

Use of Paclobutrazol and Trinexapac-ethyl on Growth, Development, and Flowering Characteristics of Safflower as an Ornamental Plant

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The aim of this study was to investigate the effects of different doses and application methods of Trinexapac-ethyl (TE) and Paclobutrazol (PAC) on the growth, development, and flowering characteristics of safflower (*Carthamus tinctorius* L.) plants. This study will contribute to revealing and expanding the potential of this species, which is known to have high drought, cold, and salinity tolerance, in the ornamental plants sector. In the experiment, two safflower cultivars (Olas and Dinçer), two different plant growth inhibitors (TE and PAC), two different application methods (foliar and soil), and different doses (TE: foliar- 0, 4, 6, 8, and 12 ppm; PAC: soil- 0, 25, and 50 mg/pot, foliar- 0, 50, 100, and 500 ppm) were studied. Based on the results obtained, the use of TE and PAC, which are plant growth inhibitors, is seen as a suitable alternative to use 'Olas' and 'Dinçer' cultivars of safflower plant as ornamental plants in landscape designs and to expand their use for this purpose. It was determined that PAC application at a dose of 500 ppm in the form of foliar spray was an appropriate application especially in terms of suppressing height growth, and the plants treated with TE had a wider plant width compared to those treated with PAC.

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INTRODUCTION

Safflower (*Carthamus tinctorius* L.) is an annual plant in the Asteraceae family and well adapted to arid conditions because it usually reaches a height of 30 cm to 150 cm and has deep taproots that enable it to draw water from deeper soil layers (Gürsoy *et al.* 2018). Bright yellow, orange, or red blooms are produced by the plant, and these blooms eventually turn into seed heads full of many oil-rich seeds (Weiss 2000). Its seeds are a marketable commodity, appearing in food items (Landau *et al.* 2004), cosmetics (Asgarpanah and Kazemivash 2013), and medication formulations (Mündel *et al.* 2004). The oil could also be used to produce biofuel (Mündel *et al.* 2004) and bagasse for animal feed additions. In addition to its health benefits and industrial uses, safflower is known to be used as a fresh and dry cut flower and ornamental plant (Pahlavani *et al.* 2004; Erbaş and Baydar 2017; Menegaes and Nunes 2020; Sefaoğlu 2022). Flower color, thornlessness characteristics and plant height are important characters for this type of use (Erbaş and Baydar 2017). The floriculture and ornamental plant industries are dynamic ones that are always looking to innovate and meet the latest trends in the market and this species has a

lot of potential in this regard for this market. Safflowers are a highly sought-after species in the floriculture industry due to their diverse floret color, size, and arrangement. They can be used as ornamental plants, cut stems, and made into bouquets. They can also be planted in gardens or pots and traded either fresh or dried (Bradley *et al.* 1999). Using specific cultivars of this herbaceous plant for floral arrangements is a common practice throughout Europe (Melo *et al.* 2019).

The safflower is an annual herbaceous plant that is self-pollinating and tolerant of high temperature, salinity, and little water supply (Dantas *et al.* 2011; Zareie *et al.* 2013; Santos and Silva 2015; Melo *et al.* 2019). In many semi-arid parts of the world, it has adapted (Mündel *et al.* 1997). It can be grown in a variety of climates, from temperate to tropical, and it grows best on well-drained soils. Because it can withstand dryness, it is a desirable crop to grow in arid and semi-arid areas. Usually, safflowers are planted in the early spring and harvested in the early fall or late summer (Emongor 2010). However, it can also be planted as a winter crop in mild regions where winters are not too cold.

Between 2010 and 2021, there was a growing tendency in Türkiye's safflower production relative to the planting area until 2015 (Akgun and Soylemez 2022). However, due to the global spread of transgenic species, including cotton, soybean, and rapeseed, there has been a rapid fall in production in recent years (Ilkdogan and Olhan 2012). Türkiye does not fully realize the potential of safflower as an ornamental plant; instead, it is grown mostly for oil production and scientific research. For this reason, investing in the potential of this species is a promising strategy. In the developing and rapidly changing world, the ornamental plants sector has become a sector that changes rapidly in terms of the species and cultivars used and new options are needed. It has become necessary to select the right and high-quality plants for landscape design purposes and to use the latest production techniques in the production of these plants. However, given the growing relevance of floriculture in Türkiye's agriculture, it becomes important to search for and offer new commodities to increase and satisfy market demand.

Safflower is very tolerant in terms of ecological requirements such as drought, cold and salinity and has a high value in terms of ornamental plant potential with its flower and leaf characteristics (Hussain *et al.* 2016; Kayaçetin 2022; Pasban Eslam *et al.* 2024). Plant height, which is a parameter of the growth of the shoots of the plant in non-woody, herbaceous species suitable for growing in pots and species used as cut flowers, is one of the factors limiting the healthy growth of the plant. If the plant height and shape is not proportional to the pot in which it is grown, it prevents the plant from standing upright and causes it to tip over (Latimer and Scoggins 2012). This problem has the potential to occur not only in ornamental plants grown in pots, but also in all ornamental plants of herbaceous character. This process can cause the species to lean to the side, not get enough light, form shaded plant parts, touch the ground when it grows taller to access the sun, rot and die. As stated in the literature, studies should be carried out to create smaller and compact forms of such a valuable plant with high cold, drought and salt tolerance that can be used as an alternative with plant growth inhibitors. A quality ornamental plant is generally characterized by uniform flowering, a densely textured and erect stem, dark green leaves, and a plant height that is aesthetically compatible with the size of the pot. Growth inhibitors are widely used in ornamental plants for different purposes and are especially necessary to control plant height when tall plants are used in design. Growth inhibitors physiologically regulate plant height by retarding cell division and elongation in shoot tissues without deforming leaves and stems. These compounds are used to obtain stunted, more densely textured plants, to darken the color of green parts, to strengthen flower stalks, as well as to

program flowering and to increase resistance to environmental influences (Halevy 1985; Larson 1985; Karagüzel 1999; Seyidoğlu and Zencirkıran 2009).

Trinexapac-ethyl (TE) is one of the newest growth regulators used in agriculture and horticulture and is from the carboxylic acid family. The TE inhibits the biosynthesis of gibberellins but inhibits gibberellin production in the biosynthetic pathway much later than chloromequat or triazole compounds (Rademacher 2000; Hafner 2001). It is one of the important growth retardants that inhibits the formation of GA1 from GA20 and the conversion of GA1 to GA8 (Adams *et al.* 1992; Rademacher 2000). TE has been found to reduce cell elongation and suppress vegetative growth (Adams *et al.* 1992) and stabilize stem growth in some cereal crops and oilseed rape (Rademacher 2000). It shortens the internodes of the plant, resulting in a shorter and more robust plant (Kerber *et al.* 1989; Adams *et al.* 1991, 1992). It is used as a stem stabilizer in cereals, rice, and sunflowers. Short-term TE spray application has been reported to have responses in cultivated plants, such as reducing plant height in sunflower and increasing dry weight of grapes, while having no effect on cotton (Correia and Leite 2012). In grass crops, TE is a widely used growth retardant that effectively reduces grass leaf growth and subsequent mowing requirements during the cool and warm season (Johnson 1994; Ervin and Koski 1998, Fagerness and Penner 1998a; Fagerness and Penner 1998b; Ervin and Koski 2001). There are scientific studies reporting that foliar application of TE can reduce vegetative growth (Johnson 1994; Ervin and Koski 1998) and increase drought and salinity tolerance (McCann and Huang 2007, 2008; Bian *et al.* 2009; Arghavani *et al.* 2012), reduce water consumption, and increase osmotic regulation, leading to increased drought resistance (Elansary and Salem 2015) in turfgrasses. Although many studies have been conducted on the effects of TE on turfgrass plants, research on its effects on other ornamental plants is quite limited (Gardner and Metzger 2005).

Paclobutrazol (β -[(4-chlorophenyl)methyl]-2-(1,1-dimethylethyl)-1H-1,2,4-triazole-1-ethanol), another plant growth inhibitor, is an inhibitor of gibberellin biosynthesis (Bilgener *et al.* 1998). Paclobutrazol (PAC), a triazole derivative, is a potent growth inhibitor that can control growth in many plants even at low doses by stopping gibberellin and sterol biosynthesis and its activity persists for a long time (Fletcher *et al.* 2000; Gent and McAvoy 2000). Transportation takes place through the xylem system. Although the applied dose varies according to plant species, it is used at rates between 2 ppm to 90 ppm. It is absorbed immediately and becomes active after absorption in the roots and stem. A small portion is absorbed in the leaves (Ören 2012). Many researchers have reported that PAC provides height control in many ornamental plants, mostly flowering potted plants (Ruter 1996; Karagüzel 1999; Francescangeli and Zagabria 2008) and increases the ornamental value of the plant by increasing flowering (Karagüzel 1999). In addition, it has been emphasized in many studies that PAC has the effect of changing the color of leaves in plants (Kim *et al.* 1999; Pinto *et al.* 2005) and is also used to give compact structure to plants, especially in potted plants (Roberts *et al.* 1990). Paclobutrazol, which inhibits gibberellin biosynthesis in some plants, has been reported to make the plant resistant to cold (frost) (Aydoğdu and Boyraz 2005). Paclobutrazol is commonly applied as foliar spray and substrate wetting (pouring). Application techniques have a significant effect on its efficacy on the crop and many studies have reported that pouring application is more effective in shortening plant height. The effect of PAC also depends on the application of the appropriate dose, which may vary with species, variety, and environmental conditions (Hazar and Bora 2018). Many applications have been encountered in the literature for the

use of PAC in ornamental plant cultivation (Karagüzel 1999; Köse and Kostak 2000; Banon *et al.* 2002; Seyidoğlu and Zencirkıran 2009; Ören 2012).

