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Concentration and Timing of Dikegulac Sodium on *Helianthus hybrida* 'Sunfinity' Seedlings for Potted Plant Production

Mason Marshall and Terri Starman
495 Horticulture Street, Department of Horticultural Sciences, Texas A&M University, College Station, TX 77843

H. Brent Pemberton
1730 FM3053, Texas A&M AgriLife Research and Extension Center, Overton, TX 75684

Calvin Trostle
1102 East FM Road 1294, Texas A&M AgriLife Research and Extension Center, Lubbock, TX 79403

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Abstract. **Sunflower 'Sunfinity' (*Helianthus hybrida*) can be produced as a potted plant if apical dominance is removed with a manual pinch to control plant height and promote branching and flower number. Chemical pinching agents such as dikegulac sodium could prove to be valuable tools to reduce the labor and costs associated with manual pinching. Our objective was to determine the time of seedling growth and concentration of dikegulac sodium foliar spray application that would result in morphology similar to manually pinched plants. Dikegulac sodium was applied to sunflower 'Sunfinity' seedlings at one of four concentrations increasing from 200 to 500 mg·L^{-1} at the time of growth when the first, second, or third node (N1, N2, or N3) was the apical node and axillary stems at those nodes were undeveloped. Applications of 400 mg·L^{-1} at N3 and 500 mg·L^{-1} at N2 removed apical dominance because of total senescence of the apical meristem and produced a well-branched plant similar to that subjected to manual pinching. Apical dominance was temporarily inhibited without senescence of the apical meristem when 400 mg·L^{-1} was applied at N2 and when 500 mg·L^{-1} was applied at N3, which, nevertheless, resulted in branching that formed a well-rounded canopy.**

Manual pinching of apical meristems of horticultural crops removes apical dominance and promotes branching, increases flower numbers, and promotes the growth of a rounded, uniform plant canopy. However, manual pinching is a time-consuming and labor-intensive practice that can become costly for growers (Cheema, 2018; Starman, 1991). Meijón et al. (2009) noted that chemical pinching agents can reduce the cost associated with manual pinching, but the plant growth response is variable. Previous research classified sunflower (*Helianthus* spp.) as having strong apical dominance that can be broken only with the removal or manual pinching of the apical meristem (Bhattacharjee and Gupta, 1984; Cline 1978). Currently, some basal branching sunflower cultivars, referred to as multifloras, generally are not pinched; however, pinching single-stem sunflower cultivars promoted multiple axillary stems with smaller flowers (Armitage and Laushman, 2003).

Dikegulac sodium is a plant growth regulator (PGR) that chemically prevents apical dominance by inhibiting cell division in the apical meristem, thereby allowing lateral branching to occur (Arzee et al., 1977; Rezazadeh et al., 2015). Dikegulac sodium has been shown to effectively increase branching of several horticultural crops such as *Sedum*, *Hydrangea*, *Phlox*, and *Nepeta* (Banko and Stefani, 1995; Cline, 1978; Grossman et al., 2013; Sun et al., 2015). Within 1 d, dikegulac sodium was detected in the apical meristem after being applied to the basal foliage of *Chrysanthemum morifolium*. However, foliar application to the apical leaves provided the maximum effect for preventing apical dominance (Bocion and DeSilva, 1977).

In vitro studies involving *Solanum nigrum* showed that dikegulac sodium did not inhibit stationary or dormant cells, but that phytotoxicity did occur on actively dividing cells (Zilkah and Gressel, 1978). Further research by Zilkah and Gressel (1979) showed that cell leakage is quickly induced after application. Latimer and Whipker (2001) recommended trialing several concentrations of dikegulac sodium for new species because responses to the chemical were species-specific. Published works have examined the effects of dikegulac sodium on *Helianthus* physiology and enzyme activities (Arzee et al., 1977; Bhattacharjee and Gupta, 1981, 1984; Purohit, 1980). However, we are not aware of studies of the ability of dikegulac sodium to chemically pinch sunflower.

