INFLUENCE OF PLANT GROWTH REGULATORS ON GROWTH, YIELD AND FRUIT QUALITY OF STRAWBERRY (*Fragaria × ananassa)* cv. CAMAROSA

Thesis

by

SUMAN
(H-2020-57-M)

submitted to

Dr. YASHWANT SINGH PARMAR UNIVERSITY OF HORTICULTURE AND FORESTRY SOLAN (NAUNI) HP- 173 230 INDIA

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CERTIFICATE- I

This is to certify that the thesis titled **"Influence of plant growth regulators on growth, yield and fruit quality of strawberry (*Fragaria* × *ananassa*) cv. Camarosa"** submitted in partial fulfilment of the requirements for the award of the degree of **Master of Science (Horticulture) Fruit Science** in the discipline of **Horticultural Sciences** to Dr. Yashwant Singh Parmar University of Horticulture and Forestry, (Nauni) Solan (HP) – 173 230 is a bonafide research work carried out by **Ms Suman (H-2020-57-M)** daughter of Shri Devi Singh under my supervision and that no part of this thesis has been submitted for any other degree or diploma.

The assistance and help received during the course of this investigation have been fully acknowledged.

Place : Nauni (Solan)
Dated :

Dr Jitender Kumar Chauhan
Major Advisor

CERTIFICATE-II

This is to certify that the thesis titled, **"Influence of plant growth regulators on growth, yield and fruit quality of strawberry (*Fragaria* × *ananassa*) cv. Camarosa"** submitted by **Ms Suman (H-2020-57-M)** daughter of Shri Devi Singh to the Dr. Yashwant Singh Parmar University of Horticulture and Forestry, (Nauni) Solan (HP) - 173 230 India in partial fulfilment of the requirements for the degree of **Master of Science (Horticulture) Fruit Science** in the discipline of **Horticultural Sciences** has been approved by the Advisory Committee after an oral examination of the student in collaboration with an External Examiner.

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Place : Nauni, Solan
Dated : **(Suman)**

CONTENTS

ABBREVIATIONS USED

Abbreviation		Description
%	:	Per cent
&	:	And
GA_3	:	Gibberellic acid
NAA	:	Naphthalene acetic acid
BA	:	Benzyl adenine
@	:	At the rate of
^0C	:	Degree centigrade
^0N	:	Degree north
^0E	:	Degree east
ANOVA	:	Analysis of variance
CD	:	Critical difference
Cm	:	Centimetre
cm^2	:	Centimetre square
cv.	:	Cultivar
DF	:	Degree of freedom
ed.	:	Editors
et al.	:	Co-workers
etc.	:	Et cetera
FYM		Farm yard manure
G	:	Gram
Ha	:	Hectare (10,000 m^2)
HP	:	Himachal Pradesh
J&K	:	Jammu and Kashmir
i.e.,	:	That is
L	:	Litre
M	:	Meter (s)
Mg	:	Milligram
mL	:	Millilitres

Mm	:	Millimetres
Nm	:	Nanometer
MSS	:	Mean Sum of Square
NS	:	Non significant
P	:	Page
Ppm	:	Parts per million
RBD	:	Randomized Block Design
S.E. (d)	:	Standard error of difference
S.E. (m)	:	Standard error of mean
SS	:	Sum of Square
var.	:	Variety
viz.	:	*Videlicet* (namely)

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Chapter-1

INTRODUCTION

Strawberry (*Fragaria* × *ananassa*) is one of the world's most popular soft fruits. It belongs to the Rosaceae family and the majority of cultivated forms are octaploid (2n=56). The fruit is an achene and attached to juicy enlarged receptacles. The cultivated strawberry is a man-made hybrid that evolved from a cross between two American species, *Fragaria chiloensis* and *Fragaria virginiana* (Duchesne, 1766).

Strawberry is native to North America and commercially grown in Europe and North American countries. Major strawberry growing countries are China, USA, Mexico, Turkey, Egypt, Spain, Russia, South Korea, Poland and Morocco. China is leading strawberry producer in the world. In India it was introduced in early sixties by National Bureau of Plant Genetic Resources Regional Station, Shimla (Himachal Pradesh). Area under strawberry cultivation in India is 3000 ha with production of 20,000 MT (Anonymous, 2021). Strawberry is cultivated commercially in Maharashtra, Punjab, Haryana, hills of Himachal Pradesh, Jammu & Kashmir, Uttarakhand, Rajasthan and West Bengal. In Himachal Pradesh, area under strawberry cultivation is 40 ha with an annual production of 210 MT (Anonymous, 2021) and commercially grown in district Kullu, Sirmour, Solan, Kangra, Shimla and Una. In the lower hills, it is cultivated mainly for marketable fruits, while in higher hills it is commonly grown for runner production.

Strawberry is a shallow-rooted, short day and herbaceous plant that grows as a perennial in temperate climates and as an annual in subtropical climates. Plants take nutrients from the top soil surface due to their shallow root systems. Thus, soil's fertility, moisture, drainage, and microbiological properties in its upper surface upto 15 cm has a significant impact on growth, development, fruit output, quality, and runner production of strawberry. Plants thrive best at temperature range of 22-30°C. Frost as well as winter injury reduces yield of berries. Plant performs well in sandy loam soil with a pH range of 5.5 to 6.5. It can be successfully cultivated in plains and hills up to an elevation of 3000 meters above mean sea level in dry or humid climates. It is one of the few crops that provide quick and substantial returns per unit area on investment. Recently, farmers are getting attracted towards the commercial cultivation of strawberry because the crop is ready for harvest within six months.

The fresh strawberry fruits are rich in vitamins, minerals and antioxidants. The berries are non-fat and low in calories, rich in vitamin-C (58 mg/100g), potassium (153 mg/100g), folate (24 µg), dietary fibre (2 %) and vitamin-B_6 (0.047 mg/100g). It also contains water (90.95 %), energy (32 kcal), carbohydrates (7.68 %), sugars (4.89 %) and protein (0.67 %) (Giampieri *et al*., 2012). The typical aroma of ripe strawberry fruit is contributed by seven volatile esters and the red colour of the fruit is due to anthocyanin pelargonidin 3-monoglucoside and traces of cyanidin. The presence of ellagic acid, which helps in prevention of cancer and heart diseases as well as abundance of anthocyanins have elevated its fruit value. It is consumed fresh and processed value-added products are also available like jam, jellies, squash and syrup etc. Fruits are considered good for kidney stones, stomach ache and diarrhea.

Plant growth regulators (PGRs) are an effective technique of increasing growth, yield and quality of fruits. It can be synthesized within plants or derived from nature. They help to improve the plant growth and quality of fruits through various physiological and metabolic processes.

Gibberellic acid helps in growth and elongation of cells. It was first discovered in Japan in 1926. It increases petiole length, plant height, plant spread and also increases number of leaves per plant in strawberry (Kumar *et al*., 2011). It also helps in early initiation of flowering, increases flower number and fruit set (Asadi *et al*., 2013).

NAA is a synthetic auxin which controls various plant metabolic processes and foliar application of NAA have been reported to prevent pre-mature fruit drop and increase fruit size. NAA helps in improving quality, increasing fruit size and accumulation of anthocyanin content and delays ripening in strawberry (Mir *et al*., 2004).

BA is a cytokinin also utilised in fruit production for a variety of reasons as a plant growth regulator. It improves fruit size, lateral bud break and shoot growth in fruit trees, resulting in increased branching. It affects fruit size and weight by stimulating cell division (Shouming *et al*., 2007). BA improves the growth of the fruit and slows the degradation of chlorophyll and the ageing of the fruit. BA also slows respiration, delays ethylene synthesis and increases mechanical resistance all of which assist to limit the rate of senescence after harvest (Kumar *et al*., 2018).

Arbuscular mycorrhiza fungi (AMF) are soil microorganisms that can create a mutualistic symbiosis with a wide range of terrestrial plants. AMF helps to improve plant growth, nutrient uptake and resistance to biotic and abiotic stress. Physico-chemical properties of fruit like soluble solids, soluble solids/titratable acidity, fruit firmness and phenolic compounds also improved (Cordeiro *et a*l., 2019). Thus, the plant growth regulators and AMF are widely used for improving plant growth, runner production, fruit set and yield in strawberry.