The objective of this study is to investigate the effects of different doses and application methods of TE and PAC on the growth, development, and flowering characteristics of *C. tinctorius* plant. In this way, it is aimed to contribute to revealing the potential of this species, which is known to have high drought, cold, and salinity tolerance, in the ornamental plants sector and to make it more commonly used.

EXPERIMENTAL

Two different cultivars of safflower were used in this study. These cultivars are ‘Olas’ developed by Thrace Agricultural Research Institute (Edirne, Türkiye) and ‘Dinçer’ cultivar developed and registered by Transitional Zone Agricultural Research Institute (Eskişehir, Türkiye) in 1977.

‘Olas’ is a yellow-flowered and thorny cultivar and was developed as the first and only cultivar with high oil content and oleic fatty acid in Türkiye. Plant height is about 70 cm to 80 cm, and it is resistant to lodging. It is suitable for cultivation in all regions (Turkish Ministry of Agriculture and Forestry 2024a). ‘Dinçer’ cultivar has orange flowers and is thornless/has medium thorns. Seeds are white in color (Turkish Ministry of Agriculture and Forestry 2024b).

Safflower seeds of ‘Olas’ and ‘Dinçer’ cultivars were sown on 27th March 2023 in the cavities of the vials filled with peat-perlite-vermiculite (2:1:1) growing medium. Germination was observed one week after regular irrigation. When the first pair of true leaves appeared one month after sowing, the seedlings were transplanted into 15 × 15 cm diameter pots filled with peat-perlite-vermiculite (2:1:1) mixture. To encourage the growth and development of the seedlings, 18-18-18 balanced fertilizer (1 g/5 L) was applied one week after transplanting.

After germination of the seeds, the first plant growth inhibitor was applied to the seedlings (approximately 8 weeks after sowing), which were transplanted into pots when 6 to 8 leaves. The second plant growth inhibitor application was made one week after the first application. Trinexapac-ethyl (TE) sold under the trade name MODDUS of Syngenta brand and Paclobutrazol (PAC) sold under the trade name CULTAR 25SC of the same brand were used as plant growth inhibitors. The TE application was made by foliar spraying and application doses were 4 doses including control. These are 0 (control), 4, 6, 8, and 12 ppm. Control group plants were sprayed with water. The PAC application was made both as foliar spray and soil drench. Soil application was 0 (control), 25, 50 mg/pot, and foliar spraying was 0 (control), 50, 100, and 500 ppm. Control group plants were sprayed with water, and thus 2 safflower cultivars (Olas and Dinçer), 2 different plant growth inhibitors (TE and PAC), 2 different application methods (foliar and soil), and different doses in each (TE; foliar - 0, 4, 6, 8, and 12 ppm, PAC; soil 0, 25, and 50 mg/pot, foliar 0, 50, 100, and 500 ppm) were studied in the experiment. The experiment was planned according to the Randomized Block Design with three replications.

Some morphological and physiological measurements and observations were taken every week during the experiment. Observations were plant height and width, number of branches, leaf color, leaf chlorophyll content, number of flowers after flowering. Plant height was measured weekly starting 1 week after TE and PAC treatments from the soil level to the top of the plant to determine the above-ground part of the plant. Plant diameter

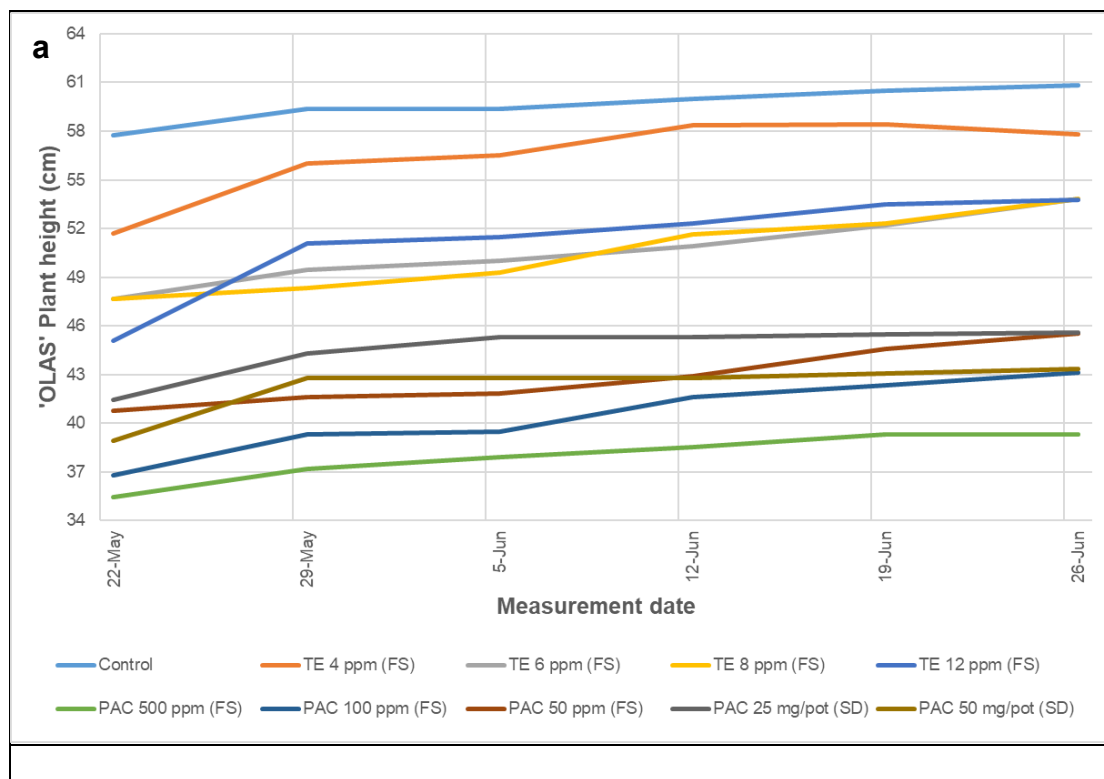
was measured weekly starting 1 week after TE and PAC treatments using the widest diameter along the top of the plant and averaged for each plant. To assess the number of branches, branches from the main stem were counted per week. Leaf color was determined using the CIELAB L^* , a^* , and b^* coordinate values, which were obtained with a CR-400 Chroma meter (Konica Minolta Sensing, Inc., Osaka, Japan). Three measurements were made on two youngest, fully grown leaves every week and averaged. Using the formula of Banon *et al.* (2002), the hue angle or value that indicates the color of the leaf was determined. When a color is viewed in a closed 360° ring or wheel, its hue is the characteristic that determines whether it is red, orange, yellow, green, blue, purple, or anywhere in between neighboring pairings of these colors. The hue angles of the four fundamental colors are as follows: blue is 270°, green is 180°, yellow is 90°, and red is 0° (Kortei and Akonor 2015). A handheld chlorophyll meter (SPAD-502 (Minolta Camera Co., Osaka, Japan) was used to measure the relative leaf chlorophyll content once a week starting after TE and PAC treatments. Rapid and nondestructive measurements that closely match the chlorophyll concentration of the leaf were made possible by the chlorophyll meter (Azia and Stewart 2001; Richardson *et al.* 2002). Every week, measurements of SPAD were obtained from the centers of each plant's two youngest, fully grown leaves. Five measurements were taken from two youngest and well grown leaves and the average value was calculated for each plant. Flowering begins approximately 2 weeks after the second TE and PAC applications. For determining number of flowers, all flowers were counted weekly for each pot until the experiment finished. At the end of 8 weeks, the experiment was terminated due to the increase in air temperatures and plant senescence. When the experiment was terminated, the plants were carefully removed from their pots. The roots were washed, then the roots and stems were separated, placed in separate envelopes, immediately taken to the laboratory, and weighed separately to obtain a fresh weight. The weighed plant root and green parts envelopes were then dried in a 72 °C oven for 48 hours and their dry weights were weighed. The averages of all data were subjected to analysis of variance in SPSS 17 program (SPSS Inc., Chicago, IL, USA), and the parameters that were statistically different according to the analysis results were compared with Duncan's multiple comparison test at the 5% significance level.

