International Journal of Chemical Studies

P-ISSN: 2349–8528
E-ISSN: 2321–4902
IJCS 2018; 6(3): 1382-1387

Received: 11-03-2018
Accepted: 15-04-2018

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A review on impact of GA_3 application on strawberry cultivation

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Abstract
Strawberry (*Fragaria* × *ananassa* Duch.) is a temperate fruit which bears aggregate fruits and responds well to plant growth regulators (PGRs). A range of varieties have been developed which are commercially being cultivated under subtropical climate as well. Application of PGRs particularly GA_3 has been commercially recommended for cultivation of strawberry. Literatures are available which have endorsed application of GA_3 at 10 to 150ppm concentration for various varieties like Pusa Early Dwarf, Senga Sengana, Missionary, Chandler, Sweet Charlie, Camarosa etc. These varieties have responded well in terms of better plant growth, runner production, flowering and fruiting enhancement, yield and quality improvement in strawberry after GA_3 treatment. A direct correlation has been reported by many authors in between GA_3 concentration and these parameters.

Keywords: gibberellic acid, growth, quality, strawberry, yield

Introduction

The cultivated strawberry (*Fragaria* × *ananassa* Duch.), family Rosaceae, has originated from the hybridization of two American species *viz.*, *Fragaria chiloensis* Duch. and *Fragaria virginiana* Duch (Martinelli, 1992) [22]. It is one of the most popular soft fruit cultivated in plains as well as in the hills up to an elevation of 3000 m in humid or dry regions. It is a unique and one of the choicest fruit among temperate fruits (Behnamian and Masiha, 2006) [6]. All commercially grown cultivars of strawberry are octaploid (2n = 8x = 56) in nature (Nathewet *et al.* 2010) [27]. Strawberry contains vitamins, minerals and also anti-cancer component called ellagic acid (Morgan, 2005) [26].

Strawberry is basically a temperate fruit crop, but during recent years area has increased in sub-tropics and tropical regions this had been possible due to modern cultivation approaches and introduction of new tropical cultivars. In Indian scenario cultivation is mainly limited to Dehradun, Nanital (Uttarakhand), Solan, Kullu (Himachal Pradesh), Srinagar (Jammu and Kashmir) and hills of Darjeeling (West Bengal). But due to its high cost return ratio and due to short growth phase, many farmers of states Punjab, Haryana, Delhi, Uttarakhand, J&K (Jammu) are looking forward for its cultivation. Profitability of Strawberry cultivation has been recognized under subtropical regions (Bhat *et al*., 2005) [7] due to development of certain cultivars suitable for such regions (Suga *et al.*, 2013) [53].

Fruits are attractive with distinct pleasant aroma and flavor, consumed as dessert and also have a special demand by the fruit processing units for the preparation of jams, ice cream, syrups, etc. Characteristic aroma in strawberries is due to presence of volatile esters. The most important aroma compounds are esters which include ethyl hexanoate, methyl hexanoate, ethyl heptanoate, ethyl propionate, ethyl butanoate, methyl butanoate and linalool. However, concentration of these compounds varies among cultivars. The ripe fruits of strawberry contain slightly more lipids than unripe ones, with higher quantity of oleic acid and lesser of linoleic acid. Essential oil can also be extracted from strawberry leaves. The major constituents of strawberry oil are linalool and nonanal. The ripe strawberries attain red colour on maturity and have soft melting pulp of a characteristic flavour, the red colour of the fruit is mainly due to the presence of an anthocyanin, pelarogonidin-3-monoglucoside and traces of cyanidin.

Plant growth regulators (PGRs) are effective means of improving fruit productivity as a result of their direct influence over the quantitative as well as qualitative aspects of fruit growth. These play an important role in controlling different growth and developmental processes of plants in conjunction with weather conditions.