Keeping in view the importance of plant growth regulators and AMF, the present study therefore on "Influence of plant growth regulators on growth, yield and fruit quality of strawberry (*Fragaria* × *ananassa*) cv. Camarosa" was carried out with following objectives:

1) To study the effect of plant growth regulators on growth yield and fruit quality of strawberry

2) To study the effect of plant growth regulators on physiological and bio-chemical parameters of strawberry

Chapter-2

REVIEW OF LITERATURE

Strawberry is a popular commercial fruit crop grown in temperate regions of the world. It is highly preferred fruit in the diet of millions of people across the world for its delicate flavour and high vitamin, mineral and antioxidant content (Bhat *et al.,* 2005). Application of growth regulators were rare under traditional system of farming and use of fertilizers were very common but nowadays farmers are shifting towards the use of growth regulators because of their direct influence on both the quantitative and qualitative elements of fruit growth.

Plant growth regulators are either natural or synthetic compounds that are directly administered to a target plant to change its biological functions. They include both naturally occurring hormones as well as synthetic substances. Phytohormones are organic substances produced spontaneously in higher plants that govern growth and other physiological functions at a distance from their source and are only active in trace amount. Thimann coined the term "phytohormone". Auxins were among the first hormones found in plants followed by gibberellins and cytokinins. Plant growth regulators in minute amounts promote, hinder or change any physiological function in plants and helps to improve the quality and production of fruit crops and also improves the yield and therefore beneficial to farmers when used in small concentration (Suman *et al.*, 2017). Symbiotic association of arbuscular mycorrhizal fungi (AMF) and plant roots helps in improvement of plant growth by nutrient uptake and resistance to biotic and abiotic stress (Sun *et al.,* 2018). Various workers reported that GA_3, NAA, BA and AMF were effective in terms of improving plant growth and physico-chemical properties of fruits (Sharma and Singh, 2009 and Cordeiro *et al*., 2019).

The effects of GA_3, NAA, BA and AMF on vegetative, floral, fruit and physico-chemical and bio-chemical parameters are reviewed in this chapter

2.1 Effect of plant growth regulators (GA_3, NAA, BA) and AMF on vegetative growth of strawberry cv. Camarosa

Thakur *et al*. (1991) recorded significant increase in vegetative growth as compared to control in strawberry cultivar Tioga with the application of NAA (5, 10 and 20 ppm) during first week of April.

Kahangi *et al.* (1992) registered maximum runner production in strawberry cultivars Nyoho, Morioka-16 and Hokowase with the application of BA at 50 ppm. Dale *et al*. (1996) reported that combination of benzyladenine at 1200 mg/L and gibberellic acid at 300 mg/L produced maximum runners in day neutral strawberries. Rana (2001) carried out an experiment to study the influence of nitrogen fixers and plant bio-regulators on growth, yield and fruit quality of strawberry cv. Chandler. He reported that foliar application of BA at 25, 50 and 100 ppm significantly increased plant height and leaf area.

Paroussi *et al.* (2002) observed increased petiole length and leaf area by application of GA_3 at 50 and 200 ppm under short and long photoperiodic conditions in three strawberry cultivars Camarosa, Laguna and Seascape in different greenhouse conditions.

Mir *et al*. (2004) found that by increasing NAA concentrations to 10, 15, 20, 25, 30 and 35 ppm resulted in substantial increases in plant height, spread, leaf area, and number of leaves per plant in strawberry cv. Sweet Charlie.

Mostafa and Saleh (2006) in their experiment sprayed 250 ppm GA_3 on seven year old apple tree variety Anna budded on MM. 106 rootstock and observed improved vegetative characters like increase in number of shoot, shoot diameter, leaf area and number of leaves on current shoot.

Tripathi and Shukla (2006) observed significant increase in plant height and number of leaves with the application of 100 ppm GA_3. Similarly, in an experiment conducted by Kumar and Tripathi (2009) studied the influence of NAA, GA_3 and boric acid on strawberry cultivar Chandler and recorded highest number of leaves (18.75), plant height (20.50 cm) and maximum number of crowns (3.50) and runners (3.50) with application of GA_3 at 100 ppm.

Patel *et al.* (2009) found improvement in plant height, trunk diameter and canopy spread in Sweet Orange cv. Mosambi by treatment of plants with N (300 g) + P (250 g) + K (300 g) + AMF (5 g) + *Azospirillium* (5 g) along with spray of 0.4 per cent micronutrients (Cu+Fe+B+Zn).

Perez *et al*. (2009) studied the effect of growth regulators on strawberry plants and they recorded increase in number of leaves per plant and crown with foliar application of GA_3 20 ppm in strawberry. Sharma and Singh (2009) found that application of GA_3 75 ppm twice during mid-November and mid-February resulted in maximum leaf number, leaf area,

petiole length, crown height and crown spread as compared to control in strawberry cultivar Chandler. Similar findings with foliar application of 75 ppm GA_3 were reported by Kumar *et al*. (2011) in strawberry cv. Sweet Charlie.

Ali *et al*. (2011) tested the effects of benzyladenine and gibberellin on runner production and several vegetative features in the strawberry cultivars Pajaro, Queen Eliza, Parso and discovered that GA_3 300 ppm and BA 1200 ppm applied in May produced the most plantlets and leaf area.

Abou *et al.* (2011) sprayed different concentrations of BA (10, 20, 30 and 40 ppm) on manzanillo Olive trees and reported increased in leaf area through 40 ppm BA application.

Eshghi *et al*. (2012) observed increase in runner production with 50 and 100 ppm GA_3 in strawberry cv. Merak.

Uddin *et al*. (2012) evaluated the effect of different concentrations of gibberellic acid (50, 75 and 100 ppm) on growth and yield of strawberry and found that GA_3 at 75 ppm produced the tallest plant (31.4 cm), maximum number of leaves, flowers and leaf area (64.5 cm^2). However, increase in runner production was recorded with 50 mg/L of GA_3 in strawberry cultivar Gaviota (Asadi *et al*., 2013).

Sehkar (2013) reported that 75 ppm GA_3 application increased plant height, leaf area and number of runners in strawberry cv. Chandler.

Khunte *et al.* (2014) observed an increase in plant height, petiole length and plant spread with combined applications of poultry manure 8.50 tones and 200 ppm GA_3 whereas, maximum number of leaves per plant were recorded with 5.50 tones poultry manure and 150 ppm GA_3.

Saima *et al*. (2014) observed that application of 75 ppm GA_3 after 75 days of transplanting resulted in maximum plant height (20.50 cm), plant spread (25.53 cm), leaf area (136.30 cm^2), number of leaves per plant (23.00) in strawberry cv. Chandler.

Hazarika *et al*. (2015) studied the effect of bio-fertilizers and plant bio-regulators on growth, yield and quality of strawberry cv. Festival. They recorded significant increase in plant height, plant spread and number of crowns per plant with the application of 75 per cent RDF + Vermicompost + *Azospirillum* + PSB + 50 ppm GA_3 + 50 ppm BA. Similarly, Thakur

et al. (2015) reported increased plant height with plant growth promoting rhizobacteria and 75 ppm GA_3 application in strawberry cv. Chandler.

Palei *et al.* (2016) studied the influence of plant growth regulators GA_3 (25, 50 and 100 ppm), NAA (25, 50 and 100 ppm) and IAA (25, 50 and 100 ppm) on strawberry cultivar Chandler under Odisha condition and noticed significant increase in plant height (25.3 cm), petiole length (13.2 cm), number of leaves (20.8), plant spread (35.7 cm) and runner production (3.2) with application of GA_3 at 100 ppm. Ikram and Qureshi (2016) found a significant increase in plant height and leaf area after spraying GA_3 at 400 ppm on strawberry plants.

An experiment carried out by Mastuane *et al*. (2016) to study the impact of different gibberellic acid concentrations (0, 25, 50 and 75 ppm) on growth of strawberry, the results revealed that GA_3 at 75 ppm impacted an increase in the number of leaves, leaf area, petiole length and plant spread. Similarly, Vishal *et al*. (2016) investigated the effect of NAA (15, 20 ppm), GA_3 (100, 125 ppm), CCC (1000, 1250 ppm) and BA (100, 125 ppm) on strawberry cultivar Sujatha and observed considerable increase in plant height, number of leaves per plant, length and breadth of trifoliate leaf, plant spread (29.70 cm east- west and 24.63 cm north- south direction) and number of runners per plant (5.87) by foliar application of 125 ppm GA_3.