'Sunfinity' (*Helianthus hybrida*), a relatively new ornamental hybrid of sunflower, has a continuous branching habit. Manual pinching above the fourth node is recommended commercially to encourage continuous lateral branching and create a uniform and rounded plant canopy. A preliminary experiment was conducted in Spring 2021, with the objective of substituting manually pinching 'Sunfinity' above the fourth node with chemical pinching. When plants had developed five, six, or seven nodes, the foliar application of dikegulac sodium was sprayed across the plant canopy on actively growing axillary stems. This resulted in phytotoxicity of leaves and axillary stems and total plant senescence within 3 weeks after application.

The objective of this experiment was to treat 'Sunfinity' seedlings with increasing concentrations of dikegulac sodium (200, 300, 400, or 500 mg·L^{-1}) at the time of growth when the first, second, or third node (N1, N2, or N3) was the apical node and when axillary buds were undeveloped to determine if the PGR effectively produced a well-branched plant comparable to that resulting from manually pinching. The overall goals were to determine which treatment resulted in growth similar to that of the manually pinched control, and to determine if chemical pinching is an effective alternative to manual pinching for the purpose of saving labor and costs. Foliar applications to the apical leaves while axillary buds were undeveloped were performed to prevent phytotoxic effects that were observed on actively growing axillary stems during our preliminary experiment.

Materials and Methods

'Sunfinity' seeds were obtained from Syngenta Flowers North America (Gilroy, CA) and sown at a depth less than 0.65 cm in 72-cell trays (with one seed per cell) containing soilless media (PRO-MIX HP with mycorrhizae; Premier Tech, Quakertown, PA) as a root substrate. Trays were placed in a glass greenhouse in College Station, TX (30.608718, −96.350350) on 28 May 2021. Cells were misted by hand multiple times daily during the germination period with reverse osmosis water. To prevent cell elongation, all

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M.M. is the corresponding author. E-mail: masonmarshall@tamu.edu.

Table 1. Effects of manual pinching and no pinching on the total plant height and diameter, plant fresh weight and dry weight, numbers of nodes and axillary stems, and axillary stem lengths for 'Sunfinity' sunflower grown in a greenhouse in College Station, TX.

Pinch treatment	Total plant ht (cm)	Total plant diam (cm)	Plant fresh wt (g)	Plant dry wt (g)	Nodes (no.)	Axillary stems (no.)	Axillary stem length (cm)
Manual	53.3 b[i]	59.3 b	147.4 a	15.6 b	4 b	8 b	38.5 a
None	85.1 a	54.9 a	175.2 a	20.1 a	18 a	21 a	10.5 b

[i] Comparison of means using the Student *t* test.

seeds received an industry standard initial paclobutrazol drench at 2 $mg \cdot L^{-1}$ on day 5 during the morning with a pipette. Other industry standard PGR applications were withheld.

Dikegulac sodium (Atrimmec; PBI/Gordon Corp., Kansas City, MO) was applied early morning as a foliar spray with a hand-held pressure sprayer at four concentrations and at three times during plant growth. The foliar spray was applied to the tops of leaves until they glistened, and runoff was withheld. The chemical concentrations applied were 200, 300, 400, and 500 $mg \cdot L^{-1}$. The times of application were when the first, second, or third node was the apical node on the plant with its true leaves 2 cm in length and the axillary stems at that node were undeveloped. These times are referred to as N1, N2, or N3, respectively, and they occurred on 7, 12, or 18 June, respectively, corresponding to 10, 15, or 21 d after sowing, respectively. There were seven replications per treatment, and two control groups (manually pinched and no-pinch) of seven plants each, resulting in a total of 98 plants. The experiment was arranged in a completely randomized design. On 21 June 2021, all plants were transplanted to 2.50-qt thermoformed containers, with one plug per pot. A nutrient solution of 200 $mg \cdot L^{-1}$ 15N–2.2P–12.5K–5Ca–2Mg was applied with every irrigation until harvest.

