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Influence of Plant Growth Regulators on Root, Shoot and Yield Attributes of Strawberry (*Fragaria × ananassa* Duch.) under Protected Conditions

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ABSTRACT: Plant growth regulators are modern day chemicals used to boost the growth and yield of the plants. Whereas, strawberry is gaining popularity day by day due to its attractive shape, colour and sensual aroma. Not only it is high in flavours but also rich in natural antioxidants including carotenoids, phenols, flavonoids, dietary glutathione and endogenous metabolites. Ellagic acid is a plant phenol that occurs naturally in strawberry fruit. It has been discovered that eating its fruits on a regular basis can help to prevent cancer and asthma. Keeping all these points in mind the present study was planned at Khalsa College, Amritsar with seven treatments in year 2022-2023. The experiment was laid out in randomized block design (RBD) with three replications each. Procurement of healthy and cheap runners was major constraint during the study, which were brought from Solan, Himachal Pradesh. Moreover, lack of pollinators in protected structure was another issue which was sorted by artificial pollination using rope pulling. The results revealed that maximum plant height, number of leaves, petiole length, plant spread (E-W & N-S), Shoot weight (both fresh & dry), number of flowers, number of fruits, yield per plant, average root length, number of root tips, root volume and root weight (both fresh & dry) with foliar application of GA_3 75 ppm. Whereas, maximum leaf area, fruit weight and minimum days to flowering were observed under the foliar application of NAA 50 ppm. Overall, it was concluded that GA_3 75 ppm was best in improving shoot, root and yield attributes of strawberry.

Keywords: Strawberry, NAA, GA_3, TIBA, Growth, yield, correlation coefficient.

INTRODUCTION

Strawberry (*Fragaria* × *ananassa* Duch.) is one of the most delicious, attractive, nutritious and refreshing soft fruit of the world. The plant is perennial dicot herbaceous plant comprising of fibrous roots, short crown attached with bunched trifoliate leaf with long petiole and the runner producing shoots. It belongs to family, Rosaceae and an octaploid species (Pandey *et al.*, 2018). Modern strawberry (*Fragaria* × *ananassa* Duch.) is a intercross between the 'Scarlet' or 'Virginia' strawberry (*Fragaria virginiana*) and the pistillate South American strawberry (*Fragaria chiloensis*) is a dicotyledonous herb grown in most arable regions of the world (Debnath, 2013). Strawberry typically produces flowers in clusters. Hermaphrodite and pistillate flowers are found in strawberries (Chattopadhyay, 2013). Tertiary flowers produce the most fruits compared to primary and secondary blossoms (Dhillon and Bhat 2011). It is an aggregate fruit which is rich in vitamins, minerals and its edible portion is known as fleshy thalamus (Bal, 2016). Strawberry cultivation is influenced by the specific regional adaptations due to critical photoperiod; temperature requirements and thus the cultural systems are highly variable. It is commercially cultivated in temperate climate, yet it can be grown under tropical and sub-tropical climatic conditions. It is a short-day plant, grown at optimum day temperatures of 22° C to 25° C and night temperature of 7° C to 13° C (De and Bhattacharjee 2012). The major pollinating agents are insects and wind. The fertility of the ovule last for 8-10 days and after fertilization receptacle swells; converts into fleshy and later on turns into edible berry. The physico-chemical alterations that are mostly associated with fruit occurs while, still attached to the plant and is non-climacteric in nature. As a result, fruits ought to be picked when they are ready to be consumed (Cordenunsi *et al.*, 2003).

Plant growth regulators are plant hormone enhancers or disruptors which are man-made or naturally derived (Kumar *et al.*, 2012). It has quick stimulative effects on plant growth, flowering and fruiting (Krishnamoorthy, 1981). Scientific evidences have also suggested that the strawberry plant responded well to growth regulator application (Sharma and Sharma 2004). Auxin is a primary hormone that regulates lateral branching of plant shoots. Auxin is exported from the primary shoot apex, transports basipetally, and suppresses axillary bud outgrowth (Zhang *et al.*, 2017). Naphthalene acetic acid had influence on various physiological activities such as photosynthesis, respiration rate with higher amount of carbohydrates and dry matter content (Singh *et al.*, 2015). Gibberellic acid (GA) encourages cell division and elongation; increase stalk length, enhance number of flowers and fruit size (Fishel, 2006). It is used to boost the development of plant, transport of ion and uptake of nutrients (Rosenvasser *et al.,* 2006). Foliar application of GA_3 plays a crucial role in enhancing the absorption of nutrients, morphological and physiological attributes of plants (Shomeili *et al.*, 2011). 2,3,5-Triiodobenzoic acid (TIBA) is another auxin transport inhibitor that inhibits polar auxin transport inside the plant. Exogenous TIBA application can promote axillary bud out growth, increase branch number, and inhibit the increase of plant height (Zhang *et al.*, 2017). Keeping all the above points in mind the present investigation was planned.