Ahire *et al*. (2017) studied the effect of plant growth regulators on growth, yield and fruit quality of strawberry cultivar Sweet Charlie and registered significant increase in plant height (18.19 cm) with the application of NAA at 400 ppm while plant spread (26.72 cm) in NS direction was maximum in plants treated with 25 ppm GA_3.

Dubey *et al.* (2017) while studying effect of foliar sprays of NAA, GA_3 and boric acid on vegetative growth of strawberry cv. Chandler and noticed significant increased plant height, number of leaves, number of crown and runners per plant with the application of 100 ppm GA_3.

Kour *et al*. (2017) investigated the impact of benzyladenine and gibberellic acid on quality and economics of runner production in strawberry under subtropical condition and reported that GA_3 at 100 ppm improved plant height (10.88 cm) and petiole length (10.70 cm). While combination of 300 ppm GA_3 and 150 ppm BA resulted in maximum number of leaves and runners/mother plant (13.53).

Singh *et al.* (2017 a) conducted an experiment to study the effect of plant growth regulators on growth and fruiting behaviour of Phalsa. They applied NAA at 100, 150 and 200 ppm and GA_3 at 50, 100 and 150 ppm and recorded that application of 150 ppm of GA_3 increased shoot length, number of leaves per shoot, internodal length and number of shoots per plant.

Hamdy (2017) investigated the effect of GA_3 and NAA on fruit yield and quality of Washington Navel orange and results revealed that foliar application of 20 ppm GA_3 and 25 ppm NAA improved the shoot length and number of leaves per shoot and leaf area as compared to control and other treatments.

Singh *et al.* (2018) reported improved vegetative characters like plant height, canopy volume and leaf area through foliar application of 100 ppm GA_3 in Kinnow.

Todeschini *et al.* (2018) also studied the effect of three different AMF (*Funneliformis mosseae, Septoglomus viscosum,* and *Rhizophagus irregularis*) in combination with three different *Pseudomonas* species (19Fv1t, 5Vm1K and Pf4) on *Fragaria* × *ananassa* var. Eliana F_1 plantlets. The factors linked with the vegetative growth parameters of the plant were predominantly influenced by AMF.

Bhople *et al.* (2019) investigated the impact of growth regulators on strawberry cv. Chandler and reported that application of GA_3 at 75 ppm increased number of leaves per plant (40.50) while NAA at 100 ppm gives maximum leaf area (124.37 cm^2).

According to Li *et al.* (2020) long day condition influenced runner growth, and treatment with 6-BA at 50 mg/L considerably increased the number of runners production in strawberry.

Pandey *et al.* (2020) studied the influence of nutrients and plant growth regulators on strawberry cultivar Chandler and noticed that application of 100 kg nitrogen ,40 kg potassium and 50 ppm of GA_3 resulted in increased plant height (25.62 and 26.97 cm), leaf area (142.29 and 143.68 cm^2), number of leaves (23.69 and 24.39), number of runners (16.77 and 16.97).

Rathod *et al.* (2021) investigated the impact of NAA (50, 75, 100 and 125 ppm) and GA_3 (50, 75, 100 and 125 ppm) on growth, yield and quality of strawberry cv. Winter Dawn

and noted significant increased in plant height, petiole length, plant spread, number of leaves and runners per plant with foliar application of 100 ppm GA_3.

Hussein and Doori (2021) conducted an experiment to study the effect of 6-BA (0, 30 and 60 mg/L) and licorice root extract on vegetative growth of strawberry cv. Rubygem. They discovered that foliar application of BA at 60 mg/L resulted in maximum leaf area (95.81 cm) and number of leaves per plant (15.78).

Xing *et al.* (2022) reported significant increase in plant height and stem diameter through inoculation of plants with AMF in snapdragon.

2.2 Effect of plant growth regulators (GA_3, NAA, BA) and AMF on flowering and fruiting of strawberry cv. Camarosa

Maibangra and Ahmed (2000) recorded increase in yield with foliar application of 100 ppm NAA in pineapple. Rana (2001) reported maximum number of berries per plant and berry yield with the foliar application of GA_3 at 100 ppm in strawberry cultivar Chandler.

Mir *et al*. (2004) noticed significant increase in number of fruits and yield by application of NAA (10, 15, 20, 25, 30 and 35 ppm) at 2-3 leaf stage in strawberry cultivar Sweet Charlie. Khokhar *et al*. (2004) found that application of GA_3 at 75 ppm resulted in highest fruit yield in strawberry cultivar Chandler.

Bona *et al.* (2015) found that inoculation of AMF along with plant growth promoting bacteria helps in increasing flower and fruit production in strawberry.

Singh and Singh (2005) studied the effect of plant bio-regulators on flowering and fruiting of strawberry cv. Sweet Charlie and observed that using BA at 100 ppm gave maximum number of flower trusses per plant and total number of flowers per plant.

Hamano *et al.* (2006) noted delayed flowering with foliar application of 50 ppm BA in strawberry cultivars Nyoho, Tochiotome and Toyonoka. Shan *et al*. (2007) studied the effect of plant growth regulators (IAA, GA_3 and 6-BA) on strawberry cultivar French and reported that application of 6-BA and IAA at 50 mg/L in late autumn significantly improved the flower number and plant quality.

Nagargoje *et al.* (2007) carried out an experiment to study the effect of NAA (50 and 100 ppm) on fruit set, drop and retention of sapota cv. Kalipatti and results revealed that foliar application of 100 ppm NAA increased fruit set, retention and also reduces the fruit drop.

Fan *et al.* (2008) observed shortening of blossom date by 3 days and shortening of fruit ripening by 4 days with inoculation of AMF in strawberry cv. Zozi.

Tripathi and Shukla (2008) reported that the plants treated with GA_3 at a concentration of 100 ppm produced their first bloom in the shortest time (89.00 days), flowering for a longer duration (72.66 days) and produced the maximum fruits (14.25) per plant in strawberry cultivar Chandler.

Chavan *et al.* (2009) investigated the influence of plant growth regulators on flowering in sapota cv. Kalipatti and found that the quantity of flowers and fruit set in sapota is improved by foliar application of NAA 150 ppm.

El-Shabasi *et al.* (2009) recorded maximum number of flowers, fruit set and yield with foliar application of 10 ppm GA_3 in strawberry cv. Sweet Charlie. Similarly, Perez *et al.* (2009) observed increase in number of flowers with 20 ppm GA_3 in strawberry.

Ghosh *et al.* (2009) studied the effect of plant growth regulators on yield and fruit quality of Pomegranate cv. Ruby. They sprayed NAA (25 and 50 ppm), GA_3 (10 and 20 ppm) and 2,4-D (5 and 10 ppm) three times at interval of 21 days and found that NAA at 25 ppm resulted in considerably higher fruit set (44.3 %) and fruit retention (44.1 %), resulting in the greatest fruit yield of 7.8 kg/plant.

Roussos *et al.* (2009) reported a positive response to GA_3 application in boosting strawberry cv. Camarosa fruit yield in a glass house condition. Similarly, Singh and Singh (2009) in their experiment conducted to study the effect of biofertilizers and plant bio-regulators on growth, yield and nutrient status of strawberry cultivar Sweet Charlie found that application of *Azotobacter* and *Azospirillum* along with 60 Kg N/ha and GA_3 at 100 ppm significantly increased fruit set and yield.

According to Sharma and Singh (2009) applying GA_3 at 75 ppm in mid-November, mid-February or both times resulted in improved blossom quantity and fruit set in strawberry.

Cekic and Yilmaz (2011) conducted an experiment to study the effect of AMF (*Glomus clarum* and *Glomus caledonium*) and different doses of phosphorus (10, 30 and 60 ppm) in soilless culture of Camarosa and Maraline strawberry cultivars and results revealed that mycorrhizal inoculation significantly increases the yield in Maraline.

Bhamre (2012) investigated the impact of plant growth regulators on mango cv. Mallika yield, quality and fruit drop reduction. When compared to other treatments, the results showed that foliar application of NAA 20 ppm resulted in significantly more fruit set.

Isam *et al.* (2012) evaluated the effect of foliar application of IBA, GA_3 and 6-BA at 0 and 50 ppm either separately or in combination on strawberry cultivars Camarosa and Camaroga under greenhouse condition. They found significant increase in number of flowers per plant (138 %) with 50 ppm GA_3 treated plants as compare to control. Fruit set is also increased by 97.24 per cent and 81.5 per cent with IBA and GA_3 application. Uddin *et al.* (2012) studied the effect of different concentrations of gibberellic acid (50, 75 and 100 ppm) on growth and yield of strawberry and reported that GA_3 at 75 ppm gave maximum number of flowers and yield per plant.