All plants were harvested on 24 July 2021. Data included total plant height (from the pot rim to the highest point on the plant), total plant diameter (measured across the widest point of the plant), plant fresh weight and dry weight (measured gravimetrically after drying for 3 d at 80 °C), number of nodes on the main stem, number of axillary stems on the main stem, and the average length of the two lowest axillary stems on the main stem. The lowest axillary stems were selected for measurement because of their length, and the subsequent growth served to round out the plant canopy and improve the overall plant architecture. Observations of treated plants were performed to evaluate potential phytotoxic effects after application.

The temperature was measured across the greenhouse with an EE08 temperature probe (E+E Elektronik, Langwiesen, Austria) housed in an aspirated radiation shield. Light at the canopy level was measured across the greenhouse every 10 min with a SQ-500 quantum sensor (Apogee Instruments, Logan, UT). Sensors were monitored and recorded by a CR1000X data logger (Campbell Scientific, Logan, UT). Throughout production, greenhouse temperatures were set at 21.1 °C, whereas the average actual temperature during production was 26.2 °C during the day. The daily light integral was 17 $mol \cdot m^{-2} \cdot d^{-1}$ during production, and it reached a maximum of 28 $mol \cdot m^{-2} \cdot d^{-1}$.

A statistical analysis was performed using JMP version 16.0.0. First, the manually pinched and no-pinch control treatments were compared using Student's *t* test. Second, a two-way analysis of variance (ANOVA) was performed, which included the manually pinched control data to identify significant interactions between the application time × PGR concentration. Finally, Dunnett's test was used to compare each treatment to the manually pinched control.

Results and Discussion

Comparison of control treatments. Manual pinching reduced the total plant height by 31.8 cm and increased the total plant diameter by 4.4 cm compared with not pinching (Table 1). Plant fresh weight was similar with both treatments; however, the pinched treatment resulted in a lower total plant dry weight compared with the no-pinch treatment. Manual pinching occurred above the fourth node, which resulted in a total of four nodes for the pinched treatment, whereas the no-pinch treatment resulted in the development of 18 nodes (Table 1). Plants with more nodes produce more axillary stems per plant (Sloan and Harkness, 2010). The pinched treatment resulted in eight axillary stems, whereas the no-pinch treatment had 21 stems. This odd number of axillary stems was attributable to 'Sunfinity' having opposite nodes up to the fifth or sixth node and alternate nodes above. The axillary stem length was increased by 28 cm with manual pinching compared with no pinching. The difference in the axillary stem length can be explained by the release of apical dominance that occurred after manual pinching. Axillary branching caused by the release of apical dominance explains the larger plant diameter of the manually pinched plants (Table 1, Fig. 1).

If plants were not manually pinched, then apical dominance ensued. Plants grew tall because of the increased node numbers and internode elongation. Each node produced one axillary stem, on average, and those stems were 10.5 cm long, giving the plant a "clubby" architecture that was prone to lodging when grown as a potted plant (Fig. 1). In contrast, manually pinched plants had analogous height and width dimensions (53 cm and 59 cm), and each of the four nodes that remained on the main stem produced two axillary stems that elongated to 38.5 cm.

