewer leaves on the short day treatment plants (Wien, 2015). Long days of 16 h or more cause the plant to remain in a vegetative state longer, allowing for the elongation of the stem before flower initiation (Pallez et al., 2002). Under long day treatments, facultative short day cultivars took longer to reach anthesis compared to short day treatments (Blacquière et al., 2002). Blacquière et al. (2002) observed that plants under the long day treatment had longer stems and were heavier short day treatments because of their larger flower.

This experiment was conducted in late August to early November in Nacogdoches, Texas in USDA Hardiness zone 8. Day lengths in Nacogdoches, Texas in late August were about 12 h 53 min decreasing in November to 10 h 41 min (Rise and Set for the Sun for 2017). Wien's study on sunflower pinching was conducted in Ithaca, New York in zone 5 during May to August. Day length in Ithaca during mid-May was about 14 h 46 min decreasing slightly in early August to 14 h 24 min. In experiment 3 the sunflowers started their life cycle 47 min over the 12h short day period. The plants ended their life cycle 1 h 6 min under the 12 h short day period.

Photoperiod trials have proven that short days lead to reduced plant stature and smaller flowers (Goyne and Schneiter, 1988; Lokhande et al., 2003). This experiment 3 was carried out when day lengths were neutral to short and resulted in generally unmarketable stem lengths and flower sizes. The short days in forced facultative short day cultivars 'Supreme Sunbright' and 'Sunrich Lemon' to flower early, leading to shorter stems and smaller flowers (Blacquière et al., 2002; Wien, 2015). The short day cultivar 'Superior Gold' was capable of elongating its stem length under the shorter day lengths but still produced inadequate disk diameters when pinched. Conversely, in Wiens study during neutral to long day lengths produced marketable flower stems and disk diameters when the plants were pinched. Differences in results suggest that short days can result in unmarketable stem lengths and flower size as observed compared to Wien (2015).

Another environmental factor that could be affecting the results is temperature. During experiment 3 the average temperature was 28°C, 25°C, 19°C, 16°C in August, September, October, and November, respectively. Wien (2015) started his trial at the end of May when the average temperature was 16°C, increasing in July to 20°C then decreasing to 18°C in August when the trial was terminated. The highest average temperature in Nacogdoches was 8°C higher than the highest average temperature in Ithaca. High temperatures cause faster flower initiation which leads to shorter stems in *Arabidopsis thaliana* (Lokhande et al., 2003). *Arabidopsis thaliana* under cooler conditions produced longer stems and later flowering occurred (Lokhande et al., 2003). Goyne and Schneiter (1988) conducted a growth chamber experiment to see how temperature affected sunflower development. They observed a reduced days to flower initiation during increased day and night temperatures of 28/22°C compared to a day/night temperature of 18/15°C (Goyne and Schneiter, 1988). Goyne and Schneiter (1988) noted that plants grew taller under higher temperatures and produced more leaves. An experiment conducted growing sunflowers in day/night temperatures of 33/29°C, respectively, found that photosynthesis decreased under the high temperature treatment, which led to decreased growth in the sunflower plants (Haba et al., 2014). The average temperature reaching 28°C in this could have stressed the plants, reducing stem length and flower size. Wiens trial (2015) had cooler temperatures and produced longer stems which supports Lohandle et al. (2003) and Haba et al. (2014) observations. A combination of high temperature and short photoperiod could be causing differences in the results between Wien's trial and this experiment.

Days to harvest for all the cultivars increased when pinched. 'Pro Cut Gold' and 'Vincents Choice' day neutral non-pinched plants had the shortest days to harvest of 47 and 51 d, respectively (Tables 3.3 and 3.6; Wien 2014a; 2014b). Both 'Supreme Sunbright' and 'Sunrich Lemon' have been observed as facultative short day plants and 'Supreme Sunbright' is especially sensitive to short days in the seedling stage (Dole et al., 2012). Both cultivars had days to harvest of about 53 d for control plants (Tables 3.5 and 3.7). 'Superior Gold' had the longest days to harvest during this study of 59 d which led to it having the longest stem lengths (Table 3.4; Blacquière, 2002). 'Superior Gold' had the longest days to harvest because it is a short day cultivar, so it developed at a slower pace than the other cultivars under the short day conditions. Pinching treatments for all cultivars followed the general trend of short day cultivars having the longest days to harvest with facultative short days having intermediate days to harvest; the day neutral cultivars had the shortest days to harvest. 'Superior Gold' had the longest days to harvest for pinched plants at 67 d. Pinching location and days to harvest did not follow an overall trend. Wien (2015) saw an increase in the number of days to harvest the later the pinching occurred. The pinch at the 5th node had the longest days to harvest of 71 d for his study. Although we had shorter days to harvest compared to Wien (2015), the results are similar in that both saw an increase in days to harvest with a pinching treatment.