Agnihotri *et al.* (2013) investigated the impact of growth regulators on fruit set of guava cv. Chittider. They found that foliar application of 200 ppm NAA considerably increased guava fruit set.

Asadi *et al.* (2013) observed that foliar application of GA_3 at 50 ppm increased the number of flowers and yield in strawberry cv. Gaviota. Similar results were obtained by Sehkar (2013) when he applied 75 ppm GA_3 in strawberry plants.

Jasrotia *et al.* (2014) sprayed three doses of GA_3 (50, 100 and 150 ppm) to test the effect of GA_3 on flowering and yield characteristics of strawberry cv. Belrubi. Plants treated with GA_3 at 50 ppm, 100 ppm and 150 ppm took the least amount of time to start flowering (53.55) and bud formation (60.08) while 50 ppm of GA_3 produced maximum number of flowers per plant (22.56), fruit yield per plant (269.89 g), and fruit yield per hectare (16.50 q/ha).

Saima *et al*. (2014) investigated the effect of plant bio-regulators on vegetative growth, yield and quality of strawberry cv. Chandler. They applied GA_3 (50, 75 and 100 ppm), NAA (25, 50 and 75 ppm) and Cycocel (500, 750 and 1000 ppm) at 75 days after

transplanting and recorded maximum number of flowers (30.22) and berries per plant (24.80) by treatment of 75 ppm GA_3 whereas early initiation of flowering (61.66 DAT) and fruit formation (66.66 DAT) was recorded with 750 ppm cycocel application.

Rajbhar *et al*. (2014) reported that foliar spray of GA_3 @ 100 ppm and the application of vermicompost 100 q/ha resulted highest fruit yield, maximum fruit number, and maximum fruit production per hectare in Strawberry cv. Chandler whereas the Douglas cultivar produce minimum number of fruits by foliar application of 25 ppm gibberellic acid and vermicompost 25 q/ha.

Thanaa *et al.* (2015) investigated the effect of foliar application of dry yeast extract and benzyladenine on growth and yield of Manzanillo olive trees and they observed increase in yield of olive by combined application of 40 g/L yeast extract and 60 ppm benzyladenine.

Palei *et al.* (2016) conducted an experiment to study the influence of plant growth regulators on strawberry cultivar Chandler and discovered that NAA at 100 ppm significantly increased the number of flowers (24.1) and fruits per plant (22.5) and took minimum days to initiate flowering (50.1).

Robinson *et al*. (2016) studied the effect of strawberry inoculated with liquid spore suspension and granular commercial inoculum of *R. irregularis*. They found that AMF-treated strawberries especially granular AMF produced more fruit from mid-to-late harvest and granular AMF and liquid AMF treatments produced significantly more fruit than the control.

Ahire *et al.* (2017) studied the effect of plant growth regulators on strawberry cv. Sweet Charlie and observed that application of 75 ppm GA_3 resulted in increased number of fruits per plant and yield.

Ennab (2017) noted significantly increased in fruit set and yield while reduction of pre-harvest fruit drop through application of 1000 g N + 20 ppm of GA_3 in Chinese mandarin trees.

Barwary *et al.* (2018) investigated the effects of GA_3 (0, 100, 200 and 300 mg/L) and Zinc (0, 2, and 4 g/L) on strawberry plant growth, yield, and quality. Results showed that

combination of GA_3 (300 mg/L) and zinc (4 g/L) at higher concentration significantly increased number of fruits per plant (21.07).

Ghorchiani *et al*. (2018) observed increase in yield by inoculation of maize with combination of *Funneliformis mosseae* and *Pseudomonas fluorescens under water stress condition.*

Singh *et al.* (2018) investigated the impact of plant growth regulators and micronutrients on yield and quality of Kinnow and they found significantly increase in number of fruits per plant (458) and yield (114.0 kg/tree) with foliar application of 100 ppm GA_3.

Sood *et al.* (2018) found that the use of a combination of bio-fertilizers and growth regulators PSB (6 kg/ha) + GA_3 (100 ppm) improved plant growth while reducing the time it took to produce the first flower (57 days) compared to control.

Bhople *et al.* (2019) recorded maximum number of flower (46.39), fruit (39.42) and yield per plant (618.50 g) treated with 50 ppm GA_3 and combination of 50 ppm GA_3 and 75 ppm NAA results maximum fruit set (85.50 %) in strawberry cv. Chandler. Similarly, Ruchitha *et al.* (2020) also reported highest number of flowers, fruits and yield per plant with the application of GA_3 at 150 ppm.

Rathod *et al.* (2021) investigated the effect of plant growth regulators on strawberry cv. Winter dawn under open field condition. The results revealed that foliar application of 100 ppm GA_3 took minimum days to flowering and increased number of flowers per plant.

Bhooriya *et al.* (2021) noted minimum days to first flower initiation and maximum number of flowers per shoot by treatment of plants with 100 per cent recommended dose of fertilizers and 20 ppm of NAA with 15 days interval of fertigation in pomegranate.

2.3 Effect of plant growth regulators (GA_3, NAA, BA) and AMF on fruit quality of strawberry cv. Camarosa

Bhautkar (1994) found that applying NAA at 35 and 51 days after planting had a substantial impact on fruit TSS in strawberry cv. Australia. Haidry *et al.* (1997) reported increase in total soluble solids, total sugars and lower acidity in plants treated with 20-40 ppm NAA while 20 ppm NAA gave maximum yield and minimize the fruit drop in mango.

Ingle *et al*. (2001) observed that three foliar sprays of NAA at 30 ppm administered in February, August and September resulted in significant improvement in fruit qualities including fruit weight in Nagpur mandarin. Similarly, fruit weight, TSS, ascorbic acid, and total sugars content of guava fruits rose considerably over control when NAA @ 20 to 60 ppm was applied, according to (Yadav *et al.,* 2001).

Rana (2001) reported maximum TSS and total sugars content in strawberry cultivar Chandler with the application of 100 ppm GA_3. Similar results were reported by Ozguven and Yilmaz (2002) that application of GA_3 at 200 ppm before flowering in strawberry cv. Camarosa resulted in greater TSS and acidity.

Kher *et al.* (2003) found that TSS, total sugars, non-reducing sugars, and TSS: acid ratio were all highest in guava cv. Sardar when NAA 60 ppm is applied, whereas reducing sugars were high in plants treated with NAA at 80 ppm. Stern and Flaishman (2003) found that application of BA at 100 mg/L two weeks after full bloom when the fruitlet diameter was 10 mm, increased the fruit size of both Spadona and Coscia pear varieties.

According to Asrey *et al.* (2004) pre harvest treatment with NAA 25 ppm favoured the greater vitamin C content (49.30 mg/100 g pulp) of strawberry cultivar Chandler in storage. Khokhar *et al.* (2004) investigated the effect of NAA (30 and 60 ppm) and GA_3 (50 and 75 ppm) on the yield and fruit quality of strawberry cv. Chandler and recorded highest anthocyanin content with the application of GA_3 at 50 ppm. Schwab and Raab (2004) found that gibberellic acid treatments significantly increased anthocyanin content in strawberry.

Sharma and Ananda (2004) registered increase in yield of apple by pre-bloom foliar spray of NAA at a concentration of 5 ppm. Similarly, Bhat *et al*. (2006) recorded maximum yield in Lemon var. Eureka with 40 and 20 ppm foliar spray of NAA.

Lenahan *et al*. (2006) discovered that applying GA_3 at 50 and 100 ppm increased TSS, firmness, and weigh in sweet cherry. Similarly, Singh and Singh (2006) noted maximum total soluble solids (8.90 °Brix), total sugars (8.50 %) and ascorbic acid (59.22 mg/100g) in strawberry cultivar Sweet Charlie through dual inoculation of *Azotobacter* and *Azospirillum* along with 100 ppm of GA_3 and 50 per cent standard dose of nitrogen.

Nawaz *et al.* (2008) sprayed different concentrations of NAA (10, 15 and 20 ppm) on Kinnow mandrin and observed maximum vitamin C content (45.30 mg/100g) through 15 ppm NAA application.