Gibberellins are natural growth hormones which play primary role in stimulating auxin reaction that helps in controlling growth as well has direct effect on internode elongation, flowering, fruiting, quality and yield. Growth regulators such as gibberellins and cytokinins play important roles in physiological functions of plant. A mixture of gibberellins and cytokinins is also effective in promoting growth and development of many fruits.

Gibberellic acids, characterized by gibbane ring structure, is a tetracyclic diterpenoid with one or two hydroxyl groups, a lactone ring and one or two carboxylic group (Tian *et al.* 2017) [56]. Various kind of gibberellins have been reported in higher plants, fungi etc. which are not equally active. Their activity depends on number and positions of hydroxyl and carboxylic groups on the gibbane ring. Among all, GA_3 is biologically most active followed by GA_1, GA_4 and GA_2 (Chauhan, 2008) [9]. The commercially available forms of gibberellins are GA_3 or GA_4 +GA_7. The role of gibberellic acids in Strawberry has been reviewed and presented below:

Growth parameters of Strawberry

Gibberellin application on strawberry has tendency to influence growth pattern positively and induces better plant height which may be associated with enhanced cell elongation in the intercalary meristem which has further stimulated the cell division (Sauter and Kende, 1992) [45]. However, the cell growth is not associated with gibberellins induced auxin synthesis as confirmed by Ockerse and Galston (1967) [28]. Barralt and Davies (1977) reported that gibberellin induced stem elongation includes early expansion with distinct kinetics followed by long term mid expansion by enhancing IAA action, however there was no any increase in endogenous level of auxins.

Luangprasert (1994) [20] applied 4 levels of GA_3 viz 50, 100, 150 and 200 ppm at 4 leaf stage and subsequently after 7 days and observed increases petiole length with GA_3 concentration while leaf size, leaf number and branch crown were not varied significantly. Runner production was significantly increased with concentration of GA_3 while fruit production was decreased. Influence of gibberellin on vegetative growth of Strawberry is more than other growth promoters and GA_3 at 80 ppm induced better vegetative growth and runner production in strawberry as reported by Rajesh *et al.* (2012) [39].

Increased vegetative growth due to application of GA_3 results in increased nutrient uptake and photosynthesis and hence intensive runner productions as reported by Ali *et al*. (2011). The increased runner production in strawberry may also be associated with its inhibitory effect on flowering and simultaneous expansion of epidermal and parenchymatous cells. This is also responsible for increase in number of leaves in strawberry as reported by Akath and Singh (2009) [1]. However, the increased leaf area is associated with elongation of epidermal cell in leaf lamina (Eshghi *et al*., 2012) [13]. Singh and Singh (2009) observed the response of nitrogen fixing bacteria with chemical fertilizers in conjunction with plant bioregulators on Sweet Charlie Strawberry cultivar and application of 100ppm of GA_3 has been reported with maximum plant height, leaf count and leaf area when applied in combination with treatment consisting of *Azotobacter* and *Azospirillium* along with 60 kg N ha^{-1}. GA_3 at 75 ppm application resulted in tallest plant, maximum number of leaves and leaf area in strawberry as confirmed by Uddin *et al*. (2012) [60]. Sangwook *et al.* (1996) [44] has also reported the vigrous runner production in strawberry cultivar Samahberi in subsequent year when runners from GA_3 treated plants were kept under cold storage for 600 hours. Role of GA_3 as growth promoter has been confirmed by many authors, Table-1 describes the impact of various concentration of GA_3 on different growth parameters like plant height, plant spread, runner productions etc. of strawberry plants. Thakur *et al*. (2017) [54] advocated application of GA_{4+7} at 15 ppm and Promalin (1.8% of GA_{4+7} and 1.8% of 6-Benzyladenine) at 6ppm for maximum plant growth and leaf area when applied 2 weeks before flowering (WBF) under protected cultivation of strawberry cultivar Chandler.