The number of stems per plant increased with a pinching treatment. Cultivar responses to pinching varied for the number of stems the plant produced and similar results have been observed previously (Wien, 2015). ‘Superior Gold’ ‘Supreme Sunbright’ and ‘Vincents Choice’ all produced the most stems per plant at the highest pinching at node 4. Pinching at node 3 yielded approximately double the stems per plant than the pinch at the 5th node (Wien, 2015). Day length could have affected how the plant responded to the pinching. Dun et al., (2006) observed that branching was reduced when *Arabidopsis* and both pinched and non-pinched peas were grown under long day conditions. Under short day conditions Dun et al., (2006) observed more branching. The findings of Dun et al., (2006) that day length can affect branching may explain the higher number of stems in compared to those reported by Wien (2015).

Conclusion

In this sunflower cultivar experiment each of the five cultivars reacted differently to all pinching treatments. The pinched plants' stem length, stem diameter, flower diameter, and disk diameter decreased compared to the non-pinched plants. Days to harvest and the number of stems per plant increased in pinched plants compared to non-pinched plants. There were no clear trends among the cultivars or treatments. 'Superior Gold' produced adequate stem lengths when pinched; however, it did not produce marketable disk diameters. Of the pinching treatments, 'Vincents Choice' pinched at the 1st node was the only cultivar and pinching treatment that produced a marketable stem length and flower diameter. The low number of marketable stems produced from pinching in East Texas suggests pinching sunflowers, particularly in the late summer to fall, is not an acceptable cultural practice to increase sunflower yield.

Response to day length can be different for the two stages of the sunflower life cycle; 1) germination to flower initiation and 2) flower initiation to anthesis (Wien, 2015). Various studies (Palmer et al., 1982; Yanez et al, 2004) found that sunflower sensitivity may change during the two stages of development (Wien, 2015). Comparing this study to the trial by Wien, it appears that photoperiod was the driving factor for the differences in results. Wien (2015) speculates giving long day treatments of 16 h to seedlings will lead to longer development, producing taller stems and larger flowers. Planting the seeds at a time where the plants will receive the longest day lengths might possibly might give the plants the best chance to develop multiple marketable stems.

SUMMARY

The results of the three pinching experiments conducted at SFASU demonstrate that the East Texas summer climate is not conducive to increasing sunflower production by pinching. Stem length for pinched plants was 40% shorter than control plants overall in the three experiments. Flower diameters decreased by 37% when pinched for the three experiments. Disk diameter was 42% smaller in pinched plants than control plants for experiment 1 and 3. In experiment 3, long day treatments on facultative short day cultivars resulted in a longer time reach anthesis compared to short day treatments (Blacquière et al., 2002). Blacquière et al. (2002), observed that plants developed longer stems under the long day treatments than short day treatments.

Overall, pinching in an East Texas climate (zone 8b) was not as successful as in Ithaca, New York (zone 5). For sunflowers to produce long stems with marketable flower sizes, long day lengths and a mild climate is necessary. New York is a good location for pinching sunflowers because the mild summers allow the plants to produce more marketable stems per plant. The East Texas climate is hot and has considerably shorter day lengths in the summer compared to in New York. Short photoperiod and higher temperatures send the plant into the flower initiation stage quicker than long days and cooler temperatures leading to shorter stems and smaller flowers (Blacquiere et al., 2002; Wien, 2015).

Wien (2015) suggests growing under long days to allow for a longer development period for stem elongation and flower development. Pinching sunflowers is not a method that should be practiced in East Texas during the summer to fall months since it leads to an unmarketable product. Growers in East Texas who would like to try the pinching method should aim to grow the sunflowers during spring (cooler temperatures) and the longest day lengths possible for that area.

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