RESULTS AND DISCUSSION

The data presented in Fig. 1 show that the retarding effect of plant growth inhibitors on plant height can be seen in all applications. After the applications, significant differences were detected in plant height depending on the cultivars and plant growth inhibitor applications. It is seen in Fig. 1 that PAC application was more effective on plant height in both examined cultivars. On June 26, when the mean values of the last plant height were examined, it was observed that the control group was 60.83 cm in 'Olas' cultivar, this value varied between 53.78 cm and 57.83 cm in TE treated plants, and between 45.61 cm and 39.28 cm in PAC-treated plants. In 'Dinçer' cultivar, the control group was found to be 83.44 cm, and this value varied between 60.11 cm and 82.05 cm in TE treated plants and between 18.37 cm and 27.68 cm in PAC treated plants (Fig. 1). The authors' findings are similar to results of other studies with PAC, such as narcissus (*Narcissus tazetta* L.) (Demir and Çelikel 2019), gypsophila (*Gypsophila bicolor* (Freyn & Sint.) Grossh.) (Parlakova Karagöz *et al.* 2023), Easter lily (*Lilium longiflorum* Thunb.) (Jiao *et al.* 1986), *Camelina sativa* (Sumit *et al.* 2012) and rice (Dewi *et al.* 2016). In Jerusalem artichoke (*Helianthus*

tuberosus), another member of the Asteraceae family, which is used both as an ornamental plant with its yellow flowers and its tuber is edible, 50 ppm PAC application was sufficient to reduce plant height compared to the control (Phasri *et al.* 2019). Similarly, in chrysanthemum (*Chrysanthemum indicum*), a widely used ornamental plant in the world belonging to the same family, 25 and 50 ppm PAC application had a positive effect in reducing plant height (Abou Elhassan *et al.* 2021). Likewise, it was determined that PAC application significantly reduced plant height compared to the control application in *Calendula officinalis* (Mahgoub *et al.* 2006). Qrunfleh and Suwwan (1988) also stated that PAC application significantly reduced plant height in *Callistephus chinensis* and *Calendula officinalis* species. Xiangting *et al.* (2020) similarly reported that PAC application by spray at 400 mg/L in *Cymbidium hybridum* reduced plant height up to 90%.

According to the current findings, foliar application of PAC was more effective compared to soil drenching. This is thought to be due to the greater amount of active ingredients contained in the 100 ppm and 500 ppm foliar spray applications. The application method plays a major role in the effectiveness of PAC (Barrett and Bartuska 1982). The application method of PAC in similar literature is largely foliar spray or soil drenching. Among these applications, soil drenching has been reported to give more positive results (Keever *et al.* 1990; Whipker and Dasoju 1998; Hawkins *et al.* 2015; Karaguzel *et al.* 2004), as it provides longer absorption time and greater absorption of active ingredients (Karaguzel *et al.* 2004; Desta and Amare 2021). Karaguzel *et al.* (2004) reported that in order to obtain a similar retarding effect on plant growth characteristics, foliar spray applications using more active ingredients per plant are required compared to media drench applications. In addition, plant growth inhibitory applications were seen to be more effective in the Dinçer cultivar (Fig. 1).



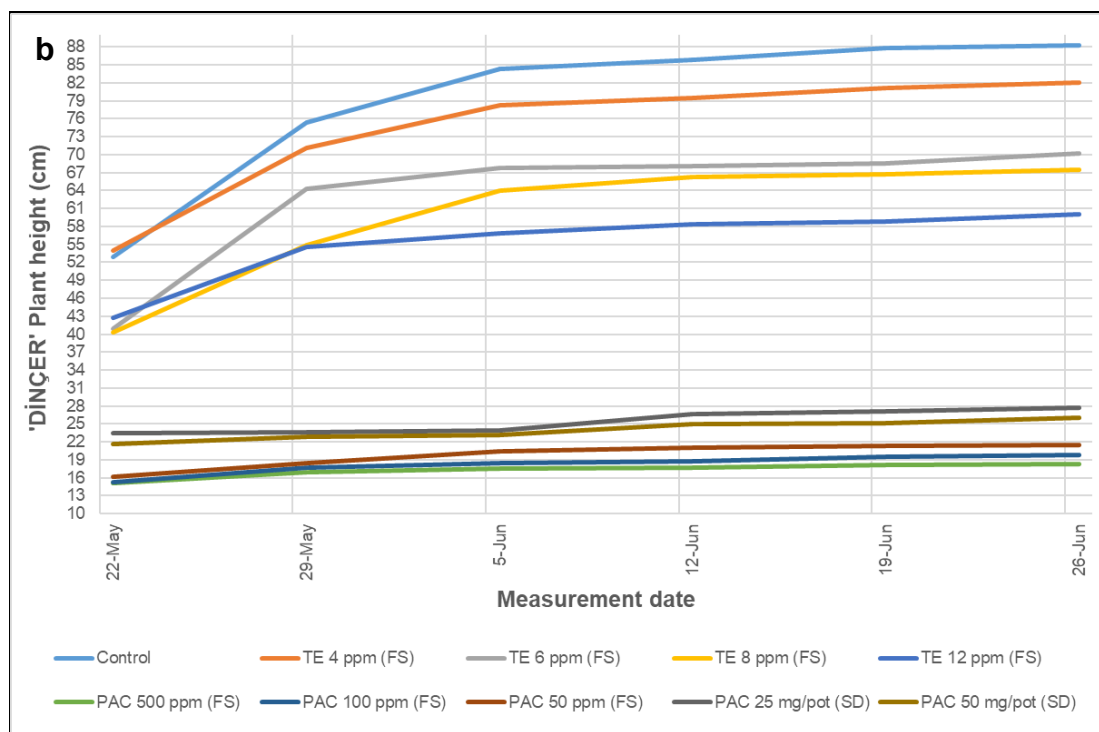


Fig. 1. Effects of growth retardants application method on plant height of *Carthamus tinctorius* during growing period

The ANOVA results showed that cultivar, plant growth inhibitor treatments, and cultivar $\times$ plant growth inhibitor treatment interactions all had significant effects on plant growth traits of safflower cultivars (Table 1).

Table 1. Analysis of Variance (Means Squares) for PH, PW, NOB, LCC, NOF, LC, SDW, and RDW of *Carthamus tinctorius* Cultivars and Evaluated Growth Retardant Applications

Source of Variation	df	Mean Square							
		PH (cm)	PW (cm)	NOB (Branches Plant ⁻¹)	LCC (spad)	NOF (Flowers Plant ⁻¹)	LC (°)	SDW (g Plant ⁻¹)	RDW (g Plant ⁻¹)
Cultivar (C)	1	103.42*	455.291***	52.678***	0.18 ^{NS}	12.577***	80.782***	4.654 ^{NS}	11.528***
Growth Retardants Applications (GRA)	9	1815.969***	22.495***	39.770***	26.057**	8.116***	25.348**	99.702***	17.511***
C $\times$ GRA	9	598.451***	9.529**	18.640***	10.21 ^{NS}	4.512***	23.997**	27.860***	2.055***
Error	40	24.883	2.841	2.923	7.01	0.834	7.642	1.151	0.099

NS, ***, **, *: Non significant, significant at $P \leq 0.01$, $P \leq 0.1$, $P \leq 0.5$, respectively.

PH: Plant height; PW: Plant width; NOB: Number of branches; LCC: Leaf chlorophyll content; NOF: Number of flowers; LC: Leaf color; SDW: Stem dry weight; RDW: Root dry weight

When the cultivar means are examined, it is seen that while no significant difference is observed in terms of plant height and stem dry weight characteristics, 'Dinçer' cultivar has higher values with significant differences in terms of other growth

characteristics (plant width, leaf chlorophyll content, number of flowers, leaf color, and root dry weight) (Table 2). Table 2 shows that in ‘Olas’ and ‘Dinçer’ cultivars, average plant height was 49.51 cm and 47.68 cm, plant width was 21.32 cm and 26.83 cm, number of branches was 10.6 and 8.73, leaf color was 65.34 SPAD and 64.40 SPAD, number of flowers was 5.22 and 6.13, leaf color was 182.15° and 184.48°, stem dry weight was 10.06 g and 10.62 g and root dry weight was 11.53 g and 2.42 g, respectively.

When the plant growth inhibitor application means were examined, it was seen in Table 2 that the height values varied between 72.14 cm and 28.82 cm. It was determined that plant heights decreased with increasing doses of plant growth inhibitors. Foliar applications of PAC were more effective compared to soil applications, and TE applications were more effective with increasing doses, showing a statistical difference from the control group, however, this effect was not as effective as PAC applications. As seen in Table 2, while the mean height values were 72.14 cm in the control group, this value was between 56.95 cm and 69.94 cm in TE treatments, between 28.82 and 33.53 cm in PAC treated plants as foliar spray and between 34.69 and 36.64 cm in PAC treated plants as a soil drench. Similarly, Vital *et al.* (2017) concluded that the plant height of sunflower plants was not affected by increasing TE doses (0 to 3, 12, 6.25 to 12.50, 25, and 75 g ha⁻¹), and the height increased 78% compared to the control. The TE is an effective growth regulator for many species of the Poaceae family, including turf grasses, and has been reported to be less active in dicotyledons than in *Poaceae* species, probably due to their relative inability to hydrolyze ethylester to the active acid form (Rademacher 2000; Sever Mutlu and Kurtulan 2015). The TE has also been reported to have little or no growth regulatory activity in various species, including marigold (*Tagetes erecta* L.), begonia (*Begonia semperflorens*), glasswort (*Impatiens wallerana*.), petunia (*Petunia × hybrida*), tomato (*Lycopersicon esculentum*), and pepper (*Capsium annuum*) (Gardner and Metzger 2005). It is seen in Table 3 that in ‘Olas’ cultivar, plant height was shortened with increasing doses of TE application, but these differences were not significantly different from the control group. In the Dinçer cultivar, while increasing doses of PAC are not statistically significant, statistically significant differences are noted in increasing doses of TE. In both cultivars, the lowest average plant height values were determined in plants to which PAC was applied *via* leaves at a dose of 500 ppm. At this dose, plant height decreased by 78% in ‘Dinçer’ cultivar compared to the control group, while this rate was 35% in ‘Olas’ cultivar. When these values were compared with the control group, it was determined that the change in plant height in the ‘Dinçer’ cultivar was greater. As a result of the research, it is seen in Table 3 that plant growth inhibitors are more effective in the ‘Dinçer’ cultivar in terms of plant height values.

