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Gibberellic acid influences the production of malformed and button berries, and fruit yield and quality in strawberry (*Fragaria* × *ananassa* Duch.)

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ABSTRACT

Experiments were conducted to observe the effects of foliar application of gibberellic acid on vegetative growth, flowering, fruiting and various disorders in 'Chandler' strawberry. GA_3 (75 ppm) was applied to the strawberry plants either during mid-November (at fruit bud differentiation stage), or mid-February (pre-flowering stage) or at both times. Fruit under control were sprayed with tap water only. Observations were recorded on vegetative attributes like crown height, crown spread, petiole length, leaf number, leaf area; flowering and fruit set, fruit size; production of albino, malformed and button berries, total yield and marketable fruit yield and quality parameters, like juice content, TSS, ascorbic acid contents, acidity etc. Results indicated that GA_3 (75 ppm) spray either during mid-November or mid-February or at both times has favourably influenced all vegetative attributes of 'Chandler' strawberry over control. Similarly, fruit set was increased, and production of malformed and button berries was reduced, but albinism remained unaffected. Although individual berry weight was reduced slightly, but fruit number, total as well as marketable yield was increased tremendously over control with no adverse effect on fruit quality parameters. In all, spraying GA_3 both during mid-November and mid-February was much more effective in achieving the desirable results than single application of GA_3 either during mid-November or mid-February.

1. Introduction

Strawberry is basically a fruit plant of temperate climate. However, during the recent years, there has been phenomenal increase in its area and production in tropical and subtropical plains of India (Sharma and Sharma, 2004; Sharma et al., 2006). It has happened because of standardization of modern agro-techniques, and introduction of many cultivars like 'Chandler', 'Sweet Charlie', 'Fern', 'Douglas', etc., from different countries, which perform very well under Indian climate as well (Asrey and Jain, 2003; Sharma and Sharma, 2004). Moreover, strawberry crop becomes ready for harvesting within few months of planting and growers near to town and cities get very high returns on their investment, which attracted Indian farmers for its cultivation. Strawberry in India is usually planted in autumn and it comes to flowering in spring after about 4 months (Sharma, 2002). In this short growing period, plants makes only limited vegetative growth, as a result, low yields of poor quality are achieved (Asrey et al., 2004; Singh and Asrey, 2005; Singh et al., 2007). In addition, there is production of albino, malformed and button berries in higher number, which further lower the fruit yield and quality (Sharma, 2002; Sharma and Sharma, 2004). Albino berries do not have proper colour and look unattractive. Malformed and button or nubbins appear misshapen, look unattractive and hence fetch poor price in the market (Sharma and Sharma, 2004), which are a loss to a grower, and if they occur frequently, the loss may be severe (Garren, 1981). Albino berries occur primarily due to excess of N and deficiency of Ca, and malformed and button berries due to inadequate pollination (Garren, 1981).

Gibberellic acid has been reported to influence vegetative growth, flowering, fruiting and various disorders in many fruit crops including strawberry (Thompson and Guttridge, 1959; Paroussi et al., 2002a; Singh and Kaul, 1970). It has specially been effective on dwarf plant types. Similarly, gibberellic acid has been reported to enhance pollen germination (Kappel and MacDonald, 2007; Paroussi et al., 2002a; Singh and Singh, 2006; Voyiatzis and Paraskevopoulou-Paroussi, 2002) and may also affect colour development in strawberry fruit. Thus, GA may also affect the occurrence of albino, malformed and button or nubbin berries to a larger extent, thereby increasing the production of healthy fruit with better quality. Hence, studies were conducted with the aim to observe the effect of GA on some vegetative characters, flowering,

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fruit-set, and production of albino, malformed and button or nubbins berries in 'Chandler' strawberry, which is the most favourite cultivar in these localities.

2. Materials and methods

2.1. Experimental site and material

These studies were conducted at Central Institute of Post Harvest Engineering and Technology, Abohar-152 116, India during 2004–2006. This region has subtropical climate and falls in semi-arid zone having hot summers (May–June) and mild winter (December–mid-February) with annual rainfall of about 180 mm, restricted mainly to July–August months. Soil of the experimental farm was sandy-loam, having pH 8.5, which was low in organic carbon (0.42%), medium in available phosphorus and high in potash.