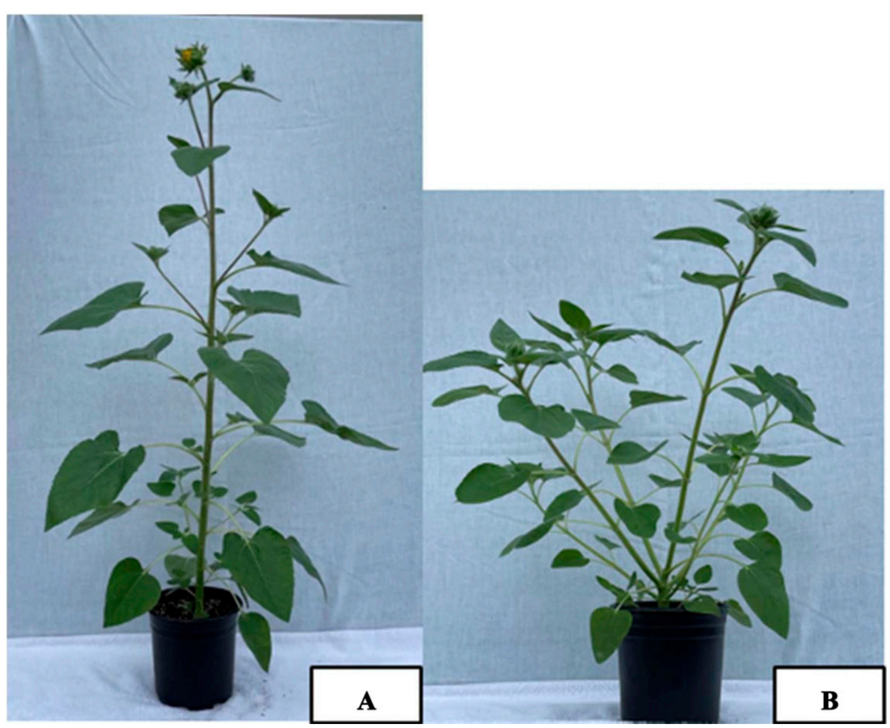

Fig. 1. Visual comparison of the effects of manual pinching on the morphology of 'Sunfinity' sunflower (**A**) subjected to the no-pinch treatment and (**B**) manually pinched to four nodes.

Table 2. Effects of dikegulac sodium application times and chemical concentrations on the total plant height, total plant diameter, fresh weight, and dry weight.

Appl. Time	Concn ($mg \cdot L^{-1}$)	Total plant ht (cm)	Total plant diam (cm)	Plant fresh wt (g)	Plant dry wt (g)
Manual pinching	0	53.29[ii]	59.29	147.40	15.58
N1[i]	200	66.4[NS]	42.9*	96.0*	10.3*
	300	45.0[NS]	41.7*	68.9*	7.2*
	400	40.1[NS]	39.4*	66.7*	7.6*
	500	18.1*	19.9*	19.8*	2.1*
N2	200	62.0[NS]	49.5[NS]	117.2[NS]	11.8[NS]
	300	66.3[NS]	56.5[NS]	137.8[NS]	13.6[NS]
	400	53.7[NS]	50.6[NS]	109.8*	12.2[NS]
	500	31.1*	35.5*	49.5*	5.2*
N3	200	64.7[NS]	43.0*	90.2*	9.7*
	300	60.3[NS]	44.9*	89.7*	9.8*
	400	31.3*	40.9*	52.5*	5.9*
	500	41.3[NS]	50.6*	84.6*	9.3*

[i] N1 = chemical application time at first node; N2 = second node; N3 = third node.
[ii] Single point comparison of the manual pinched control and concentration using Dunnett's test.
*$P \leq 0.05$. NS = not significant.

These results produced a rounded canopy that was suitable for potted plant production, although other PGRs would need to be applied to reduce internode elongation.

Comparison of treatments and the manually pinched control. A two-way ANOVA showed a significant interaction between application time × PGR concentration for all measured variables. The manually pinched treatment was used as the control group for the comparison using Dunnett's test (Table 2, Fig. 2). Compared with manual pinching, the total plant height for N1 500, N2 500, and N3 400 were reduced (Table 2). At N1 and N3, all concentrations reduced the total plant diameter; however, at N2, only 500 $mg \cdot L^{-1}$ reduced the total plant diameter compared with manually pinching (Table 2). All treatments decreased plant fresh weight compared with manually pinching, except for 200 and 300 $mg \cdot L^{-1}$ at N2 (Table 2). Excluding 200 to 400 $mg \cdot L^{-1}$ at N2, all treatments reduced the plant dry weight compared with manually pinching (Table 2).