MATERIAL AND METHODS

Runners of cv. Camarosa were transplanted in the first week of November with 45 × 30 cm spacing in double row system in protected structure of Research farm of P.G Department of Agriculture, Khalsa College, Amritsar (year 2022-2023) with seven treatments with three replications each. Treatment details are as follow: T_1 (NAA 25 ppm), T_2 (NAA 50 ppm), T_3 (GA_3 50 ppm), T_4 (GA_3 75 ppm), T_5 (TIBA 25 ppm), T_6 (TIBA 50 ppm), T_7 (control). Foliar application of plant growth regulators was sprayed 30 & 45 days after transplanting.

A. Observations noted

Plant height, petiole length and plant spread (N-S & E-W) was recorded with centimeter scale. Number of leaves (per plant) were counted manually from tagged plants at end of trial. Leaf area was recorded by using graph paper method. Days to first flowering were noted from days to transplanting. Number of flowers and fruits were noted in each flush and added at end of trial to receive an average number of flowers and fruits per plant. Fruit weight and yield per plant was recorded by using digital weighing balance. Average number of root tips were counted manually in each plant by washing roots properly. Tagged plants were uprooted and cleaned and root and shoots were separated and weighed fresh and then dried in oven at 70° C till constant weights, dry biomass was recorded. The root volume was measured by water displacement method where as root length of plants was measured with help of centimeter scale.

B. Statistical analysis

The experiment was laid out in Randomized Block Design (RBD) with three replications for each treatment. Means were separated using LSD test. Differences were considered significant at the level $p \leq 0.05$ using statistical analysis system software R studio (4.3.0). Standard error for each treatment was worked out using in build tools of MS-Excel. Correlation coefficient heatmap diagram was formed by using OPSTAT-CCS-HAU, Hisar.

RESULTS AND DISCUSSION

A. Effect of plant growth regulators on shoot attributes of strawberry

The data pertaining in Table 1 depicts that maximum plant height (28.39 cm) was recorded with application of treatment GA_3 75 ppm (T_4). The possible reason for maximum plant height and number of leaves might be due to the ability of gibberellins to stimulate the process of cell division; expansion in epidermal and parenchyma cells has been well documented (Bist *et al.*, 2018). Similar, results were recorded by Kumar *et al.* (2022) experiment on the effect of plant growth regulators and mulches on growth and yield of strawberry (*Fragaria* × *ananassa* Duch.) cv. Chandler. Rathod *et al.* (2020) also reported same results in strawberry. Moreover, maximum (E-W) and (N-S) plant spread with 35.33 cm and 25.67 cm was reported under the use of treatment GA_3 75 ppm (T_4). Whereas, minimum plant spread was noted under control (T_7). This might be due to spraying of gibberellins which induced the growth by cell division, cell enlargement or both (Turner, 1963). These finding are also in conformity with Palei *et al.* (2016). Furthermore, highest number of leaves per plant (23.06) were registered with foliar application of GA_3 75 ppm (T_4). Lamo *et al.* (2020) also recorded maximum number of leaves with foliar application of GA_3 as compared to other treatments. Lolaei *et al.* (2013) also observed that the plants treated with gibberellic acid produced highest number of leaves per plant as compared to control in strawberry. Such activities in the meristematic tissue of leaf primordial in GA_3 treated plants might be higher and perhaps a greater number of leaves with broader leaf lamina and petiole of longer length (Kumar *et al.*, 2022). Whereas, maximum leaf area (22.86 cm^2) was noted under treatment NAA 50 ppm (T_2). It might be due to Naphthalene acetic acid (NAA) induces cell division in cambium cells, resulting in the production of xylem tissue in lower internodes, which provides mechanical support to plants, which also improves nutrient and minerals uptake (Thakur *et al.,* 2017) which resulted in increase in leaf area of strawberry plant. These results are in conformity with Kumar *et al.* (2017); Kumar and Tripathi (2009); Mir *et al.* (2004). While, highest petiole length (17.02 cm) was found with application of treatment GA_3 75 ppm (T_4). However, minimum petiole length was recorded under control. Gibberellins induced increase in length of petiole might be due to changes in cellular microtubule. Similar results were reported by Palei *et al.* (2016); Sharma and Singh (2009); Tafazoli & Vince-Prue (1978) in strawberry. Likewise, maximum fresh shoot weight (19.80 g) and dry shoot weight (8.13 g) was recorded with the implication of treatment GA_3 75 ppm (T_4) while, minimum fresh and dry shoot weight was recorded under control. The outcome of our research is in line with the results of Ouzounidou *et al.* (2010); Sharma and Singh (2009); Qureshi *et al.* (2013); Fagherazzi *et al.* (2016) who indicated that GA_3 considerably enhanced dry weight of shoot, accumulation of dry matter and leaves photosynthetic activities. The results of the present research are also similar with Alvim (1960) who proposed that treatments of gibberellic acid increased in weight of fresh and dry leaves of strawberry.