Table 1: Impact of varying concentration of GA_3 on vegetative growth of strawberry

Concentration	Impact	Cultivars	Authors
GA_3 at 30 ppm	Growth of strawberry plants was observed to be satisfactory in plants treated with GA_3 at 1/3 of the total concentration applied three times at weekly intervals starting three weeks after transplanting.	Campinas and Monte Alegre	Lucchesi and Minami (1980)
GA_3 at 100 ppm	Increased leaf petiole length and runner production was reported when applied at first bloom.	Honeoye	Archbold (1989)
GA_3 at 75 ppm	Increased plant height and plant spread.	Pusa Early Dwarf	Sharma and Singh (1990)
GA_3 at 100 ppm	Maximum plant height, number of leaves per plant and number of runner per plants.	Murree	Mohammed *et al.* (1990)
GA_3 at 0.008%	The production of usable runners improved by 22 per cent.	Yasna and Senga Sengana	Pankov (1992)
GA_3 at 50 ppm + BA at 50 ppm	The runner production was highest.	Nyoho, Meriaka-16 and Hokouase	Kahangi *et al*. (1992)
GA_3 at 50 ppm or BA at 50 ppm or GA_3 at 50 ppm + BA at 50 ppm	Significantly increased petiole length in all three varieties while number of leaves was only increased in Miyoshi.	Summer Berry, Miyoshi and Enrai	Pipattanawong *et al.* (1996)
GA_3 at 300 ppm + BA at 1200 ppm	Increased runner production under protected condition.	Day neutral strawberries	Dale *et al*. (1996)
GA_3 at 50 or 100 ppm	Increased number of runners per m^2 and stem diameter when applied 30 or 60 days after planting.	Cruz, Vista, Tufts, Aliso and Pocahontas	Turemis and Kaska (1997)
GA_3 at 50 ppm	Maximum leaf number, leaf area, petiole length and greater number of runners.	Senga Sengana and Missionary	Dwivedi *et al.* (1999)
GA_3 at 200 ppm	Maximum leaf area and petiole length was reported when applied after flower initiation.	Camarosa, Laguna and Seascape	Paroussi *et al.* (2002a,b)

GA_3 at 20, 40 and 60 ppm	Significantly increased the number of runners.	Sweet Charlie	Mir *et al.* (2004)
GA_3 at 100 ppm	Tallest plant (20-39 cm) with higher number of leaves.	Chandler	Tripathi and Shukla (2006)
GA_3 at 90 ppm	The maximum vegetative growth and runner production.	Sweet Charlie	Kumar *et al.* (2008)
GA_3 at 20 ppm	The highest count of leaves, crown, flowers and inflorescences.	Chandler	Perez *et al.* (2008); Perez *et al.* (2009)
GA_3 at 10 ppm	Increased plant petiole length and carbohydrate content of plant foliage.	Sweet Charlie	El-Shabasi *et al.* (2009)
GA_3 at 75 ppm	Leaf petiole size, leaf count and area significantly increased.	Chandler	Sharma and Singh (2009)
GA_3 at 300 ppm + BA at 1200 ppm	Highest number of runners and maximum leaf number when sprayed during April.	Pajaro, Queen Eliza and Paros	Momenpour *et al.* (2009)
GA_3 at 100 ppm	Increased plant height, leaf count and runner production when sprayed on the plants before bud initiation.	Chandler	Singh and Tripathi (2010)
GA_3 at 75 ppm	Vegetative attributes of strawberry plants like plant growth, petiole development, leaf count and LAI (Laf Area Index) were significantly improved.	Sweet Charlie	Kumar *et al.* (2012)
GA_3 at 100 ppm	Maximum number of runners and leaf area.	Merak	Saied *et al.* (2012)
GA_3 at 50 ppm	Increase in number of runners and flowers.	Goviota	Asadi *et al.* (2013)
GA_3 at 75 ppm	Maximum plant height, spread, leaf count, petiole length and leaf area.	Chandler	Saima *et al.* (2014)
GA_3 at 75 ppm	Highest plant growth, leaf area, runners counts and crown counts	Chandler	Thakur *et al.* (2015)
GA_3 at 125 ppm	Highest plant height, number of leaves, size of leaves, plant spread, number of runners, leaf area index and growth rate per day.	Sujatha	Vishal *et al.* (2016)
GA_3 at 150 ppm	Highest plant height, number of runners per plant, length of runners and number of leaves per plant.	Sweet Charlie	Rustam *et al.* (2017)
GA_3 at 75 ppm	Maximum plant height, leaf count and leaf area when applied along with fermented cow dung at 10%.	Chandler, Selva, Confictura	Rajbhar *et al.* (2017)