Saleem *et al*. (2008) studied the effect of spring application of growth regulators on fruit quality of Blood Red Sweet Orange. They recorded increased juice content, pulp, reducing sugars, non-reducing sugars and total sugars with foliar application of 20 ppm GA_3.

Iqbal *et al.* (2009) sprayed various concentrations of NAA (0, 15, 30, 45, 60, 75, and 90 ppm) at the marble and walnut stages of Red Flesh Guava and found that foliar application of 45 ppm NAA reduced fruit drop (8.83 %) and increased total soluble solids (11 %) and total sugars (7.45 %) while lowering acidity.

Kumar and Tripathi (2009) investigated the effects of NAA, GA_3, and boric acid on strawberry cultivar Chandler growth, yield, and quality. Plants treated with NAA at 20 ppm produced berries with the highest TSS (7.68 °Brix), total sugars (5.97 %), and titratable acidity (0.92 %), whereas GA_3 (100 ppm) produced berries with better length (3.14 cm), width (1.95 cm), and ascorbic acid content (56.66 mg/100g).

Villarreal *et al.* (2009) recorded that the application of naphthalene acetic acid (NAA) to strawberry fruits delayed ripening and anthocyanin accumulation. According to Agrawal and Dikshit (2010) TSS, reducing sugars, non-reducing sugars, and total sugars were all significantly increased in sapota fruit after foliar application of NAA 100 ppm.

Tripathi and Shukla (2010) investigated the influence of plant bio-regulators, boric acid and zinc sulphate on yield and fruit character of strawberry cultivar Chandler. Plants were sprayed with NAA (5, 10 and 15 ppm), GA_3 (25, 50 and 100 ppm), CCC (500, 1000 and 1500 ppm), BA (25, 50 and 100 ppm), boric acid (0.1 and 0.2 %) and zinc sulphate (0.2 and 0.4 %) before flower bud initiation and found that GA_3 at 100 ppm generated the largest berries in terms of length, volume, and weight, whereas CCC at 1000 ppm produced the largest berries in terms of breadth.

Yadav *et al.* (2010) investigated the effect of NAA, GA_3, boric acid and $Ca(NO_3)_2$ on fruit retention, growth, yield and quality of aonla (*Emblica officinalis*) cv. Banarasi. Results showed that 30 ppm NAA helps in improvement of fruit size, weight, yield, total soluble solids, total sugars, ascorbic acid and decreases acidity content.

Garasiya *et al*. (2013) investigated the impact of different concentrations of GA_3 (50 and 100 ppm), NAA (20 and 40 ppm), 2, 4-D (5 and 10 ppm), and CCC (250 and 500 ppm) on the yield of the winter season guava cv. L-49. They found that fruit diameter was dramatically increased and improvement in fruit weight, volume, quantity and yield were recorded by application of 20 ppm NAA.

Kumar *et al.* (2013) studied the effect of gibberellic acid and blossom removal on fruit quality of strawberry cv. Belrubi reported that application of 50 ppm GA_3 with partial de blossoming significantly increased fruit TSS, sugars and juice content.

Narayan *et al.* (2013) investigated the impact of growth regulators on guava cv. Allahabad Safeda and found that foliar application of 50 ppm GA_3 improved fruit length, girth, weight and also reduce fruit drop.

Khunte *et al.* (2014) conducted a study to see how plant growth regulators such as NAA, GA_3, Tricontanol, and CCC as well as organic manure affected the physico-chemical parameters of strawberry cv. Chandler and found highest acidity of fruit juice was achieved by applying 5.50 tonnes ha-poultry manure + 150 ppm GA_3 and maximum TSS with 100 ppm GA_3 and maximum juice content with 200 ppm GA_3.

Hemalatha *et al*. (2015) found that fruits treated with 50 ppm BA and 6 per cent wax had the maximum juice content, ascorbic acid, and firmness in Sweet Orange cultivar Sathgudi.

Thakur *et al.* (2015) discovered that application of plant growth promoting rhizobacteria (PGPR) + GA_3 @ 75 ppm to strawberry cv. Chandler improved fruit quality considerably. According to Tomar *et al.* (2016) combining GA_3 30 ppm+ NAA 30 ppm and 2,4-D 5 ppm in tomato resulted in a considerable increase in fruit weight and yield.

Cecatto *et al.* (2016) reported increase in anthocyanin content in strawberry cv. Splendor, Sabrina and Fortuna by inoculation of plants with AMF during transplanting.

Singh *et al*. (2017b) conducted an experiment to study the effect of plant growth regulators on yield and fruit quality of guava cv. Allahabad Safeda. They observed that application of 200 ppm NAA helps in improvement of fruit size, weight, TSS, reducing sugars, total sugars and ascorbic acid of fruits.

Tiwari *et al.* (2017) recorded maximum total soluble solids content (9.6 °Brix), total acidity (0.65 %), ascorbic acid (53.43 mg/100 g fruit pulp) in strawberry cultivar Chandler through application of 150 ppm GA_3. Similarly, Gaikwad and Ahire (2017) reported that foliar treatment with 75 ppm GA_3 gave best results by increasing total soluble solids in strawberry cultivar Sweet Charlie.

Khandaker *et al.* (2017) investigated the effect of localised GA_3 (0, 20, 50 and 100 mg/L) treatment on wax apple and discovered that rubbing fruits with 50 mg/L GA_3 improved fruit length, diameter, weight and anthocyanin content while lowering chlorophyll level as compared to control.

Kumar and Sharma (2017) investigated the effect of GA_3 in combination with urea phosphate and BA on yield and physical quality of Thompson seedless grape. Results revealed significant increase in length, width and weight of berry with combination of GA_3 30, 40 ppm and BA 10 ppm when sprayed at pre bloom and berry set stage.

Nazir *et al*. (2017) sprayed GA_3 (25 and 50 mg/L), BA (10 and 20 mg/L), 2,4-D (10 and 25 mg/L), TRIA (10 and 20 mg/L) and a natural extract (4 gm/L) four weeks after full bloom in kiwifruit and found that TSS/ acidity ratio, vitamin C, total phenols, and total carotenoids were also at their greatest with 25 ppm GA_3 followed by 50 ppm GA_3.

Paikra *et al.* (2018) evaluated the effect of different concentrations of GA_3 (25, 50, 75, 100 and 125 ppm) and NAA (10, 20, 30, 40 and 50 ppm) on quality of strawberry cultivar Sabrina and reported increased TSS (9.91 °Brix), TSS: acid ratio (18.02), total sugars (8.92 %), reducing sugars (5.71 %), non-reducing sugars (3.21 %) and ascorbic acid (65.05 mg/100g) while decrease in acidity of fruit (0.55 %) by foliar application of 75 ppm of gibberellic acid.

Yadav *et al.* (2018) studied the effect of micronutrients (Borax, $ZnSO_4$) and plant growth regulators on strawberry cultivar Chandler and observed that foliar spray of $ZnSO_4$ (0.4 %) + NAA (15 ppm) resulted in maximum fruit TSS (8.06 ºBrix), reducing sugars (5.45 %), non-reducing sugars (2.58 %) and total sugars (8.03 %).

Chiomento *et al.* (2019) reported increased anthocyanin content (65 %) of fruits obtained from plants inoculated with AMF. Cordeiro *et al*. (2019) observed that inoculation with AMF in strawberry increased soluble solids content, soluble solids/titratable acidity

ratio. According to Kong *et al.* (2019) increase in soluble solids, soluble sugars and vitamin C content of tomato fruits were recorded by soil application of AMF in saline alkaline soil.

El- Gould and Amal (2020) found that when plants of watermelon were treated with the mixture of 25 per cent compost + 25 per cent vermicompost + 25 per cent chicken + 25 per cent cow manures (8 T/fed.) + Vermitea 4 + AMF, they observed maximum total soluble solids, total sugars, reducing sugars and non- reducing sugars.

Sharifi and Sarikhani (2020) carried out an experiment to study the effect of light intensity and foliar application of calcium chloride and NAA on growth, yield of strawberry cv. Paros. They observed maximum anthocyanin content in plants treated with NAA and shade condition.

Rathod *et al.* (2021) sprayed NAA and GA_3 at 50, 75, 100 and 125 ppm at 30 and 60 days after transplanting. They found increased in fruit TSS (8.98 °Brix), ascorbic acid (97.18 mg/100g), acidity (0.74 %), total sugars (9.72 %), reducing sugars (5.14 %), non-reducing sugars (4.57 %) and fruit firmness (0.97 kg/cm^2) by application of 125 ppm NAA whereas improvement in fruit weight (15.37 g), length (3.98 cm) and maximum numbers of fruits per plant (18.67) were observed by application of 100 ppm GA_3 in strawberry cultivar Winter Dawn.