B. Effect of plant growth regulators on yield attributes of strawberry

It is evident from Table 2 that minimum days to flowering (55.73) were noted under treatment with NAA 50 ppm (T_2). Whilst, control (T_7) took maximum days to flowering. It might be due to auxin particularly NAA induces flowering by stimulating florigen which moved from petiole to growing tip and converts vegetative bud to flowering bud and fruit set refers to the change in the ovary leading to the development of the fruit. These changes are usually induced after pollination and fertilization which is triggered by NAA (Kumar *et al.,* 2011). These findings are inclined with Kaur and Mirza (2018); Rathod *et al.* (2020); Kumar *et al.* (2022) in strawberry. Highest number of flowers per plant (23.20) were recorded with foliar application of GA_3 75 ppm (T_4). However, minimum number of flowers per plant were found under control. It might be because of GA_3 application which accelerated the development of differentiated inflorescence and stimulated flowering and thus, creating favourable condition for growth and development of plant (Thakur *et al.*, 1991). The outcomes of present investigation are similar with the findings of Isam *et al.* (2012); Kumar *et al.* (2017) in strawberry. Moreover, maximum number of fruits per plant (18.06) were calculated with use of treatment GA_3 75 ppm (T_4) as foliar spray. This significant rise in number of fruits per plant with GA_3 treatment may be due to greater supply of nutrients and photosynthates to the plants (Kumar and Tripathi 2009). The present findings are in conformity with results of Kaur and Mirza (2018); Singh *et al.* (2022); Kumar *et al.* (2022) in strawberry. Whereas, maximum fruit weight (10.93 g) was registered with the application of NAA 50 ppm (T_2) which was statistically at par with NAA 25 ppm (T_1) which recorded 10.73 g fruit weight. However, minimum fruit weight (5.86 g) was noted under control (T_7). It might be due to the improvement in the water by the treatment, which increased the photosynthetic rate causing maximum fruit weight (Nor *et al.*, 2014). Our result is in the line of conformity with the findings of Palei *et al.* (2016); Kaur and Mirza (2018); Kumar *et al.* (2022) in strawberry. While, highest yield per plant (166.13 g) was recorded with application of GA_3 75 ppm (T_4). However, minimum yield per plant (49.40 g) was noted under control (T_7). This significant rise in yield might be due to increase in photosynthetic ability of plants treated with GA_3, which in turn might have favoured and increased the accumulation of dry matter which resulted in more fruit yield per plant (Kaur and Mirza 2018). The present results findings are in conformity the findings of Palei *et al*. (2016); Rathod *et al*. (2020); Kumar *et al.* (2022) in strawberry.