The soil of the experimental plot was thoroughly ploughed and raised beds of 25 cm height and one meter width were prepared at a distance of 50 cm. Healthy runners of 'Chandler' strawberry were procured from Dr. Y.S. Parmar University of Horticulture and Forestry, Solan (H.P.) and planted at a spacing of 25 × 25 cm during mid-October on raised beds. All cultural practices were followed uniformly in the experimental plot. The whole experiment was laid out in randomized block design with four replications.

2.2. Treatment combinations

Foliar spray of GA_3 (75 ppm) was applied to the plants either during mid-November (at fruit bud differentiation stage), or mid-February (pre-flowering stage) or at both times. In all, following treatment combinations were tried: T_1: water spray only (control), T_2: GA_3 (75 ppm) during mid-November, T_3: GA_3 (75 ppm) during mid-February, T_4: GA_3 (75 ppm) twice i.e., during mid-November and mid-February.

2.3. Observations recorded and methodology followed

Observations were recorded on petiole length (cm), crown height (cm), crown spread (cm), leaf number, leaf area (cm^2); flowering and harvesting period (days), fruit-set (%); fruit size (g), production of albino (%), malformed (%) and button berries (%), and quality parameters, like juice content (%), TSS (%), acidity (%), ascorbic acid content (mg per 100 g edible part), etc.

Crown height, crown spread, leaves number and leaf area were recorded in randomly selected 10 plants in a bed. Crown height was measured from base of crown to tip with the help of a scale. Crown spread for N–S, and E–W direction was measured and averaged. Petiole length was measured from the base of the conjunction of the lamina with the help of a scale in first 2 basal leaves of 10 randomly selected plants per bed. Leaf area was measured with the help of leaf area meter in 4 randomly selected leaves of 10 plants per bed. Records were made on initiation and termination of flowering and fruiting. For recording the incidence of various disorders, all fruits after harvesting were counted, and then divided in different lots by counting albino, malformed and button berries, and represented as percent of total healthy fruit (Sharma et al., 2006). TSS was recorded with the help of refractometer and corrected at 20 °C. Juice contents were measured after crushing 20 randomly selected fruit from each harvest. Acidity was measured following standard procedures (AOAC, 1989).

2.4. Statistical design and analysis of data

The whole experiment was laid out in randomized block design (RBD). For laboratory studies, completely randomized design was followed. Since, there was no significant different between data of two years, hence, data were first pooled and then subjected to analysis (Panse and Sukhatme, 1984). Similarly, data on percentage (e.g., fruit set, albino, malformed and button berries, TSS, and acidity) were first transformed as per Arc Sin values before subjection to analysis. The differences between the treatments were separated by calculating the critical difference (C.D.) from the ANOVA.

3. Results

3.1. Effects of GA on vegetative characters

Gibberellic acid spray (75 ppm) either during mid-November, mid-February or both in mid-November and mid-February has significantly influenced all the vegetative parameters like crown height, crown spread, petiole length, leaf number and leaf area of 'Chandler' strawberry (Table 1). Although, mid-November application of GA_3 was lesser effective than mid-November or both mid-November and mid-February application. Maximum crown height (18.5 cm), crown spread (21.4 cm), petiole length (7.2 cm), leaf number (17.8) and leaf area (31.6 cm^2) were achieved when GA_3 was sprayed twice i.e., in mid-November and mid-February (Table 1). Further, the plants in control had least crown height (4.5 cm), crown spread (6.2 cm), petiole length (3.5 cm), leaf number (12.3), and leaf area (22.2 cm^2).

3.2. Effects of GA on flowering and harvesting season

GA_3 applied at either time has affected the initiation and duration of flowering and harvesting season over control. For instance, mid-November application of GA_3 has reduced the days taken for initiation of flowering (82.5 DAP) and harvesting (128.0 DAP) but increased flowering (65.7 days) and harvesting period (54.2 days) over control or other GA applications (Table 2). Plants took highest days after planting (DAP) for initiation of flowering (104.4 days) with minimum flowering duration (60.5 days), when GA_3 was sprayed twice, i.e., in mid-November and mid-February. Further, plants, which received GA twice, i.e., during mid-November and mid-February had produced maximum flowers/plant (64.6), and had highest fruit set (81.4%). In contrast, fruit set was very low (45.2%) in plants under control (Table 2).

3.3. Effects of GA on fruit yield and fruit disorders

GA_3 applied at either time has reduced the average fruit weight, but has increased total as well as marketable fruit yield. Further, production of malformed and button or nubbin berries was decreased significantly, but the albinism incidence remained

Table 1
Effect of GA_3 on vegetative characters of 'Chandler' strawberry.