Table 2. Mean Comparisons on the Effects of PH, PW, NOB, LCC, NOF, LC, SDW, and RDW for Cultivars and Growth Retardant-applications of *Carthamus tinctorius*

Treatments	Growth Characteristic							
	PH (cm)	PW (cm)	NOB (Branches Plant ⁻¹)	LCC (SPAD)	NOF (Flowers Plant ⁻¹)	LC (°)	SDW (g Plant ⁻¹)	RDW (g Plant ⁻¹)
Cultivar								
Olas	49.51 a ^z	21.32 b	10.60 a	65.34 a	5.22 b	182.15 b	10.06 a	1.53 b
Dinçer	47.68 a	26.83 a	8.73 b	64.40 a	6.13 a	184.48 a	10.62 a	2.42 a
Growth Retardants Applications								
Control	72.14 a	26.17 ab	11.85 ab	60.87 c	5.36 cd	184.06 ab	13.86 bc	2.44 c
TE 4 ppm (FS)	69.94 a	27.72 a	13.16 a	63.49 bc	6.66 b	184.51 ab	14.89 b	4.13 a
TE 6 ppm (FS)	62.03 b	25.10 bc	11.42 ab	65.09 ab	6.50 bc	185.76 a	13.05 c	2.73 c
TE 8 ppm (FS)	60.62 b	25.27 bc	13.14 a	66.04 ab	8.11 a	184.07 ab	16.51 a	4.39 a
TE 12 ppm (FS)	56.95 b	23.33 cd	9.83 bc	66.45 ab	5.5 cd	185.02 ab	11.61 d	3.75 b
PAC 50 ppm (FS)	33.53 cd	21.53 d	7.5 de	66.75 ab	5.44 cd	178.68 c	7.50 e	0.44 d
PAC 100 ppm (FS)	31.47 cd	23.23 cd	7.67 de	67.03 ab	5.28 d	181.88 bc	6.94 e	0.69 d
PAC 500 ppm (FS)	28.82 d	22.25 d	6.06 e	68.18 a	3.83 e	184.03 ab	5.34 f	0.29 d
PAC 25 mg/pot (SD)	36.64 c	22.56 d	8.33 cd	64.33 b	5.11 d	183.39 ab	6.32 ef	0.42 d
PAC 50 mg/pot (SD)	34.69 cd	23.62 cd	7.67 de	65.33 ab	4.94 d	181.74 bc	7.39 e	0.38 d

^z: In each column and treatment factor, means followed by the same letter are not significantly different at the 5% level according to Duncan's multiple range tests.

TE: Trinexapac-ethyl, PAC: Paclobutrazol, FS: Foliar spray, SD: Soil Drench;

PH: Plant height; PW: Plant width; NOB: Number of branches; LCC: Leaf chlorophyll content; NOF: Number of flowers; LC: Leaf color; SDW: Stem dry weight; RDW: Root dry weight

Table 3. Mean Comparisons for Interaction Effects of Cultivar × Growth Retardant Applications on PH, PW, NOB, LCC, NOF, LC, SDW, and RDW of *Carthamus tinctorius*

Cultivar	Growth Retardants Application	Growth Characteristic							
		PH (cm)	PW (cm)	NOB (Branches Plant ⁻¹)	LCC (SPAD)	NOF (Flowers Plant ⁻¹)	LC (°)	SDW (g Plant ⁻¹)	RDW (g Plant ⁻¹)
Olas	Control	60.83 a ^z	21.1 bc	14.11 a	60.35 b	3.94 c	183.21 ab	12.18 a	1.41 c
	TE 4 ppm (FS)	57.83 a	24.28 a	10.98 ab	64.09 ab	5.11 bc	184.42 ab	12.54 a	2.87 b
	TE 6 ppm (FS)	53.83 a	20.44 bc	11.11 ab	66.55 a	6.89 a	187.02 a	11.56 ab	1.48 c
	TE 8 ppm (FS)	53.80 a	23.04 ab	11.89 ab	67.60 a	6.34 ab	184.14 ab	12.90 a	4.26 a
	TE 12 ppm (FS)	53.78 a	21.9 abc	9.89 b	68.13 a	4.67 c	185.35 a	9.65 bc	2.91 b
	PAC 50 ppm (FS)	45.5 b	19.58 c	9.11 b	65.01 ab	5.33 abc	173.42 c	8.55 cd	0.36 d
	PAC 100 ppm (FS)	43.11 bc	20.59 bc	9.33 b	65.32 ab	5.00 bc	178.19 bc	8.80 cd	0.57 d
	PAC 500 ppm (FS)	39.28 c	20.71 bc	8.45 b	67.10 a	4.22 c	181.81 ab	7.40 d	0.39 d
	PAC 25 mg/pot (SD)	45.61 b	20.75 bc	10.78 ab	63.99 ab	5.34 abc	183.11 ab	7.35 d	0.54 d
	PAC 50 mg/pot (SD)	43.32 bc	20.8 bc	10.44 ab	65.25 ab	5.33 abc	180.86ab	9.69 bc	0.4 d
Dinçer	Control	83.44 a	31.19 a	9.59 c	61.39 b	6.78 bc	184.91 a	15.54 bc	3.47 c
	TE 4 ppm (FS)	82.05 a	31.16 a	15.44 a	62.90 b	8.22 b	184.61 a	17.23 b	5.40 a
	TE 6 ppm (FS)	70.22 b	29.77 ab	11.72 b	63.63 b	6.11 cd	184.51 a	14.54 cd	3.99 bc
	TE 8 ppm (FS)	67.45 b	27.5 bc	14.39 a	64.47 ab	9.89 a	183.99 a	20.12 a	4.51 b
	TE 12 ppm (FS)	60.11 b	24.76 cd	9.78 c	64.76 ab	6.33 cd	184.69 a	13.58 d	4.60 b
	PAC 50 ppm (FS)	21.55 c	23.48 d	5.89 d	68.49 a	5.56 cd	183.93 a	6.45 e	0.53 d
	PAC 100 ppm (FS)	19.84 c	25.87 cd	6.00 d	68.75 a	5.56 cd	185.57 a	5.08 ef	0.81 d
	PAC 500 ppm (FS)	18.37 c	23.79 d	3.67 e	69.25 a	3.45 e	186.26 a	3.29 f	0.19 d
	PAC 25 mg/pot (SD)	27.68 c	24.38 cd	5.89 d	64.67 ab	4.89 de	183.67 a	5.28 e	0.29 d
	PAC 50 mg/pot (SD)	26.05 c	26.45cd	4.89 de	65.42 ab	4.55 de	182.62 a	5.09 ef	0.27 d

^z: In each column and treatment factor, means followed by the same letter are not significantly different at the 5% level according to Duncan's multiple range tests.

TE: Trinexapac-ethyl, PAC: Paclobutrazol, FS: Foliar spray, SD: Soil drench;

PH: Plant height; PW: Plant width; NOB: Number of branches; LCC: Leaf chlorophyll content; NOF: Number of flowers; LC: Leaf color; SDW: Stem dry weight; RDW: Root dry weight

When the averages were examined in terms of plant width and branch number content, the highest values were determined in plants applied with foliar TE at a dose of 4 ppm (Table 2). These values are 27.7 cm and 13.16 pieces, respectively. It is seen in Table 2 that plant width and branch number values decreased with increasing doses of TE and in all applications of PAC compared to the control group. Similarly, in terms of plant width, Whipker and Dosoju (1998) reported that soil PAC application in sunflower plants (*Helianthus annuus* cv. 'Pacino') grown in pots shortened plant height 27% compared to the control, while reducing plant width 16%. Similarly, Piphawatthanakul *et al.* (2024) determined that 400 ppm foliar and soil PAC application in *Dendranthema grandiflora* species significantly reduced plant width. The findings obtained in this study in terms of plant width are also parallel to the findings obtained in *Cymbidium hybridum* (Xiangting *et al.* 2020) and *Dendranthema grandiflora* (Piphawatthanaku *et al.* 2024). In both species, PAC application significantly reduced plant width. The findings obtained in terms of branch number are parallel to Parlakova Karagöz *et al.* (2023) and (Taha and Sorour 2016). Parlakova Karagöz *et al.* (2023) determined that PAC application in *Gypsophila bicolor* caused a decrease in the number of branches compared to the control group. Similarly, in another potted ornamental plant, *Pentas lanceolata*, increasing PAC doses suppressed vegetative growth and caused a decrease in the number of branches (Taha and Sorour 2016).