Flowering and Yield related attributes of Strawberry

The yield and related attributes are function of sink capacity of plants which depends on vegetative growth of the plant resulting formation of more metabolites and enhanced flowering, fruit set and berry formations as confirmed by Mohammad *et al*. (1990) [24]. Sharma and Singh (2009) showed that spray of GA_3 at 75 ppm has positively affected fruit set in Chandler with slight reduction in individual berry weight, however marketable yield and total fruit number was increased over control without any negative impact on fruit quality parameters. Maximum fruit set and yield was recorded by Singh and Singh (2009) in Strawberry cv. Sweet Charlie treated with 100 ppm of GA_3 and fertilized with combination of *Azotobacter*, *Azospirillum* and 60 kg N ha^{-1} (50 % N of the standard dose). GA_3 applied in combination with Auxin (Phenothiol) significantly increased marketable yield in straw berry cultivar Camarosa (Roussos *et al*., 2009) [40]. Uddin *et al.* (2012) [60] observed maximum number of flowers, number of fruits, fruit weight and yield in strawberry due to application of GA_3 at 75 ppm.

Thakur *et al.* (2017) [55] have also confirmed the best flower counts, fruit counts, percentage fruit set, fruit size, fruit weight and 196.36% increase in fruit yield after application of GA_{4+7} at 15 ppm followed by 137.92% increase in yield after application of Promalin (1.8% of GA_{4+7} and 1.8% of 6-Benzyladenine) at 6ppm for maximum plant growth and leaf area when applied 2 weeks before flowering (WBF) under protected cultivation of strawberry cultivar Chandler. A number of researchers have evaluated the flowering and fruiting response in strawberry after application of GA_3. Few of these are listed in Table-2.

Table 2: Flowing and fruiting response in strawberry after GA_3 application

Concentration	Impact	Cultivars	Authors
GA_3 at 10 ppm	Increased fruit yield	Monte Alegre	Castro *et al.* (1976)
GA_3 at 75 ppm	Highest increase in fruit number per plant and yield was observed when covering cloches were used.	Pusa Early Dwarf	Sharma and Singh (1990)
GA_3 at 50.0 ppm	Resulted well advanced flowering when applied in November.	Aliso, Pocahontas and Tioga	Ozguven and Kaska (1991)
GA_3 at 50 ppm	Early inflorescence, accelerated flowering, earlier fruit setting and maturation in Seascape.	Camarosa, Laguna and Seascape	Paroussi *et al.* (2002)
GA_3 at 5, 10 and 20 ppm	Early flowering with increasing GA_3 doses and the highest yield was obtained using 5 and 10 ppm of GA_3.	Camarosa	Ozguven and Yilmaz (2002)
GA_3 at 100 ppm	The earliest flowering (116.50 days), produced the maximum number of flowers per trusses, fruit set, better yield and yield attributing characters.	Sweet Charlie	Singh and Singh (2005)
GA_3 at 100 ppm	Maximum number of flowers (16.23), extended duration of flowering (72.66 days) and higher yield (112.95 gram per plant) when applied before bud initiation stage.	Chandler	Tripathi and Shukla (2006); Tripathi and Shukla (2010)
GA_3 at 10 ppm	Increases the number of flowers, improved fruit set with maximum monthly and total yield.	Sweet Charlie	El-Shabasi *et al.* (2009)
GA_3 at 20 ppm	Maximum number of inflorescences and flowers.	Chandler	Perez *et al.* (2009)
GA_3 at 75 ppm	The highest fruit yield was reported.	Sweet Charlie	Kumar *et al*. (2012)
GA_3 at 50 ppm	A significant effect on flowering and fruiting was reported with nearly 138% increase over control.	Camrosa and Camaroga	Isamabdulbaset *et al.* (2012)