Treatment	Petiole length (cm)	Crown height (cm)	Crown spread (cm)	Leaf number	Leaf area (cm^2)
Control	3.5	4.5	6.2	12.3	22.2
GA_3, 75 ppm (mid-November)	6.7	16.5	18.2	16.2	24.3
GA_3, 75 ppm (mid-February)	5.2	14.3	15.6	12.4	28.5
GA_3, 75 ppm (mid-November and mid-February)	7.2	18.5	21.4	17.8	31.6
C.D. (0.05)	0.8	1.6	1.4	1.1	2.3

Table 2
Effect of GA_3 on flowering and harvesting period and fruit-set in 'Chandler' strawberry[a].

Treatment	Flowering		Harvesting		No. of flowers/plant	Total fruit/plant	Fruit set (%)
	Initiation (DAP)	Duration (days)	Initiation (DAP)	Duration (days)			
Control	97.2	61.3	141.2	41.2	28.3	12.8	45.2
GA_3, 75 ppm (mid-November)	82.5	65.7	128.0	54.2	39.8	26.3	66.1
GA_3, 75 ppm (mid-February)	103.4	62.5	156.2	29.5	63.6	50.4	79.1
GA_3, 75 ppm (mid-November and mid-February)	104.4	60.5	158.3	26.3	64.6	52.6	81.4
C.D. (0.05)	4.2	2.8	5.2	3.2	1.8	4.8	1.6

[a] DAP = Days after planting.

Table 3
Effect of GA_3 on fruit yield contributing factors and fruit disorders in 'Chandler' strawberry.

Treatment	Fruit weight (g)	Total fruit yield (g/plant)	Albino fruit (%)	Malformed fruit (%)	Buttons (%)	Marketable yield (g/plant)
Control	11.6	148.5	10.4	12.4	10.3	99.4
GA_3, 75 ppm (mid-November	11.2	294.6	9.6	9.2	8.7	213.6
GA_3, 75 ppm (mid-February	10.5	529.2	9.5	6.6	5.6	414.4
GA_3, 75ppm (mid-November and mid-February	10.0	526.0	9.5	2.2	1.8	455.0
C.D. (0.05)	0.3	19.8	NS	1.2	0.8	16.8

unaffected (Table 3). Plants, which received GA_3 (75 ppm) twice i.e., both in mid-November and mid-February produced minimum sized fruit (10.0 g), but with maximum total (526.0 g/plant) and marketable fruit yield (455.0 g/plant). Although plants, which received water spray only (control), produced fruit of largest size (11.6 g), but the total (148.5 g/plant) as well as marketable fruit yield (99.4 g/plant) was very low (Table 3). Furthermore, plants receiving water spray only produced highest proportion of albino (10.4%), malformed (12.4%) and button berries (10.8%) whereas those, which received GA_3 (75 ppm) twice, i.e., in mid-November and mid-February produced least proportion of malformed (2.2%), and button berries (1.8%) but albinism remained unaffected (9.5%) over control (Table 3).

3.4. Effects of GA on juice content and fruit quality parameters

Although, GA application at any time has significantly increased juice content (%), and ascorbic acid content in fruit, but TSS and acidity decreased slightly over control (Table 4). Of course, lowest juice (71.2%) was extracted from fruit in control, but highest juice (%) was extracted from fruit, which were harvested from plants receiving GA_3 (75 ppm) twice (mid-November and mid-February) (Table 4). Similarly, fruit harvested from plants receiving GA_3 (75 ppm) both in mid-November and mid-February had highest ascorbic acid content (50.4 mg/100 g pulp) and those, which were harvested from plants in control had the lowest (41.6 mg/100 g pulp) (Table 4).

4. Discussion

'Chandler' strawberry has shown very marked response to GA application on vegetative growth, fruit yield, and reduction in the production of malformed and button berries without adverse effects on fruit quality attributes. Increase in vegetative growth after GA application is very common in fruit crops including strawberry (Guttridge, 1970; Guttridge and Thompson, 1964; Martinez et al., 1994). Strawberry plants usually do not have distinct above ground stem, and hence vegetative growth following GA application was essentially reflected as increase in crown height, crown spread, petiole length, leaf number and leaf area. Mid-February application of GA was more effective than mid-November application in increasing the petiole length, crown height or spread, leaf area and leaf number, primarily because of increase in temperature with the onset of spring season, which favoured vegetative growth following GA application in mid-February (Martinez et al., 1994; Singh and Kaul, 1970). Further, GA application twice i.e., in mid-November and mid-February was much more effective than single application of GA in favouring vegetative growth of strawberry, primarily because of synergistic influence of both doses of GA on growth parameters.