It is noteworthy that leaf chlorophyll content increased with increasing doses of PAC in foliar and soil applications, while in TE application, this value did not show significant difference depending on the dose in general, but TE application caused a statistically significant increase compared to the control group (Table 2). The mean leaf chlorophyll content in control plants was 60.87. This value varied between 63.49 and 66.45 spad in TE treated plants, between 66.75 and 68.10 in PAC treated plants as foliar spray and between 64.33 and 65.33 in PAC treated plants as a soil drench. It has been reported that PAC application effectively reduced the vegetative growth of rice plants while increasing the chlorophyll content (Dewi *et al.* 2016). Similarly, in chrysanthemum (*Chrysanthemum indicum*) species, 25 and 50 ppm PAC application increased the chlorophyll content (Abou Elhassan *et al.* 2021). Similarly, in peony (*Paeonia lactiflora*), it was shown that PAC-treated plants were superior in terms of increased photosynthetic properties compared to untreated controls (Xia *et al.* 2018). Similar results were obtained in gerbera (*Gerbera jamesonii*) species (Lee and Lee 1990). Chlorophyll, a critical component of the primary photosynthetic reaction, has a dual function in photosynthesis. It captures light and it serves as a medium for light-induced charge separation and electron transport. The biosynthesis of chloroplast pigments is significantly affected by PAC. Various studies on tef plant (Tsegaw *et al.* 2005) and camelina plant (Sumit *et al.* 2012) showed that the amount of chlorophyll was higher in PAC-treated plants compared to the control. The increase in chlorophyll content in PAC-treated plants may be due to minimization of the damage caused by reactive oxygen species and changes in the levels of carotenoids, ascorbate, and ascorbate peroxidase. Nivedithadevi *et al.* (2015) reported that PAC-treated plants synthesized more cytokinins, which increased chloroplast differentiation and chlorophyll biosynthesis and prevented chlorophyll degradation. In *Camelina sativa* L. species, PAC application also increased the chlorophyll content, leading to higher photosynthesis and higher yield (Sumit *et al.* 2012). The results of Dewi *et al.* (2016) showed that black rice plants treated with 25 or 50 ppm PAC had greener leaves compared to the control and the leaves also experienced delayed senescence. It was thought that this could be due to the increase in the activity of oxidative enzymes that

prevent cell maturation. Regarding TE application, Sever Mutlu and Kurtulan (2015) reported that TE application in ornamental pepper (*Capsicum annuum* L.) increased the chlorophyll content in plants. They reported that TE application increased the chlorophyll content in plants. It is known in the literature that TE increases the mesophyll cell density and chlorophyll concentration in grass plants (Ervin and Koski 2001; Heckman *et al.* 2005; McCullough *et al.* 2006a, 2006b). The current findings are parallel to the literature reports.

The highest leaf color values were determined in plants applied with foliar TE at a dose of 6 ppm (185.8°), and the lowest values were found in plants applied with foliar PAC at a dose of 50 ppm (178.7°). In parallel with these findings, there are many studies reporting that TE application darkens leaf color, especially in turfgrass species (Ervin and Koski 2001; Heckman *et al.* 2001, 2005; McCullough *et al.* 2006; Anand 2023). Similarly, TE application in rosemary (*Rosmarinus officinalis*) and thuja (*Thuja orientalis* “Morgan”) species used as ornamental plants increased the leaf chlorophyll content, resulting in plants with darker green leaves (Zamani *et al.* 2016). Regarding PAC application, leaves treated with PAC in peony (*Paeonia lactiflora*) had a darker green color with decreased brightness (L^*) and increased color tone angle (h°) (Xia *et al.* 2018). The PAC has also been reported to intensify leaf color in azalea, fuchsia, and poinsettia (Witt 1986), rhododendron (Heursel and Witt 1985), and carnation (Banon *et al.* 2002). Although the literature research found that PAC application darkened leaf color, it was observed in this study that PAC application doses had different effects on the species in terms of leaf color parameter. When the means were examined at the interaction level, it was seen that the differences in leaf color values and chlorophyll amount were not significant in Dinçer cultivar, while the differences observed in Olas cultivar were statistically significant (Table 3).

Flowering is an important issue in species grown for ornamental plant purposes. While control plants had a mean number of 5.36 flowers, plants treated with 4 ppm, 6 ppm, 8 ppm and 12 ppm TE had 6.66, 6.50, 8.11 and 5.5 flowers respectively, plants treated with 50 ppm, 100 ppm and 500 ppm PAC as foliar spray had 5.44, 5.28 and 3.83 flowers respectively, plants treated with 25 mg and 50 mg PAC as soil drench 5.11 and 4.94 flowers respectively. In plants applied with PAC, the decrease in the number of flowers with increasing dose shows a statistically significant difference from the control application (Table 2). In contrast, it is noteworthy that the average number of flowers in plants applied with the highest dose of TE did not show a significant difference from the control group (Table 2). It is thought that the effect of PAC application on flowering may be highly dependent on the species (Hawkins *et al.* 2015). Although there are findings in the literature that PAC application increases the number of flowers (Haque *et al.* 2007; Mishra and Yadava 2011; Chauhan *et al.* 2021), there are also researchers who argue the opposite. In the literature, it has also been reported that PAC application delays flowering in some plants. For example, it delayed flowering in carnation (Atanassova *et al.* 2004) and Japanese rose (*Hibiscus rosa-sinensis*) species (Nazarudin 2012). Similarly, the findings we obtained regarding the number of flowers are parallel to the findings obtained in potted sunflower (*Helianthus tuberosus* L.), which is in the same family as the safflower plant examined in the scope of the current study. It was found that increasing PAC application decreased the number of flowers. In Bodrum daisy (*Osteospermum ecklonis* (DC.) Norl.) species, PAC applied from soil delayed flowering by 5 to 7 days (Barnes *et al.* 2009). Flower bud formation was reported to be delayed by 7 to 8 days in lily hybrids (Sharma *et al.* 2009). Because delayed flowering can make plants less marketable, a plant growth inhibitor that delays growth while having a positive or neutral effect on flowering time is desirable (Hawkins *et al.* 2015).

When the data are considered in terms of growth inhibitor averages, the highest root and shoot dry weight values were found in plants treated with foliar TE at a dose of 8 ppm (4.39 g and 16.51 g, respectively), while the lowest values were found in plants treated with foliar PAC at a dose of 500 ppm (0.29 g and 5.34 g, respectively) (Table 2).

In all doses and applications of PAC, low values were measured in terms of root dry weight averages without any statistically significant difference (Table 2). While the root dry weight was 2.44 g in the control plants, this value was between 0.29 g and 0.69 g in PAC treated plants (Table 2). Similarly, Taha and Sorour (2016) reported that PAC application caused a significant decrease in stem dry weight in *Pentas lanceolata* species. In terms of PAC application method, it was revealed that foliar spray application was more effective in reducing stem dry weight. Again, Zamani *et al.* (2016) reported that PAC application reduced root and stem fresh and dry weights in rosemary (*Rosmarinus officinalis*) and thuja (*Thuja orientalis* “Morgan”) species used as ornamental plants. The PAC significantly reduced plant dry mass in petunia, pansy, geranium, and carnation species (Collado and Hernández 2021). Ruter (1994) reported it decreased as PAC application increased in *Pyracantha coccinea* species. Abod and Yasin (2002) reported that the root dry mass of *Acacia mangium* seedlings was 12% lower than control plants after 12 weeks of exposure to PAC. Unlike the current findings with TE application, Elansary and Salem (2015) reported that a decrease in root dry weight was observed after TE sprays in *Spirea nipponica*, *Pittosporum eugenoides*, and *Viburnum nadum* species compared to plants without TE application, but this application had no effect on root dry weight in *S. nipponica*. When the means were considered at the interaction level, it was observed that the root dry weight values of Dinçer cultivar (2.42 g) were higher than Olas cultivar (1.53 g) (Table 3).

CONCLUSIONS

1. This study investigated the effects of various doses and application methods of TE and PAC on growth and flowering characteristics of safflower (*Carthamus tinctorius*) plant. These plants are known to have high drought, cold, and salinity tolerance. Within the scope of this study, the utilization potential of this species in the ornamental plants sector was revealed and has contributed to its popularization. The appropriate doses and application methods of plant growth inhibitors were determined in terms of the parameters considered in 'Olas' and 'Dinçer' cultivars.
2. The results from this study showed that the retarding effect of plant growth inhibitors on plant height can be seen in all applications and that the effectiveness of the applied plant growth regulators varies depending on the cultivars.
3. It was determined that PAC application was more effective on plant height in both examined cultivars and that foliar spraying of PAC was more effective than soil drenching application.
4. The decrease in the width, branch and flower number values of the plants with increasing doses of foliar spraying of PAC causes a decrease in the ornamental plant value of safflower cultivars.

5. Foliar application of PAC at a dose of 50 ppm can be used to increase the number of flowers and partially control plant height without reducing the ornamental value of safflower cultivars.
6. The results of this study revealed that the effects of higher doses of TE should be investigated.