GA_3 at 75 ppm	Higher yield and number of flowers.	Chandler	Saima *et al.* (2014)
GA_3 at 75 ppm	Maximum fruit size and fruit yield	Chandler	Thakur *et al.* (2015)
GA_3 at 125 ppm	Maximum fruit set, number of fruits per plant and yield per plant.	Sujatha	Vishal *et al.* (2017)
GA_3 at 100 ppm	Highest yield was reported.	Sweet Charlie	Rustam *et al.* (2017)

Effect of gibberellic acid on quality

The plant growth stimulators have influence on quality of fruits of Strawberry and improve fruit quality when applied precisely in terms of time and concentration. The quality of fruit might be regulated with antioxidant activity of fruit juice as reported by Roussos *et al*. (2009) [40]. They had observed relatively higher antioxidant activity in strawberry juice when plants were treated with Auxin (Phenothiol) in combination to gibberellin in Camarosa cultivar. This might be result of high phenolic and flavonoid content. However, no significant effect was reported on pH, titratable acidity, TSS, organic acid and carbohydrates content. They have further confirmed highest fruit size and total anthocyanin content in fruits after treatment with the plant hormones. However, nonsignificant impact was reported over pH, acidity, TSS or organic acid. Singh and Singh (2009) studied the response of nitrogen fixing bacteria with chemical fertilizers in conjunction with plant bioregulators on growth, yield and nutrient status of strawberry cv. Sweet Charlie. Results showed highest chlorophyll content and optimum fruit quality in the plants treated with combination of *Azotobacter* + *Azospirillium* + 60 kg N ha^{-1} + 100 ppm GA_3. GA_3 (50, 75 and 100 ppm) has been reported with increased the sweetness of the strawberry fruits as reported by Uddin *et al*. (2012) [60] while increase in vitamin C and acidity in strawberry due to application of GA_3 at 80 ppm has been confirmed by Rajesh *et al*., (2012) [39]. Many authors have worked on application of different doses of GA_3 for quality production of strawberry fruits, some of them are given in Table-3:

Table 3: Quality fruit production after GA_3 application in strawberry

Concentration	Impact	Cultivars	Authors
GA_3 at 25, 50 and 75 ppm	Application of GA_3 before flowering increased the per cent sugar content,	Magestic	Singh and Phogat (1983)
GA_3 at 40 ppm	Increase in acidity and TSS/acid ratio,	Douglas	Lopez *et al.* (1989)
75 ppm GA3 + cloches	Increase in individual fruit weight, fruit TSS and acidity.	Pusa Early Dwarf	Sharma and Singh (1990)
GA_3 at 200 ppm	Application of GA_3 before flowering resulted in higher TSS and acidity.	Camarosa	Ozguven *et al.* (2000)
GA_3 at 100 ppm	Increased fruit quality like berry size and weight.	Sweet Charlie	Singh and Singh (2006)
GA_3 at 100 ppm	GA_3 applied before flower bud initiation stage resulted maximum length and weight of berries.	Chandler	Tripathi and Shukla (2006); Tripathi and Shukla (2010)
GA3 at 90 ppm	Maximum acidity was reported.	Sweet Charlie	Kumar *et al*. (2008)
GA_3 (50, 75 and 100 ppm)	Increased berry length, breadth, total soluble solids and total sugars.	Chandler	Singh and Tripathi (2010)
GA_3 at 75 ppm	Significantly influenced fruit TSS, TSS: acid ratio and acidity.	Chandler	Thakur *et al*. (2015)
GA_3 at 150 ppm	Maximum acidity was reported.	Chandler	Khunte *et al*. (2014)

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