With 500 $mg \cdot L^{-1}$ for all application times, 400 $mg \cdot L^{-1}$ at N1 and N3, and 300 $mg \cdot L^{-1}$ at N1, the numbers of nodes were similar to those of the control (four nodes) because of chemical removal or temporary inhibition of the apical meristem (Fig. 2). Only 200 $mg \cdot L^{-1}$ at N1, 500 $mg \cdot L^{-1}$ at N2, and 400 $mg \cdot L^{-1}$ at N3 reduced the number of axillary stems compared with the control. All other treatments resulted in outcomes similar to the eight axillary stems of the control. Applications of 200 $mg \cdot L^{-1}$ at N1 and N3 and of 500 $mg \cdot L^{-1}$ at N2 reduced the axillary stem length compared with the control (Fig. 3). All other treatments produced a stem length that had an adequate length to form a rounded plant canopy like that of the control. Considering all the measured variables,

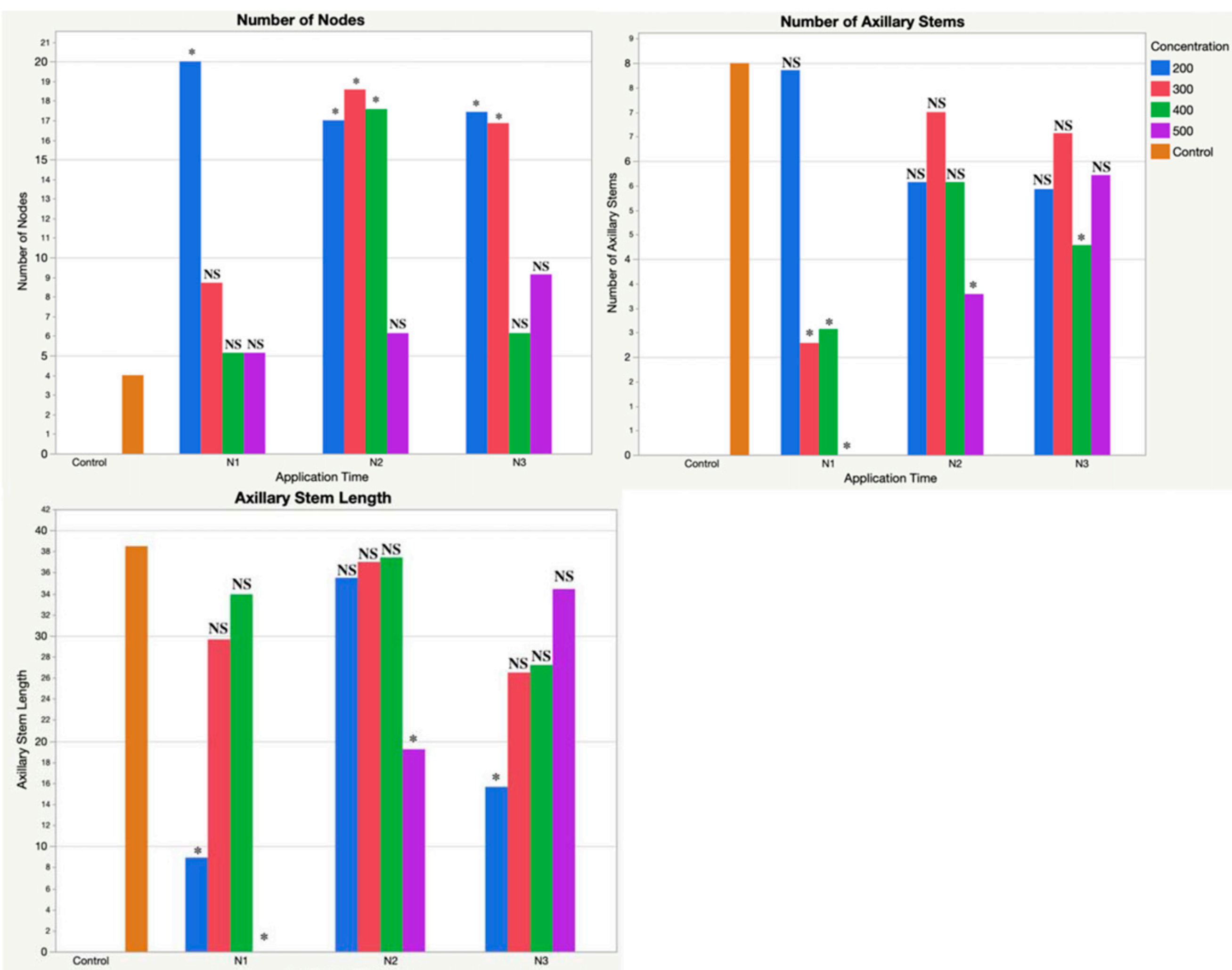

Fig. 2. Dunnett's test was performed to compare the means of dikegulac sodium application times (N1, N2, N3) and chemical concentrations on 'Sunfinity' sunflower to the manually pinched control and evaluate the number of nodes, number of axillary stems, and axillary stem length.

Fig. 3. Dikegulac sodium applied at 200, 300, 400, or 500 mg·L^{-1} at three application times (N1, N2, N3) for 'Sunfinity' sunflower. CP = chemical pinch (i.e., percentage of reps with apical meristem senescence).

500 mg·L^{-1} at N3 produced an overall plant architecture that was most like that of the manually pinched control (Figs. 3 and 4). Although 50% of the treatment groups had approximately four nodes that were similar to those of the control, this was not always coupled with an increased number of axillary stems or axillary stem lengths.