Senjam and Singh (2021) studied the effect of foliar application of NAA, 2,4-D and urea on fruit yield and quality of *Citrus limon* cv. Assam lemon. They reported increase in juice content (40.47 ml/fruit), reducing sugars (0.51 %) and ascorbic acid (48.56 mg/100 g) by application of NAA @ 20 ppm + 2,4-D @ 20 ppm + 1 per cent urea whereas increase in TSS (9.88 °B), total sugars (1.66 %) and minimum titratable acidity (3.10 %) with application of NAA @ 10 ppm + 2,4-D @ 10 ppm + 1 per cent urea.

2.4 Effect of plant growth regulators (GA_3, NAA, BA) and AMF on bio-chemical and physiological parameters of strawberry cv. Camarosa

Yuan and Xu (2001) observed increased in net photosynthesis rate by application of 90 ppm GA_3 in broad bean. Similar results were obtained by Ashraf *et al.* (2002) that GA_3 application helps to improve photosynthesis rate in wheat grown under different medium.

Stylianidis *et al.* (2004) conducted an experiment on effect of plant growth regulators on fruit shape and inorganic nutrient concentration in leaves and fruits of red delicious apple and results showed that GA_3 at 100 ppm significantly increase the photosynthetic rate, transpiration rate and stomatal conductance.

Guo *et al*. (2006) recorded increased net photosynthetic rate in leaves by application of sodium bisulfite and benzyladenine while stomatal conductance and transpiration rate increased only by the application of benzyladenine.

Wu and Xia (2006) studied the influence of AMF on plant growth, osmotic adjustment and photosynthesis of *Citrus tangerine* grown in pots under well-watered and water stress condition. Results revealed that seedlings inoculated with AMF had higher leaf water potential, transpiration rates, photosynthetic rates, stomatal conductance than non-AM seedlings.

Shan *et al.* (2007) reported that application of plant growth regulators (IAA, GA_3 and 6-BA) during autumn increased Chlorophyll a, b content and net photosynthetic rate of strawberry cv. French. Singh and Singh (2009) studied the effect of biofertilizers and growth regulators on growth, yield and quality of strawberry cv. Sweet Charlie and noticed highest chlorophyll content in plants treated with *Azotobacter* + *Azospirillum* + 60 kg N /ha + 100 ppm GA_3.

Abou *et al*. (2011) studied the effect of Benzyladenine on growth, flowering and fruiting of Manzanillo Olive trees and they recorded increased chlorophyll content through foliar application of 40 ppm BA.

Bagheri *et al.* (2013) sprayed different concentrations of NAA (0, 10 and 20 mg/L) on *Alstroemeria hybrida* and revealed that application of 20 mg/L NAA helps in increasing chlorophyll b content.

Sehkar (2013) observed highest chlorophyll content and photosynthesis with foliar application of CPPU 6 ppm + GA_3 50 ppm in strawberry cultivar Chandler. Similarly, Zang *et al.* (2016) conducted an experiment to investigate the effect of gibberellic acid application on growth attribute, return bloom and fruit quality of rabbit eye blueberry and observed significantly increase in chlorophyll content, chlorophyll a and b by foliar application of 500 mg/L GA_3.

Al-Rawi *et al*. (2016) conducted an experiment to study the effect of foliar application of Gibberellic acid and Sea weed extract on growth and leaf mineral content of Peach trees and they found that foliar application of 100 ppm GA_3 and 4ml/L seaweed extract increased chlorophyll content of leaves (37.18 mg/g).

Chen *et al.* (2017) found root activity, chlorophyll content, net photosynthetic rate, and light saturated rate of CO_2 absorption all increased significantly after AMF colonization in cucumber.

Ayad *et al.* (2018) studied the effect of foliar application of GA_3 on strawberry cultivars BG4.370 and Splendor. They observed higher photosynthesis rate in both the cultivars sprayed with 200 mg/L GA_3 than control and highest stomatal conductance, transpiration rate were observed by the application of 50 mg /L GA_3 in BG4.370 and 100 ppm GA_3 in Splendor.

Barwary *et al.* (2018) recorded increase in leaf chlorophyll content by combination of GA_3 (30 mg/L) and Zinc (4 g/L) in strawberry cultivar Tioga. Highest chlorophyll content by application of 70 ppm NAA at 50 days after emergence in mustard was recorded by (Begum *et al.*, 2018).

Kumari *et al.* (2018) studied the impact of PGPR and GA_3 on strawberry cv. Chandler and they reported increased chlorophyll content, photosynthesis, stomatal conductance and transpiration with PGPR and 75 ppm GA_3 treatment as compared to control.

Mikiciuk *et al.* (2019) conducted an experiment to study the impact of AMF and rhizosphere bacteria on fruit quality, selected physiological parameter and yield of strawberry cv. Rumba and reported increased rate of transpiration, chlorophyll a and total chlorophyll content.

Huang *et al.* (2020) revealed that mycorrhizal colonization improved apple drought tolerance by enhancing gas exchange capacity and raising chlorophyll levels. Similarly, increase in chlorophyll content is observed in tomato by inoculation of AMF by (Turhan, 2021). Das *et al.* (2021) studied effect of NAA (20, 30, 40 and 50 ppm) and GA_3 (10, 15, 20 and 25 ppm) on *Citrus lemon* cv. Eureka and found that plants treated with 25 ppm GA_3 resulted in increased chlorophyll content.

Chapter-3

MATERIALS AND METHODS

The present study entitled "**Influence of plant growth regulators on growth, yield and fruit quality of strawberry (*Fragaria* × *ananassa)* cv. Camarosa''** was carried out during 2021-2022 at Horticulture Research & Training Station and Krishi Vigyan Kendra, Solan at Kandaghat. The detail of the material and methodologies used during the course of study has been described into the following heads:

3.1 GEOGRAPHICAL CONDITIONS

The experiment was carried out at Horticulture Research & Training Station and Krishi Vigyan Kendra, Solan at Kandaghat. The experimental farm is situated at the elevation of 1425 m above mean sea level with latitude of 30.92°N and longitude of 77.15°E and area falls under the sub-temperate, sub-humid and mid-hill agro-climatic zone of Himachal Pradesh. The average summer temperature is about 25.2°C and minimum temperature during winter is about 9°C. The average annual temperature of the experimental area is 18°C and annual rainfall is about 375mm.

3.2 EXPERIMENTAL METHODOLOGY

3.2.1 Preparation of beds

Prior to preparation of beds, the land was thoroughly prepared by repeated ploughing with the help of power tiller and well rotten FYM is also incorporated in the soil. The raised beds 1m × 1m size were prepared and six healthy runners of strawberry cultivar Camarosa were planted in these beds at a spacing of 30 cm × 60 cm during first week of October. The uniform cultural practices like weeding, hoeing, irrigation and mulching were done at regular intervals in each bed.

3.2.2 Preparation of spray material and method of spray

The required amount of GA_3 and NAA was first dissolved in 50 ml ethanol solution and then desired volume was made with water. The required amount of BA was first dissolved in 1 per cent NaOH and then desired volume was made with distilled water. Plants were inoculated with 10 g arbuscular mycorrhizal fungi per plant for 30 minutes.

Plant growth regulators were sprayed uniformly with the help of pneumatic volume sprayer till the leaves were wet and droplets of solution started trickling down. One liter of solution was required for each treatment. Spray was done twice during morning hours in month of November and December.