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REFERENCES CITED

- Abod, S. A., and Yasin, S. (2002). "Effects of paclobutrazol and daminozide on the growth of *Acacia mangium* seedlings," *Pertanika Journal of Tropical Agricultural Science* 25(2), 143-148.
- About Elhassan, M. H., Bosila, H. A., Hamza, M. A. Elateeq, A. A., and Abdel-Gawad, A. I. (2021). "Effect of cycocel and paclobutrazol on the dwarfing characteristics of *Chrysanthemum indicum* L. Al-Azhar," *Journal of Agricultural Research* 46(2), 41-50. DOI: 10.21608/AJAR.2022.254848
- Adams, R., Weiler E. W., Kerber E., Pfister K., and Schar, H. P. (1991). "Studies on the action of the new growth retardant CGA 163'935," in: *The BCPC Conference- Weeds* 2, Brighton, England, pp. 1133-1138.
- Adams, R., Kerber, E., Pfister, K., and Weiler, E. W. (1992). "Studies on the action of the new growth retardant CGA 163'935 (Cimectacarb)," in: *Plant Growth Regulation, 14th Inter. Conf. Plant Growth Substances*, Amsterdam, Netherlands, pp. 818-827.
- Akgun, M., and Soylemez, E. (2022). "Determining the future trends of safflower plant in Türkiye," *International Journal of Agriculture, Environment and Food Sciences* 6(1), 50-57. DOI: 10.31015/jaefs.2022.1.8
- Anand, M. (2023). "Role of growth regulators on turf grass," *Agri Articles* 03(03), 382-384.
- Arghavani, M., Kafi, M., Babalar, M., Naderi, R., Hoque, M. A., and Murata, Y. (2012). "Improvement of salt tolerance in Kentucky bluegrass by trinexapac-ethyl," *HortScience* 47, 1163–1170. DOI: 10.21273/HORTSCI.47.8.1163
- Asgarpanah, J., and Kazemivash, N. (2013) "Phytochemistry, pharmacology and medicinal properties of *Carthamus tinctorius* L.," *Chin. J. Integr. Med.* 19(2), 153-159. DOI: 10.1007/s11655-013-1354-5
- Atanassova, B., Filipova, I., and Alexieva, V. (2004). "Effect of plant growth regulators alar, MEIA and paclobutrazol on the phenophase of flowering and some ornamental parameters of mini carnation (*D. caryophyllus* f. spray Hort.)," *Bulg. J. Agric. Sci.* 10, 305-309. DOI: 10.17660/ActaHortic.2019.1237.21
- Aydoğdu, M., and Boyraz, N. (2005). "Plant growth regulators (hormone) and resistance to diseases (A review)," *J. Crop Res.* 1, 35-40.

- Azia, F., and Stewart, K. A. (2001). "Relationship between extractable chlorophyll and SPAD values in muskmelon leaves," *J. Plant Nutr.* 24, 961-966. DOI: 10.1081/PLN-100103784
- Banon, S., Gonzales, A., Cano, E. A., Franco, J. A., and Fernandez, J. A. (2002). "Growth development and colour response of potted *Dianthus caryophyllus* cv. Mondriaan to paclobutrazol treatment," *Scientia Horticulturae* 94(3-8), 371-377. DOI: 10.1016/S0304-4238(02)00005-5
- Barrett, J. E., and Bartuska, C. A. (1982). "PP333 effects on stem elongation dependent on site of application," *HortScience* 17, 737-738.
- Barnes, J., Whipker, B., Buhler, W., and McCall, I. (2009). "Osteospermum growth control with paclobutrazol substrate drenches," in: *Proc. 36th Annu. Mtg. of the Plant Growth Regulat. Soc. Amer.*, Asheville, NC, USA, pp. 96-99.
- Bian, X., Merewitz, E., and Bingru, H. (2009). "Effect of trinexapac-ethyl on drought responses in creeping bentgrass associated with water use and osmotic adjustment," *J. Am. Soc. Hortic. Sci.* 134, 505-510. DOI: 10.21273/JASHS.134.5.505
- Bilgener, S. K., Demirsoy, H., and Beyhan, N. (1998). "Effect of paclobutrazol on vegetative growth and fruit quality of some peaches grown in Samsun," *Turkish Journal of Agriculture and Forestry* 22(5), 425-434.
- Bradley, V. L., Guenther, R. L., Johnson, R. C., and Hannan, R. M. (1999). "Evaluation of safflower germplasm for ornamental use," in: *Perspectives on New Crops and New Uses*, J. Janick (ed.), ASHS Press, Alexandria, VA, USA, pp. 433-435.
- Chauhan, V., Bohra, M., Tomar, R., and Dobhal, N. (2021). "Effect of paclobutrazol and daminozide on floral attributes of chrysanthemum (*Dendranthema grandiflora* Tzvelve)," *Int. J. Curr. Microbiol. App. Sci.* 10(02), 2754-2759. DOI: 10.20546/ijcmas.2021.1002.304
- Collado, C. E., and Hernández, R. (2021). "Effects of light intensity, spectral composition, and paclobutrazol on the morphology, physiology, and growth of petunia, geranium, pansy, and dianthus ornamental transplants," *Journal of Plant Growth Regulation* 41(2), 461-478. DOI: 10.1007/s00344-021-10306-5
- Correia, N. M., and Leite, G. J. (2012). "Selectivity of the plant growth regulators trinexapacethyl and sulfometuron-methyl to cultivated species," *Sci. Agric.* 69(3), 194-200. DOI: 10.1590/S0103-90162012000300004
- Dantas, C. V. S., Silva, I. B., Pereira, G. M., Maia, J. M., Lima, J. P. M. S., and Macedo, C. E. C. (2011). "Influence of sanity and water deficit on seed germination of *Carthamus tinctorius* L.," *Brazilian Journal of Seeds* 33(3), 574-582.
- Dasoju, S., Evans, M. R., and Whipker, B. E. (1998). "Paclobutrazol drench activity in coir-and peat-based root substrates," *HortTechnology* 8(4), 595-598. DOI: 10.21273/HORTTECH.8.4.595
- Demir, S., and Çelikel, F. G. (2019). "Effects of plant growth regulators on the plant height and quantitative properties of *Narcissus tazetta*," *Turkish Journal of Agriculture and Forestry* 43(1), 105-114. DOI: 10.3906/tar-1802-106
- Desta, B., and Amare, G. (2021). "Paclobutrazol as a plant growth regulator," *Chem. Biol. Technol. Agric.* 8(1), DOI: 10.1186/s40538-020-00199-z
- Dewi, K., Agustina, R. Z., and Nurmalika, F. (2016). "Effects of blue light and paclobutrazol on seed germination, vegetative growth and yield of black rice (*Oryza sativa* L. 'Cempo Ireng')," *Biotropia* 23(2), 85-96. DOI: 10.11598/btb.2016.23.2.478
- Elansary, H. O., and Salem, M. Z. M. (2015). "Morphological and physiological responses and drought resistance enhancement of ornamental shrubs by trinexapac-

- ethyl application,” *Scientia Horticulturae* 189, 1-11. DOI: 10.1016/j.scienta.2015.03.033
- Emongor, V. (2010). “Safflower (*Carthamus tinctorius* L.) the underutilized and neglected crop: A review,” *Asian Journal of Plant Sciences* 9(6), 299-306. DOI: 10.3923/ajps.2010.299.306
- Erbaş, S., and Baydar, H. (2017). “Genetic of flower color and leaf spininess in safflower (*Carthamus tinctorius* L.),” *Anadolu J. Agr. Sci.* 32 (2), 244-248. DOI: 10.7161/omuanajas.321085
- Ervin, E. H., and Koski, A. J. (1998). “Growth responses of *Lolium perenne* L. to trinexapac-ethyl,” *HortScience* 33(7), 1200-1202. DOI: 10.21273/HORTSCI.33.7.1200
- Ervin, E. H., and Koski, A. J. (2001). “Trinexapac-ethyl effects on Kentucky bluegrass evapotranspiration,” *Crop Science* 41, 247-250.
- Fagerness, M. J., and Penner, D. (1998a), “Evaluation of V-10029 and trinexapac-ethyl for annual bluegrass seedhead suppression and growth regulation of five cool-season turfgrass species,” *Weed Technol.* 12, 436-440. DOI: 10.1017/S0890037X00044109
- Fagerness, M. J., and Penner, D. (1998b), “¹⁴C-Trinexapac-ethyl absorption and translocation in Kentucky bluegrass,” *Crop Science* 38, 1023-1027.
- Fletcher, R. A., Gilley, A., Sankhla, N., and Davis, T. D. (2000). “Triazoles as plant growth regulators and stress protectants,” *Horticultural Reviews* 24, 55-138.
- Francescangeli, N., and Zagabria, A. (2008). “Paclobutrazol for height control of petunias,” *Chilean Journal of Agricultural Research* 68(3), 309-314. DOI: 10.4067/S0718-58392008000300012
- Gardner, D. S., and Metzger, J. D. (2005). “Use of trinexapac-ethyl for growth regulation of chrysanthemum (*Dendranthema x grandiflora*),” *HortScience* 40(3), 670-674. DOI: 10.21273/HORTSCI.40.3.670
- Gent, M. P. N., and McAvoy, R. J. (2000). “Plant growth retardants in ornamental horticulture: A critical appraisal,” in: *Plant Growth Regulators in Agriculture and Horticulture*, A. S. Basra (ed.), Food Products Press, New York, NY, USA, pp. 89-145.
- Gürsoy, M., Başalma, D. and Nofouzi, F. (2018). “Effects of safflower cultivars (*Carthamus tinctorius* L.) on yield and yield components of different row and row spaces,” *Selcuk J Agr Food Sci* 32(1), 20-28.
- Hafner, V. (2001). “Moddus – universal product for lodging prevention in cereals,” in: *5th Slovenian Conference on Plant Protection*, Catez ob Savi, Slovenia, pp. 167-172.
- Haque, S., Farooqi, A. H. A., Gupta, M. M., Sangwan, R. S., and Khan, A. (2007). “Effect of ethrel, chlormequat chloride and paclobutrazol on growth and pyrethrins accumulation in *Chrysanthemum cinerariaefolium*,” *Plant Growth Regulators* 51, 263-269. DOI: 10.1007/s10725-007-9170-6
- Halevy, A. H. (1985). “Recent advances in the use of growth substances in ornamental horticulture,” in: *Plant Growth Substances*, M. Bopp (ed.), Springer-Verlag, Heidelberg, Berlin, pp. 391-398.
- Hawkins, S. M., Ruter, J. M., and Robacker, C. D. (2015). “Spray and drench treatments of paclobutrazol influence growth of dissotis and tibouchina,” *HortScience* 50(10), 1514-1517. DOI: 10.21273/HORTSCI.50.10.1514
- Hazar, D., and Bora, Ö. F. (2018). “Küpe çiçeğinde (*Fuchsia* spp.) paclobutrazol uygulamalarının bitki gelişimi üzerine etkileri [Effects of paclobutrazol applications