C. Effect of plant growth regulators on root attributes of strawberry

The data pertaining to root attributes as influenced by plant growth regulators are presented in Table 3. The results show that highest number of root tips (390.20) were recorded with application of GA_3 75 ppm (T_4) which was statistically at par with NAA 50 ppm (T_2) which was noted with 382.87 number of root tips. However, lowest number of root tips (83.20) were counted with control (T_7). This might be due to auxin's direct role in root proliferation is well known (Rademacher, 2015). These results were supported by Bhatt and Dhar (2000) which also concluded that growth regulators significantly improved number of roots in strawberry. Sevik and Turhan (2015) also reported growth regulators to increase root number in onion. Maximum average root length (13.73 cm) was recorded with the use of NAA 50 ppm (T_2). However, minimum average root length (8.06 cm) was noted under control (T_7). This might be due to GA_3 converted to naturally occurring indol-3-ylacetic acid in plant body. Auxins are also in use to stimulate rapid root growth of a wide range of trees, vines and shrubs, and annual and perennial plants (Cobb and Reade 2010). These results of present findings are in conformity with Guney *et al.* (2016) who found GA_3 to increase root length in plums. Whereas, highest root volume (27.53 cc) was registered in plants treated with GA_3 75 ppm (T_4). However, lowest root volume (8.53 cc) was calculated under control (T_7). Similar results were recorded by Cao *et al.* (2022) in cotton by application of GA_3. Tagliavini and Looney (1991) also recorded rise root volume in peach seedling with GA_3 application. Furthermore, maximum fresh root weight (10.40 g) was noted with foliar application of GA_3 75 ppm (T_4) which stood at par with NAA 50 ppm (T_2) and GA_3 50 ppm (T_3) which contained 9.73 and 9.46 g of fresh root weight, respectively. Similarly, maximum dry root weight (3.06 g) was reported with treatment GA_3 75 ppm which was statistically at par with NAA 50 ppm (T_2) and NAA 25 ppm (T_1) which recorded 2.80 and 2.40 g dry root weight, respectively. This seems to be the effect of mobilization of water and nutrients transported at higher rate which might have promoted more production of photosynthetic product and translocated them to various plant parts which might have resulted in better growth of the seedlings and hence, more fresh and dry weight (Anjanawe, 2013). These results of present investigation were in conformity with the findings of Uddin *et al.* (2023) who concluded rise in root and shoot weight with foliar application of GA_3 in *Ammi majus* L. Chaudhary *et al.* (2006) in their experiment on chilli also reported increase in root fresh and dry weight with application of GA_3.

Table 1: Effect of plant growth regulators on various shoot attributes of strawberry.

Treatment	Plant height (cm)	Plant spread (cm)		Number of leaves	Leaf area (cm^2)	Petiole length (cm)	Shoot weight (g)	
		E-W	N-S				Fresh	Dry
T_1 (NAA 25 ppm)	$17.36^{c}\pm0.26$	$24.73^{d}\pm0.20$	$20.86^{c}\pm0.14$	$19.13^{d}\pm0.14$	$21.46^{b}\pm0.05$	$9.73^{c}\pm0.24$	$13.13^{d}\pm0.30$	$4.53^{b}\pm0.33$
T_2 (NAA 50 ppm)	$18.06^{c}\pm0.11$	$26.27^{c}\pm0.24$	$21.13^{c}\pm0.12$	$20.93^{c}\pm0.30$	$22.86^{a}\pm0.14$	$10.33^{c}\pm0.05$	$17.40^{ab}\pm0.75$	$4.93^{b}\pm0.48$
T_3 (GA_3 50 ppm)	$26.37^{b}\pm0.26$	$32.66^{b}\pm0.30$	$23.73^{b}\pm0.20$	$22.13^{b}\pm0.32$	$20.06^{c}\pm0.11$	$14.66^{b}\pm0.24$	$16.67^{bc}\pm0.71$	$5.46^{b}\pm0.39$
T_4 (GA_3 75 ppm)	$28.39^{a}\pm0.27$	$35.33^{a}\pm0.31$	$25.67^{a}\pm0.31$	$23.06^{a}\pm0.11$	$20.46^{b}\pm0.43$	$17.02^{a}\pm0.34$	$19.80^{a}\pm1.14$	$8.13^{a}\pm0.14$
T_5 (TIBA 25 ppm)	$15.38^{d}\pm0.25$	$23.73^{e}\pm0.36$	$18.46^{d}\pm0.07$	$18.01^{e}\pm0.25$	$21.93^{b}\pm0.30$	$7.80^{d}\pm0.28$	$12.13^{d}\pm0.54$	$3.13^{c}\pm0.16$
T_6 (TIBA 50 ppm)	$14.39^{e}\pm0.21$	$22.60^{e}\pm0.16$	$17.80^{d}\pm0.38$	$18.06^{e}\pm0.12$	$21.46^{b}\pm0.39$	$8.53^{d}\pm0.20$	$13.73^{cd}\pm0.96$	$2.73^{c}\pm0.20$
T_7 (Control)	$11.41^{f}\pm0.27$	$17.80^{f}\pm0.41$	$13.66^{e}\pm0.30$	$15.13^{f}\pm0.14$	$18.06^{d}\pm0.20$	$5.73^{e}\pm0.24$	$7.67^{e}\pm0.52$	$2.06^{c}\pm0.11$
Mean ±S. E	18.76±0.13	26.16±0.11	20.19±0.11	19.49±0.06	20.90±0.15	10.54±0.06	14.36±0.10	4.42±0.08
LSD $_{(p \leq 0.05)}$	0.82	1.12	0.95	0.82	0.73	0.92	3.04	1.13