Five of the seven plants (71%) of a treatment group were chemically pinched (i.e., the apical meristem was senesced) when dikegulac sodium was applied at 400 mg·L^{-1} at N1 and N3 and at 500 mg·L^{-1} at N2 (Fig. 3). Although 57% of the plants treated with 500 mg·L^{-1} at N1 were chemically pinched, the axillary stems did not grow; therefore, the plants were stunted (Fig. 3). Although chemical pinching did not occur with 400 mg·L^{-1} at N2 and occurred only 29% of the time with 500 mg·L^{-1} at N3, the resulting growth from axillary stems created a well-rounded canopy (Fig. 5) because of temporary inhibition of the apical meristem. Concentrations of 200 mg·L^{-1} and 300 mg·L^{-1} at all application timings except 300 mg·L^{-1} N1 did not result in chemical pinching or apical meristem inhibition. Inadvertently, the total plant heights with 200 mg·L^{-1} and that with 300 mg·L^{-1} at all timings, except for 300 mg·L^{-1} at N1, were greater and axillary stem lengths were less than those of the control and not sufficient to produce a well-rounded canopy (Fig. 3).

Phytotoxic effects appeared ≈5 to 7 d after foliar application for each treatment. Initial symptoms of phytotoxicity were chlorosis on the upper leaves and apical meristem, followed by upward leaf curling and the eventual death of the apical meristem, which occurred 18 to 21 d after application (Fig. 5A and B). Arzee et al. (1977) recorded similar results for the distorted foliage of *Helianthus annuus* 'Peredovic' when applying dikegulac sodium at 100 to 750 mg·L^{-1}, and they noted that the effect was transient. Although all treatments displayed extensive chlorosis and eventually greened during our experiment, several plants exhibited a change in leaf morphology from cordate–ovate to linear (Fig. 5C).

Although we recorded practical results with the dikegulac sodium application, the results were somewhat variable because not all plants of a treatment were chemically pinched. Regardless, plants subjected to such a treatment had similar appearances because of

Fig. 4. Dikegulac sodium applied at 500 mg·L^{-1} at N3 had node numbers, axillary stem numbers, and axillary stem lengths similar to those of the manually pinched control and resulted in a well-rounded canopy. However, bud development was delayed by 1 week.