- on plant growth in fuchsia (*Fuchsia* spp.),” *Süleyman Demirel Üniversitesi Ziraat Fakültesi Dergisi* 1, 528-538.
- Heckman, N. L., Gaussoin, R. E., Horst, G. L., and Elowsky, C. G. (2005). “Growth regulator effects on cellular characteristics of two turfgrass species,” *Int. Turfgrass Soc. Res. J.* 10, 857-861.
- Heckman, N. L., Horst, G., and Gaussoin, R. (2001). “Influence of trinexapac-ethyl on specific leaf weight and chlorophyll content on *Poa pratensis*,” *International Turfgrass Society Research Journal* 9, 287-290.
- Heursel, J., and Witt, H. H. (1985). “Bonzi-a new growth regulator for evergreen azaleas,” *Deutscher Gartenbau* 39(37), 1742-1746.
- Hussain, M. I., Lyra, D. A., Farooq, M., Nikoloudakis, N., and Khalid, N. (2016). “Salt and drought stresses in safflower: A review,” *Agronomy for Sustainable Development* 36(4), 1-31. DOI: 10.1007/s13593-015-0344-8
- Ilkdogan, U. Y. (2012). *Necessary Conditions for Safflower Production in Turkey and Policies to be Established* (Report No. 205), Ministry of Food, Agriculture and Livestock Institution of Agricultural Economics and Policy Development, Ankara, Türkiye.
- Jiao, J., Tsujita, M. J., and Murr, D. P. (1986). “Effects of paclobutrazol and a-rest on growth, flowering, leaf carbohydrate and leaf senescence in 'Nellie White' easter lily (*Lilium longiflorum* Thunb.),” *Scientia Horticulturae* 30(1-2), 135-141. DOI: 10.1016/0304-4238(86)90089-0
- Johnson, B. J. (1994). “Influence of plant growth regulators and mowing on two bermudagrasses,” *Agron. J.* 86, 805-810. DOI: 10.2134/agronj1994.00021962008600050011x
- Karagüzel, O. (1999). “Effects of paclobutrazol on growth and flowering of *Bougainvillea spectabilis* WILLD,” *Turkish Journal of Agriculture and Forestry* 23, 527-532.
- Karaguzel, O., Baktir, I., Cakmakci, S., and Ortacesme, V. (2004). “Growth and flowering responses of *Lupinus varius* L. to paclobutrazol,” *HortScience* 39(7), 1659-1663. DOI: 10.21273/hortsci.39.7.1659
- Kayaçetin, F. (2022). “Assessment of safflower genotypes for individual and combined effects of drought and salinity stress at early seedling growth stages,” *Turkish Journal of Agriculture and Forestry* 46, 601-612. DOI:10.55730/1300-011X.3029
- Keever, G. J., Foster, W. J., and Stephenson, J. C. (1990). “Paclobutrazol inhibits growth of woody landscape plants,” *J. Environ. Hort.* 8(1), 41-47. DOI: 10.24266/0738-2898-8.1.41
- Kerber, E., Leypoldt, G., and Seiler, A. (1989). “CGA 163'935, a new plant growth regulator for small grain cereals, rape and turf,” in: *The BCPC Conference – Weeds*, Brighton, England, pp. 83-88.
- Kim, S. H., De Hertogh, A. A., and Nelson, P. V. (1999). “Effects of plant growth regulators applied as sprays or media drenches on forcing of dutch-grown bleeding heart as a flowering potted plant,” *HortTechnology* 9(4), 629-33. DOI: 10.21273/HORTTECH.9.4.630
- Kortei, N. K., and Akonor, P. T. (2015). *Correlation Between Hue-angle and Colour Lightness of Gamma Irradiated Mushrooms*, *Annals Food Science and Technology*, Valahia University Press, Accra, Ghana.

- Köse, H., and Kostak, S. (2000). "The propagation of *Nerium oleander* L. cv. Variegata with cuttings and effects of paclobutrazol on growth and flowering," *Anadolu Journal of Aegean Agricultural Research Institute* 10(1), 31-42.
- Landau, S., Friedman, S., Brenner, S., Bruckental, I., Weinberg, Z. G., Ashbell, G., Hen, Y., Dvash, L., and Leshem, Y. (2004). "The value of safflower (*Carthamus tinctorius* L.) hay and silage grow under mediterranean conditions as forage for dairy cattle," *Livestock Production Science* 88, 263-271. DOI: 10.1016/j.livprodsci.2003.11.011
- Larson, A. R. (1985). "Growth regulators in floriculture," *Hort. Reviews* 7, 400-481. DOI: 10.1002/9781118060735
- Latimer J. G., and Scoggins H. (2012). "Using plant growth regulators on containerized herbaceous perennials," *Virginia Cooperative Extension*. Retrieved from: http://pubs.ext.vt.edu/430/430-103/430-103_pdf.pdf
- Lee, P. O., and Lee, J. S. (1990). "Effects of ancymidol and paclobutrazol on growth and flowering of potted gerbera," *Journal of the Korean Society for Horticultural Science* 31(3), 300-304.
- Mahgoub, M. H., Abd El Aziz, N. G., and Youssef, A. A. (2006). "Influence of foliar spray with paclobutrazol or glutathione on growth, flowering and chemical composition of *Calendula officinalis* L. plant," *Journal of Applied Sciences Research* 2(11), 879-883.
- McCann, S. E., and Huang, B. (2007). "Effects of trinexapac-ethyl in creeping bentgrass responses to combined drought and heat stress," *Crop Sci.* 47, 2121-2128. DOI: 10.2135/cropsci2006.09.0614
- McCann, S. E., and Huang, B. (2008). "Drought responses of Kentucky bluegrass and creeping bentgrass as affected by abscisic acid and trinexapac-ethyl," *J. Am. Soc. Hortic. Sci.* 133, 20-26. DOI: 10.21273/JASHS.133.1.20
- McCullough, P. E., Liu, H., McCarty, L. B., and Toler, J. E. (2006). "Ethephon and trinexapac-ethyl influence creeping bentgrass growth, quality, and putting green performance," *Appl. Turfgrass Sci.* 3(1), 1-7. DOI: 10.1094/ATS-2006-0324-01-RS
- McCullough, P. E., Liu, H., McCarty, L. B., Whitwell, T., and Toler, J. (2006a). "Nutrient allocation of 'TifEagle' bermudagrasses influenced by trinexapac-ethyl," *J. Plant Nutr.* 29, 273-282. DOI: 10.1080/01904160500476178
- McCullough, P. E., Liu, H. B., McCarty, L. B., Whitwell, T., and Toler, J. E. (2006b). "Bermudagrass putting green growth, color, and nutrient partitioning influenced by nitrogen and trinexapac-ethyl," *Crop Sci.* 46, 1515-1525. DOI: 10.2135/cropsci2005.08-0286
- Melo, G. G., Costa, D. S., Loges, V., Silva, S. S., Sanglard, D. A., and Filho, P. A. (2019). "Evaluation of the ornamental potential of safflower (*Carthamus tinctorius* L.)," *Journal of Experimental Agriculture International* 33(6), Article ID 30157. DOI: 10.9734/jeai/2019/v33i630157
- Menegaes, J. F., and Nunes, U. R. (2020). "Safflower: Importance, use and economical exploitation," *Sci. Agrar. Parana., Marechal Cândido Rondon* 19(1), Article Number 21250. DOI: 10.18188/sap.v19i1.21250
- Mishra, D. K., and Yadava, L. P. (2011). "Influence of paclobutrazol application on the flower size and yield of China aster (*Callistephus chinensis* (L.) Nees)," *Journal of Applied Horticulture* 13(2), 147-149. DOI: 10.37855/jah.2011.v13i02.33
- Mündel, H. H., Riverland, N., and Tanaka, D. L. (1997). "Safflower agro-production I: yield," in: *Proceedings of the 4th International Safflower Conference*, Bari, Italy, pp. 47-55.