Table 2: Effect of plant growth regulators on flowering and yield attributes of strawberry.

Treatment	Days to flowering	Number of flowers	Number of fruits	Fruit weight (g)	Yield (g)
T_1 (NAA 25 ppm)	$55.93^{d}\pm0.38$	$15.26^{d}\pm0.20$	$12.06^{d}\pm0.20$	$10.73^{ab}\pm0.29$	$122.40^{d}\pm1.84$
T_2 (NAA 50 ppm)	$55.73^{d}\pm0.36$	$16.06^{d}\pm0.29$	$13.20^{c}\pm0.34$	$10.93^{a}\pm0.20$	$132.20^{c}\pm1.70$
T_3 (GA_3 50 ppm)	$59.80^{c}\pm0.33$	$21.73^{b}\pm0.36$	$16.80^{b}\pm0.41$	$8.67^{d}\pm0.05$	$143.80^{b}\pm2.86$
T_4 (GA_3 75 ppm)	$61.66^{b}\pm0.94$	$23.20^{a}\pm0.41$	$18.06^{a}\pm0.20$	$9.06^{d}\pm0.11$	$166.13^{a}\pm2.49$
T_5 (TIBA 25 ppm)	$57.13^{d}\pm0.30$	$18.06^{c}\pm0.29$	$13.46^{c}\pm0.33$	$9.80^{c}\pm0.16$	$127.67^{cd}\pm3.59$
T_6 (TIBA 50 ppm)	$56.06^{d}\pm0.35$	$17.46^{c}\pm0.05$	$13.66^{c}\pm0.24$	$10.20^{bc}\pm0.19$	$130.47^{c}\pm1.52$
T_7 (Control)	$73.06^{a}\pm0.21$	$10.73^{e}\pm0.24$	$7.93^{e}\pm0.14$	$5.86^{e}\pm0.14$	$49.40^{e}\pm1.77$
Mean ±S. E	59.91±0.14	17.50±0.05	13.60±0.08	9.32±0.10	124.58±1.90
LSD $_{(p \leq 0.05)}$	1.69	1.13	1.09	0.60	7.52

Table 3: Effect of plant growth regulators on various root attributes of strawberry.