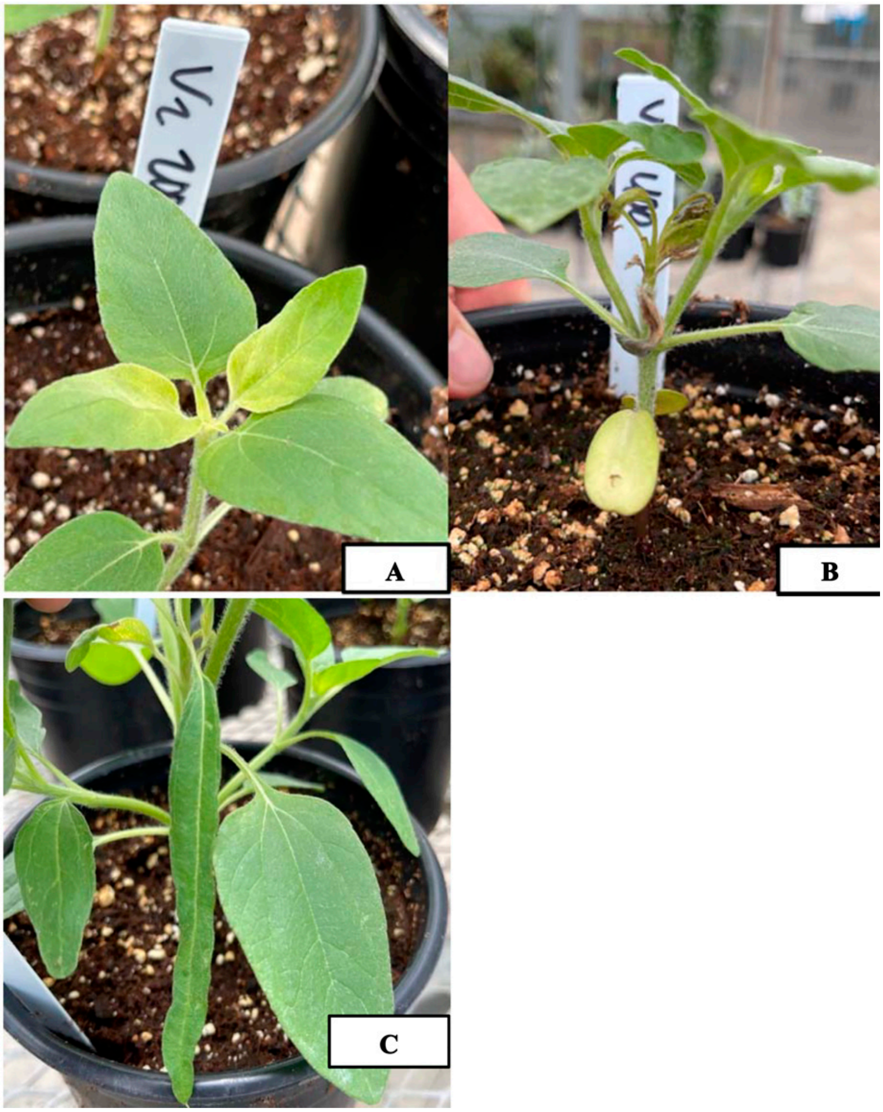

Fig. 5. Phytotoxic effects of dikegulac sodium after foliar application to 'Sunfinity' sunflower. (**A**) Leaf chlorosis appearing at 3 to 5 d. (**B**) Damage to the apical meristem and axillary growth at 21 d. (**C**) Linear leaves compared to normal cordate–ovate leaves.

(what we believe was) temporary inhibition of apical dominance because branching was increased even though the apical meristem remained viable. Sun et al. (2015) noted the efficacy of dikegulac sodium on plant growth depends on several factors, such as culture, species, environmental conditions, and chemical dose.

Ideally, a marketable plant that is manually pinched would have a low number of nodes with axillary stems forming proportional plant height and width. It is important to understand the overall morphology regarding the number of nodes and their relationship with other plant growth parameters when concluding which treatment resulted in growth similar to that of the manually pinched control and whether chemical pinching proved to be an effective alternative to manual pinching. Days to anthesis was not measured; however, visual observations showed that bud development was delayed by 1 week for plants treated with dikegulac sodium. Based on visual observations of the plant quality during harvest, combining the PGR to reduce internode elongation with dikegulac sodium applied at 400 or 500 mg·L^{-1} at N2 or N3 could result in a plant of marketable size that is chemically pinched and well-branched.

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