GA applied at either time has affected the initiation and duration of flowering and harvesting season, flower number/plant, fruit set and fruit number/plant significantly over control. With mid-November GA application, flowering initiation was reduced but with other treatments, it was increased, primarily because of temperature rise during mid-February application. Increase in flower number and fruit set following GA application may be due to its known effect on flowering and fruit set of various fruit crops including strawberry (Kappel and MacDonald, 2007; Singh and Singh, 2006; Turner, 1963; Verzilov et al., 1963). Highest flower production and fruit setting in plants receiving GA both in mid-November and mid-February application may be due to synergistic effect of both the sprays, which were given during fruit bud differentiation stage (mid-November) and pre-flowering stage (mid-February).

GA application has, in general, decreased average fruit size, but increased total and marketable yield of 'Chandler' strawberry. Similar reduction in fruit size or weight has also been reported by Singh et al. (1960) and Singh and Kaul (1970). The decrease in fruit size was much more marked in mid-February application, primarily because of production of large number of secondary and tertiary fruit. The decrease in fruit size in mid-November application was lesser because it hastened harvesting by about two weeks, which mainly constituted of primary fruit (Singh and Kaul, 1970; Paroussi et al., 2002a). Similar increase in strawberry yield following GA application has also been reported by Singh et al. (1960), Turner (1963), Verzilov et al. (1963), Singh and Kaul (1970) and Paroussi et al. (2002a,b). The increase in yield is due to increase

Table 4
Effect of GA_3 on fruit quality parameters of 'Chandler' strawberry.

Treatment	Juice (%)	TSS (%)	Acidity (%)	Ascorbic acid (mg/100 g pulp)
Control	71.2	7.23	0.77	41.6
GA_3, 75 ppm (mid-November)	73.4	6.86	0.72	45.9
GA_3, 75ppm (mid-February)	74.2	7.14	0.88	49.7
GA_3, 75ppm (mid-November and mid-February)	74.8	7.20	0.82	50.4
C.D. (0.05)	0.2	0.68	0.16	1.2

in flower number, better fruit setting and marked decline in the production of malformed, and button berries besides better vegetative growth. GA spray at either time could not reduce the production of albino fruit perhaps because it has not played any significant role in fruit colour development as albinism occur due to poor colour development in strawberries. However, marked influence of GA on reduction in malformed and button berries may be attributed to its effects on better pollen germination and fruit set, which favoured the production of larger number of normal berries. These disorders occur primarily due to defective pollination of deficiency of some nutrients like B or excess of N (Singh et al., 2007). In fact, the enlargement of the strawberry fruit is dependent on the auxin produced by the developing achenes, and if the flowers remain unpollinated, the cells fail to elongate. GA might have helped in the elongation of cells in the unpollinated region of the fruit. As well, GA might have affected the auxin metabolism, which might have indirectly helped in the fruit enlargement, and so in the production of normal fruit in higher number (Kappel and MacDonald, 2007; Singh and Singh, 2006).

Further, strawberry is a short day plant, and GA is known for producing long day affects in short day plants (Thompson and Guttridge, 1959; Guttridge and Thompson, 1964; Paroussi et al., 2002a,b). Thus, it appears that GA had resulted in the production of larger number of flowers with rapid elongation of peduncle, leading to full development of flower buds having all functional reproductive parts (Voyiatzis and Paraskevopoulou-Paroussi, 2002), which increased fruit set tremendously over control. Reduction in fruit size following GA application may be due to rapid vegetative growth, and production of higher number of flowers and fruit/plant within a short time, which might have created competition for food material and thus reduced the fruit size (Singh and Kaul, 1970; Singh and Singh, 2006). These effects were much effective with two sprays of GA (mid-November and mid-February), which coincide respectively with fruit bud differentiation and pre-flowering stages in India.

5. Conclusion

A spray GA_3 both during mid-November and mid-February was much more effective for getting better vegetative and reproductive growth in strawberry with less proportion of malformed and button berries, but with higher marketable fruit yield, without any adverse effect on fruit quality.

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