- Mündel, H. H., Blackshaw, R. E., Byers, J. R., Huang, H. C., Johnson, D. L., Keon, R., Kubik, J., McKenzie, R., Otto, B., Roth, B., and Stanford, K. (2004). *Safflower Production on the Canadian Prairies*, Agriculture and Agri-Food Canada, Lethbridge, Canada.
- Nazarudin, A. (2012). "Plant growth retardants effect on growth and flowering of potted *Hibiscus rosa-sinensis* L.," *J. Trop. Plant Physiol.* 4, 29-40.
- Nivedithadevi, D., Somasundaram, R., and Pannerselvam, R. (2015). "Effect of abscisic acid, paclobutrazol and salicylic acid on the growth and pigment variation insolanum trilobatum (l)," *International Journal Drug Development and Research* 4(3), 236-246.
- Ören, B. (2012). *Effects of Paclobutrazol and Uniconazole on Height Control of Some Bedding*, Master's Thesis, Uludağ University Graduate School of Natural and Applied Sciences Department of Horticulture, Bursa, Türkiye.
- Pahlavani, M. H., Mirlohi, A. F., and Saeidi, G. (2004). "Inheritance of flower color and spininess in safflower (*Carthamus tinctorius* L.)," *Journal of Heredity* 95(3), 265-267. DOI: 10.1093/jhered/esh030
- Parlakova Karagöz, F., Dursun, A., and Kotan, M. M. (2023). "Determining of the effects of paclobutrazol treatments on seedling height control of wild *Gypsophila bicolor* (Freyn&Sint.) Grossh," *Notulae Botanicae Horti Agrobotanici Cluj-Napoca* 51(2), Article number 12913. DOI:10.15835/nbha51212913
- Pasban Eslam, B., Chenari Bouket, A., Oszako, T., and Belbahri, L. (2024). "Physiological indices for the selection of drought-tolerant safflower genotypes for cultivation in marginal areas," *Applied Sciences* 14(12), article 5106. DOI: 10.3390/app14125106
- Phasri, W., Neera, S., Jogloy, S., and Hongpakdee, P. (2019). "Effect of paclobutrazol application on growth, flowering and inulin content of ornamental *Helianthus tuberosus* L.," *Acta Hort.* 1237, 161-168. DOI: 10.17660/ActaHortic.2019.1237.21
- Pinto, A. C. R., Rodrigues, T. J., Leite, I. C., and Barbosa, J. C. (2005). "Growth retardants on development and ornamental quality of potted 'lilliput' *Zinnia elegans* Jacq.," *Sci. Agric.* 62, 337-345. DOI: 10.1590/S0103-90162005000400006
- Piphatwatthanakul, P., Boonkamjat, T., and Saetiew, K. (2024). "Effect of paclobutrazol on growth retarding in potted chrysanthemum (*Dendranthema grandiflora*)," *International Journal of Agricultural Technology* 20(2), 731-748.
- Qrunfleh, M. M., and Suwwan, M. A. (1988). "Response of three summer annuals to Paclobutrazol application," *Advances in Horticultural Science* 2(1), 15-18.
- Rademacher, W. (2000). "Growth retardants: Effects on gibberellin biosynthesis and other metabolic pathways," *An. Rev. Plant Physiol. Plant Mol. Biol.* 51, 501-577. DOI: 10.1146/annurev.arplant.51.1.501
- Richardson, A. D., Duigan, S. P., and Berlyn, G. P. (2002). "An evaluation of noninvasive methods to estimate foliar chlorophyll content," *New Phytol.* 153, 185-194. DOI: 10.1046/j.0028-646X.2001.00289.x
- Roberts, C. M., Eaton G. W., and Seywerd, F. M. (1990). "Production of fuchsia and tibouchina standards using paclobutrazol or chlormequat," *HortScience* 25(10), 1242-1243.
- Ruter, J. M. (1994). "Growth and landscape establishment of *Pyracantha* and *Juniperus* after application of paclobutrazol," *HortScience* 29(11), 1318-1320. DOI: 10.21273/HORTSCI.29.11.1318

- Ruter, J. M. (1996). "Paclobutrazol application method influences growth and flowering of new gold lantana," *HortTechnology* 6(1), 19-20.
- Santos, R. F., and Silva, M. A. (2015). "Carthamus tinctorius L.: An alternative crop for Brazil," *Acta Iguazu* 4(1), 26-35.
- Sefaoğlu, F. (2022). "Safflower cultivation. Specialization area book series," (https://otti.kastamonu.edu.tr/wp-content/uploads/2022/12/3.-Aspir-Ciftci-El-Kitabi_tk.pdf), Accessed 19 Nov 2024.
- Sever Mutlu, S., and Kurtulan, N. (2015). "Trinexapac-ethyl modifies plant architecture of ornamental pepper," *Hortic. Sci* 80(6), 280-287. DOI: 10.17660/eJHS.2015/80.6.3
- Seyidoğlu, N., and Zencirkiran, M. (2009). "The use of growth retardant agents (dwarfing) in some ornamental pot plants in interior planting design," *Artvin Çoruh University Faculty of Forestry Journal* 10(1), 72-77.
- Sharma, P., Sharma, Y. D., and Gupta, Y. C. (2009). "Effect of paclobutrazol and benzyl adenine on Oriental lily hybrids," *J. Hort. Sci.* 4(2), 128-133. DOI: 10.24154/jhs.v4i2.529
- Sumit, K., Ghatty, S., Satyanarayana, J., Guha, A., Chaitanya, B. S. K., and Reddy, A. R., (2012). "Paclobutrazol treatment as a potential strategy for higher seed and oil yield in field-grown *Camelina sativa* L. Crantz," *BMC Research Notes* 5, Article number 137. DOI: 10.1186/1756-0500-5-137
- Taha, A. M., and Sorour, M. A. (2016). "Effect of paclobutrazol and its method of application on the growth of *Pentas lanceolata* plants," *J. Adv. Agric. Res. (Fac. Agric. Saba Basha)* 21(4), 686-699. DOI: 10.21608/jalexu.2016.195603
- Tsegaw, T., Hammes, S., and Robbertse, J. (2005). "Paclobutrazol-induced leaf, stem, and root anatomical modification in potato," *HortScience* 40(5), 1343-1346.
- Turkish Ministry of Agriculture and Forestry (2024a). "Dinçer," (<https://arastirma.tarimorman.gov.tr/gktaem/Belgeler/Tescilli%20%C3%87e%C5%9Fitlerimiz/Aspir/din%C3%A7er.pdf>), Accessed 19 Nov 2024.
- Turkish Ministry of Agriculture and Forestry (2024b). "Olas," (<https://arastirma.tarimorman.gov.tr/ttae/Sayfalar/Detay.aspx?SayfaId=170>), Accessed 19 Nov 2024.
- Vital, R., Jakelaitis, A., Costa, A., Silva, F., and Batista, P. (2017). "Sunflower plant response to simulated drift of glyphosate and trinexapac-ethyl," *Planta Daninha* 35, 1-13. DOI: 10.1590/s0100-83582017350100045
- Weiss, E. A. (2000). *Oilseed Crops*, Blackwell Science, Malden, MA, USA.
- Whipker, B. E., and Dasoju, S. (1998). "Potted sunflower growth and flowering responses to foliar applications of daminozide, paclobutrazol, and uniconazole," *HortTechnology* 8(1), 86-88. DOI: 10.21273/HORTTECH.8.1.86
- Witt, H. H. (1986). "Bonzi promises economy," *Deutscher Gartenbau* 40(6), 239-243.
- Xia, X., Tang, Y., Wei, M., and Zhao, D. (2018). "Effect of paclobutrazol application on plant photosynthetic performance and leaf greenness of herbaceous peony," *Horticulturae* 4(1), Article Number 5. DOI: 10.3390/horticulturae4010005
- Xiangting, Li., Yang, W., Wan, J., and Liang, J. (2020). "Effects of paclobutrazol on bud, plant height and antioxidant enzyme activities of *Cymbidium hybridum*," *IOP Conf. Series: Earth and Environmental Science* 440(2), Article ID 022038. DOI: 10.1088/1755-1315/440/2/022038
- Zamani, N., Etemadi, N., and Mohammadkhani, A. (2016). "The effect of paclobutrazol and trinexapac-ethyl on morphological and physiological characteristics of rosemary

(*Rosmarinus officinalis*) and thuja (*Thuja orientalis* “Morgan”) as two hedging plants,” *Iranian J. Hort. Sci.* 47(3), 511-519. DOI: 10.22059/ijhs.2016.59813
Zareie, S., Mohammadi-Nejad, G., and Sardouie-Nasab, S. (2013). “Screening of Iranian safflower genotypes under water deficit and normal conditions using tolerance indices,” *Australian Journal of Crop Science* 7(7), 1032-1037.

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