3.2.3 Details of Experiment

The experimental plants were subjected to different treatments of GA_3, NAA and BA as per details given below:

Total number of treatments	:	10 viz
T_1	:	5 ppm NAA
T_2	:	10 ppm NAA
T_3	:	15 ppm NAA
T_4	:	25 ppm GA_3
T_5	:	50 ppm GA_3
T_6	:	75 ppm GA_3
T_7	:	5 ppm BA
T_8	:	10 ppm BA
T_9	:	15 ppm BA
T_{10}	:	Control
No. of replications	:	3
Time of application	:	a) 30 and 60 days after transplanting
	:	b) Root inoculation of all the plants with AMF 10g/plant
Fruit species	:	Strawberry
Cultivar	:	Camarosa
Design of experiment	:	Randomized Block Design (RBD)

3.3 OBSERVATIONS RECORDED:

Data on following parameters were recorded in the experiment:

A. Vegetative Parameters

1. Plant Height (cm)
2. Petiole Length (cm)

3. Number of Leaves per plant
4. Leaf Area (cm^2)
5. Number of crowns
6. Number of runners

B. Flowering and Fruiting Parameters

1. Time of initiation of flowering
2. Duration of flowering
3. Number of flowers per plant
4. Fruit set (%)
5. Cumulative fruit number
6. Cumulative fruit yield

C. Fruit Quality Parameters

1. Fruit Size
2. Fruit Weight (g)
3. Fruit Firmness (kg/cm^2)
4. Total Soluble Solids (°B)
5. Titratable Acidity (%)
6. TSS: acid ratio
7. Sugars (%)
8. Ascorbic acid content (mg/100g)
9. Anthocyanin content

D. Bio-Chemical Parameter

1. Chlorophyll Content (mg/g fresh weight)

E. Physiological Parameters

1. Photosynthesis ($\mu mol\ CO_2/m^2/sec$)
2. Stomatal Conductance ($mol\ H_2O/m^2/sec$)
3. Transpiration **(**$mmol\ H_2O/m^2/sec$)

Below are the specifics of the methodology used to document various observations:

3.3.1 VEGETATIVE PARAMETERS

3.3.1.1 Plant Height:

Plant height was measured using a measuring scale from the crown to the apex of primary leaves and the results were expressed as an average height in centimeters (cm).

3.3.1.2 Petiole Length:

The petiole length of plants was measured on a scale from the base of the petiole to the base of the leaf blade and the results were represented as average petiole length in centimeters (cm).

3.3.1.3 Leaf Area:

Ten fully expanded leaves were taken from the plants in the month of May and leaf area were measured with the help of LI-COR 3000 leaf area meter and average was expressed in square centimeter (cm^2).

3.3.1.4 Number of Leaves per plant

Fully expanded leaves were counted from randomly selected plants and the results were expressed as average number of leaves per plant.

3.3.1.5 Number of Crowns

Number of crowns were counted at the end of fruiting season from randomly selected plants. The average values were expressed as total number of crowns per plant.

3.3.1.6 Number of Runners

At the end of the growing season the total number of runners per plot was counted and the average number of runners per plant was calculated.

3.3.2 FLOWERING AND FRUITING PARAMETERS

3.3.2.1 Time of initiation of flowering

The number of days between the date of planting and the first flower opening was recorded as time of initiation of flowering.

3.3.2.2 Duration of flowering

The date of opening of first flower and opening of last flower during the cropping season was recorded to calculate the duration of flowering.

3.3.2.3 Number of flowers per plant

Total numbers of flowers were counted from randomly selected plants and the average was expressed as number of flowers per plant.

3.3.2.4 Fruit Set

To observation on fruit set, counting the number of flowers at twenty days interval was done according to Westwood (1978) using the formula:

$$\text{Fruit set (\%)} = \frac{\text{Total number of fruits set}}{\text{Total number of flowers}} \times 100$$

3.3.2.5 Cumulative fruit number

The primary, secondary and tertiary fruits were counted throughout the season and the total number of fruits were expressed as cumulative fruit number.

3.3.2.6 Cumulative fruit yield

The fruit were handpicked twice a week with a total eight to ten times of harvesting throughout the cropping period. The observations were recorded on total marketable yield of berries, and expressed in grams per plant (g/plant).

3.3.3 FRUIT QUALITY PARAMETERS

3.3.3.1 Fruit Size

Fruit dimension (length and breadth) of five randomly selected fruits (berries) was measured with the help of digital vernier scale (± 0.05 mm accuracy). Average of fruit length and breadth was calculated and the values were expressed in millimetres (mm).

3.3.3.2 Fruit Weight

Fruit weight of randomly selected five fruits were measured on a top pan electronic balance. The average was taken and the values were expressed in grams (g).

3.3.3.3 Fruit Firmness

Fruit firmness was determined using digital fruit pressure tester (ACSY4) and the values were expressed in Kg/cm^2.

3.3.3.4 Total Soluble Solids

The total soluble solids of the fruit juice was determined with the help of Erma-Hand Refractometer (0 to 32 °B). The refractometer was calibrated with distilled water before use. The readings were recorded for each sample by putting a drop of juice on the prism (A.O.A.C, 1980). A temperature correction was applied when it was above or below 20°C and the readings were expressed in degree Brix (°B).

3.3.3.5 Titratable Acidity

Twenty five gram of pulp of fruit samples was homogenized with distilled water in an electric blender and volume was made to 250 ml. The contents were filtered through Whatman No. 1 filter paper. 10 ml of the extract was taken and then titrated against 0.1 N NaOH solution using phenolphthalein (indicator). The appearance of light pink colour indicated the end point. The results were expressed as per cent of fresh weight of the fruit pulp. The remaining extract was kept for estimation of sugars. Excess lead acetate and contents were again filtered. The volume was made to 250 ml with distilled water. Out of this solution, 50 ml was kept for determining total sugars. The titratable acidity was calculated by using the following formula:

$$\text{Titratable acidity} = \frac{\text{Titre value} \times \text{Normality of Alkali} \times \text{Volume made up} \times \text{Equivalent weight of acid} \times 100}{\text{Volume of sample taken for estimation} \times \text{Volume of aliquot taken} \times 1000}$$

3.3.3.6 TSS: acid ratio

TSS: acid ratio is worked out by dividing the total soluble solids (TSS) to the titratable acidity (TA) of the fruit samples.

3.3.3.7 Total sugars

Total sugars content of the fruits was determined by Lane and Eynon's volumetric method (A.O.A.C., 1980). The remnant 200 ml of the extract left from titratable acidity was taken and subsequently, 10 ml of 45 per cent standard lead acetate was added to it. After 10 minutes, 10 ml of potassium oxalate (22 %) was added to precipitate the excess of lead acetate. The volume was then made to 250 ml with distilled water proceeded by the filtration of solution. Afterwards, 50 ml of the filtrate was taken and 5 ml of concentrated HCl was added to it. The solution was kept overnight for hydrolysis at room temperature. On the next

day, excess of HCl was neutralized with saturated 1N NaOH solution and final volume was made to 250 ml with distilled water. The total sugars were estimated by titrating boiling mixture of 5 ml of both Fehling A and Fehling B with hydrolyzed solution using methylene blue as an indicator. The appearance of brick red colour after titration indicated the end point. The total sugars content in fruit samples was expressed as percentage of fresh weight of fruit pulp.

$$\text{Total sugar (\%)} = \frac{\text{*Factor} \times \text{Dilution}}{\text{Titre value} \times \text{Weight or Volume of sample taken}} \times 100$$

*Factor = 0.05

3.3.3.8 Reducing sugars

The remaining unhydrolyzed solution obtained after the estimation of total sugars was titrated against boiling solution of 5 ml each of Fehling A and Fehling B using methylene blue as an indicator (A.O.A.C., 1980). The end point was marked by the appearance of brick red colour. The reducing sugars content was expressed as the per cent of fresh weight of fruit pulp.

$$\text{Reducing sugars (\%)} = \frac{\text{*Factor} \times \text{Dilution}}{\text{Titre value} \times \text{Weight or Volume of sample}} \text{ x } 100$$

*Factor = 0.05

3.3.3.9 Non-reducing sugars

The amount of non-reducing sugars was worked out by subtracting the reducing sugars from total sugars and multiplying the difference with a standard factor i.e., 0.95. The results were expressed as per cent of non-reducing sugars using formula as:

Non-reducing sugars (%) = (Total sugars - Reducing sugars) x 0.95

3.3.3.10 Ascorbic acid content

Extraction solution

Fifteen grams of metaphosphoric acid pellets were dissolved in 40 ml glacial acetic acid and 200 ml of distilled water. The volume was made to 500 ml by using distilled water.

The solution was filtered rapidly through Whatman No. 1 filter paper and stored in coloured bottle in refrigerator.

Preparation of solution

100 g of analytical grade ascorbic acid (reference standard) was weighed accurately on electronic balance and dissolved in 10 ml of metaphosphoric acid extraction solution. The content was then transferred to a 100 ml volumetric flask and the final volume was made to 100 ml with metaphosphoric acid solution. The solution was then diluted to 1 litre before use with metaphosphoric acid solution, so that it consumes less dye.