Treatment	Number of root tips	Average root length (cm)	Root volume (cc)	Root weight (g)	
				Fresh	Dry
T_1 (NAA 25 ppm)	$260.07^{b}\pm15.18$	$12.13^{bc}\pm0.14$	$15.73^{c}\pm0.29$	$9.06^{bc}\pm0.38$	$2.40^{ab}\pm0.25$
T_2 (NAA 50 ppm)	$382.87^{a}\pm24.29$	$13.73^{a}\pm0.23$	$22.80^{b}\pm0.25$	$9.73^{ab}\pm0.24$	$2.80^{a}\pm0.19$
T_3 (GA_3 50 ppm)	$224.93^{bc}\pm12.45$	$11.73^{bcd}\pm0.27$	$14.67^{c}\pm0.57$	$9.46^{ab}\pm0.33$	$2.06^{bc}\pm0.20$
T_4 (GA_3 75 ppm)	$390.20^{a}\pm31.02$	$12.20^{b}\pm0.19$	$27.53^{a}\pm0.48$	$10.40^{a}\pm0.35$	$3.06^{a}\pm0.24$
T_5 (TIBA 25 ppm)	$165.47^{c}\pm26.41$	$11.20^{cd}\pm0.28$	$12.46^{d}\pm0.54$	$7.93^{c}\pm0.11$	$1.53^{c}\pm0.14$
T_6 (TIBA 50 ppm)	$151.40^{cd}\pm17.35$	$10.80^{d}\pm0.41$	$12.40^{d}\pm0.47$	$9.07^{bc}\pm0.54$	$1.60^{c}\pm0.16$
T_7 (Control)	$83.02^{d}\pm19.44$	$8.06^{e}\pm0.20$	$8.53^{e}\pm0.27$	$3.86^{d}\pm0.14$	$0.73^{d}\pm0.05$
Mean ±S. E	236.85±11.31	11.41±0.12	16.30±0.15	8.50±0.08	2.02±0.04
LSD $_{(p \leq 0.05)}$	79.28	0.94	1.63	1.30	0.71

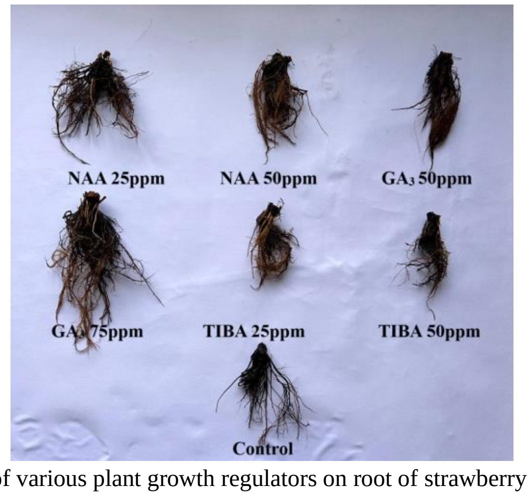
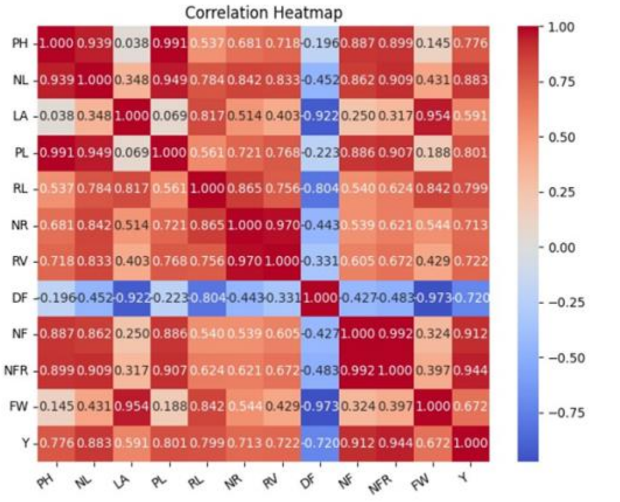


Fig. 1. Effect of various plant growth regulators on root of strawberry at end of trial.



PH- Plant height, **NL**- Number of leaves, **LA**- Leaf area, **PL**- Petiole length, **RL**-Root length, **NR**- Number of root tips, **RV**- Root volume, **DF**- Days to flowering, **NF**- Number of flowers, **NFR**- Number of fruits, **FW**- Fruit weight and **Y**- Yield per plant.

Fig. 2. Correlation coefficient between various shoot, root and yield attributes of strawberry.

CONCLUSIONS

Foliar application of various plant growth regulators was successful in improving shoot, root and yield attributes of strawberry as compared to control. But from all the plant growth regulators, NAA and GA_3 was most successful in enhancing growth and yield of strawberry. Plants sprayed with NAA were first to flower and had higher leaf area and fruit weight. Whereas, GA_3 application significantly increased plant height, root length, average number of root tips, number of leaves, petiole length, number of flowers, number of runners and yield per plant.

FUTURE SCOPE

Strawberries fetch good price in market, thus increasing farmers income and profit. Whereas, plant growth regulators improve plant's ability to fight against the biotic, abiotic stresses which improves growth and yield of strawberry which ultimately secure good profit for growers.

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Conflict of Interest. None.

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