Indophenol Standard Solution

50 mg of 2, 6-dichlorophenol indophenol sodium salt was dissolved in 150 ml distilled water in a beaker. 42 mg of sodium bicarbonate was added to it. The contents were shaken vigorously and when 2, 6-dichlorophenol indophenol was dissolved, it was diluted with distilled water to 200 ml. It was then filtered and stored in dark coloured bottle in refrigerator.

Estimation

25 g of fruit pulp was homogenized in metaphosphoric acid (extraction solution) and the volume was made to 100 ml in a volumetric flask. The 10 ml of this solution was then titrated against 2, 6-dichlorophenol indophenol dye as indicated by appearance of light pink colour (the end point). The amount of ascorbic acid present in the fruit juice was calculated by using formula:

$$\text{Ascorbic acid} = \text{Dye factor} \times \frac{\text{Titre value} \times \text{Volume made}}{\text{Wt. of fruit taken} \times \text{Volume taken for estimation}} \times 100$$

3.3.3.11 Anthocyanin content

One gram of berry pulp was macerated in a known quantity of methanol containing 1 per cent hydrochloric acid. The content was kept to overnight at 0°C temperature in a deep freezer. The absorbance of red colored solution was recorded at 530 nm on Spectrophotometer (NUKES). Anthocyanin content was expressed as absorption units at 530 nm per gram fresh berry (Harborne, 1973)

3.3.4 BIOCHEMICAL PARAMETER

3.3.4.1 Chlorophyll content

Five fully expanded and mature leaves from each treatment were collected in the month of May during morning hours (Halfacre *et al.,* 1968) and immediately placed in ice box and brought to the laboratory. The samples were then kept in refrigerator at sub-zero degree temperature to avoid degradation of chlorophyll pigment. The leaves under each sample were then chopped into fine pieces under subdued light and 100 mg of chopped leaf samples were placed in vials containing 7 ml of Dimethyle sulphoxide. The contents of the vials were incubated at 65°C for half an hour and then, the extract was transferred to graduated test tube and the final volume was made to 10 ml with Dimethyl sulphoxide (Hiscox and Israelstam, 1979).

Estimation

The optical density (O.D.) values of the extracts were recorded in spectrophotometer (NUKES) at 645 and 663 nm wavelengths against a Dimethyl sulphoxide blank. The total chlorophyll content was calculated by using the following formula:

$$\text{Total chlorophyll} = \frac{20.2\ A_{645} + 8.02\ A_{663}}{A \times 1000 \times W} \times V$$

Where,

V = Volume of the extract made
A = Length of the light path in cell (usually 1 cm)
W = Weight of the sample (g)
A_{645} = Absorbance at 645 nm
A_{663} = Absorbance at 663 nm

The results thus obtained were expressed as mg of total chlorophyll per gram of fresh weight.

3.3.5 PHYSIOLOGICAL PARAMETERS

3.3.5.1 Photosynthesis

Ten mature leaves from each plot were selected randomly. The observations were recorded between 9:00 to 11:00 AM with the help of LICOR6200 Portable Photosynthesis Meter. The result was expressed in µmol $CO_2/m^2/sec$.

3.3.5.2 Stomatal Conductance

Ten mature leaves from each plot were selected randomly. The observations were recorded between 9:00 to 11:00 AM with the help of LICOR6200 Portable Photosynthesis Meter. The result was expressed in mol $H_2O/m^2/sec$.

3.3.5.3 Transpiration

Ten mature leaves from each plot were selected randomly. The observations were recorded between 9:00 to 11:00 AM with the help of LICOR6200 Portable Photosynthesis Meter. The result was expressed in mmol $H_2O/m^2/sec$.

3.3.6 Statistical Analysis

Statistical analysis of the data was carried out using general linear model of the standard errors of the mean. The data obtained in Randomized Block Design (RBD) for each parameter were tested by ANOVA using MS-Excel and OPSTAT. The difference between the treatments was compared by critical difference (CD) at 5 per cent level of probability (confidence), wherever the results were significant (Gomez and Gomez, 1984). The calculated F-values were compared with tabulated F-value. When F-test was significant, CD was then calculated to find out the comparative effectiveness among different treatments. The standard error and CD at 5 per cent level of significance was calculated as follows:

Se (m)$\pm$ = $\sqrt{Me/r}$

SE (d)$\pm$ = $\sqrt{2Me/r}$

$CD_{0.05}$ = SE (d) x $t_{0.05}$ (r-1) (t-1) df

Where,

SE (m) ± = Standard error of mean

SE (d) ± = Standard error of differences

$CD_{0.05}$ = Critical difference at 5% level of significance

Chapter-4

RESULTS AND DISCUSSION

The present investigation on **"Influence of plant growth regulators on growth, yield and fruit quality of strawberry (*Fragaria* × *ananassa)* cv. Camarosa"** was carried out at Horticulture Research & Training Station and Krishi Vigyan Kendra, Solan at Kandaghat during year 2021-2022.

The findings of the present study have been discussed and presented under the following headings:

4.1 Vegetative Parameters

4.2 Flowering and Fruiting Parameters

4.3 Fruit Quality Parameters

4.4 Bio-chemical Parameter

4.5 Physiological Parameters

4.1 Vegetative Parameters

4.1.1 Plant Height

The data pertaining to influence of different plant growth regulators on plant height of strawberry cv. Camarosa is demonstrated in Table 4.1 and Figure 4.1. Plants treated with 75 ppm GA_3 (T_6) reported highest plant height (23.17 cm) which was statistically at par with plants treated with 50 ppm GA_3 i.e., T_5 (22.57 cm). However lowest plant height was observed in treatment T_{10} (9.83 cm) i.e., control. Plant height increased due to rapid cell division and cell elongation by GA_3 in strawberry plants and it also increased the endogenous level of auxin production in plants. Similarly, increase in plant height with foliar application of 75 ppm GA_3 was observed by Sharma and Singh (2009) in strawberry when applied twice during mid-November and mid-February. Uddin *et al*. (2012) also reported increase in plant height by foliar application of 75 ppm GA_3 in strawberry. The current study was similar with the results of Saima *et al.* (2014), Vishal *et al*. (2016), Mastuane *et al*. (2016), Kour *et al.*

(2017) and Khunte *et al*. (2020). Xing *et al*. (2022) recorded maximum plant height with inoculation of plants with AMF.

Table 4.1 Effect of plant growth regulators on plant height and petiole length of strawberry cv. Camarosa

Treatments	Plant Height (cm)	Petiole Length (cm)
T_1 NAA 5ppm	12.77	9.80
T_2 NAA 10ppm	15.33	10.23
T_3 NAA 15ppm	17.20	11.57
T_4 GA_3 25ppm	21.33	14.23
T_5 GA_3 50ppm	22.57	15.60
T_6 GA_3 75ppm	23.17	16.93
T_7 BA 5ppm	12.50	9.73
T_8 BA 10ppm	13.43	10.10
T_9 BA 15ppm	15.90	10.77
T_{10} Control	9.83	8.87
CD $_{(0.05)}$	**1.16**	**1.23**

4.1.2 Petiole length

Plant growth regulators had significant effect on petiole length which was showed in Table 4.1 and Figure 4.1. Petiole length ranges between 8.87 cm to 16.93 cm. Highest petiole length was recorded in treatment T_6 (75 ppm GA_3) i.e., 16.93 cm which was statistically at par with its lower concentration of 50 ppm GA_3 in treatment T_5 (15.60 cm). While, lowest petiole length was reported in control (8.87 cm).

The application of GA_3 led to increase in plant height and petiole length by cell division and cell elongation in strawberry plant Uddin *et al.* (2012). Similar results were reported by Sharma and Singh (2009), Kumar and Tripathi (2009), Sehkar (2013), Saima *et al*. (2014), Vishal *et al*. (2016), Dubey *et al*. (2017), Khunte *et al*. (2020) and Pandey *et al.* (2020) that plant height and petiole length was increased with foliar application of GA_3.

4.1.3 Number of Leaves

Plant growth regulators had significant effect on number of leaves per plant. In Table 4.2, maximum number of leaves per plants was recorded under treatment T_6 (75 ppm GA_3) i.e., 23.33 which was superior among all other growth regulators. This treatment was followed by T_5 (50 ppm GA_3) i.e., 21.33 and T_4 (25 ppm GA_3) i.e., 20.67. However, minimum number of leaves were observed under treatment T_{10} (control) i.e., 17.00.

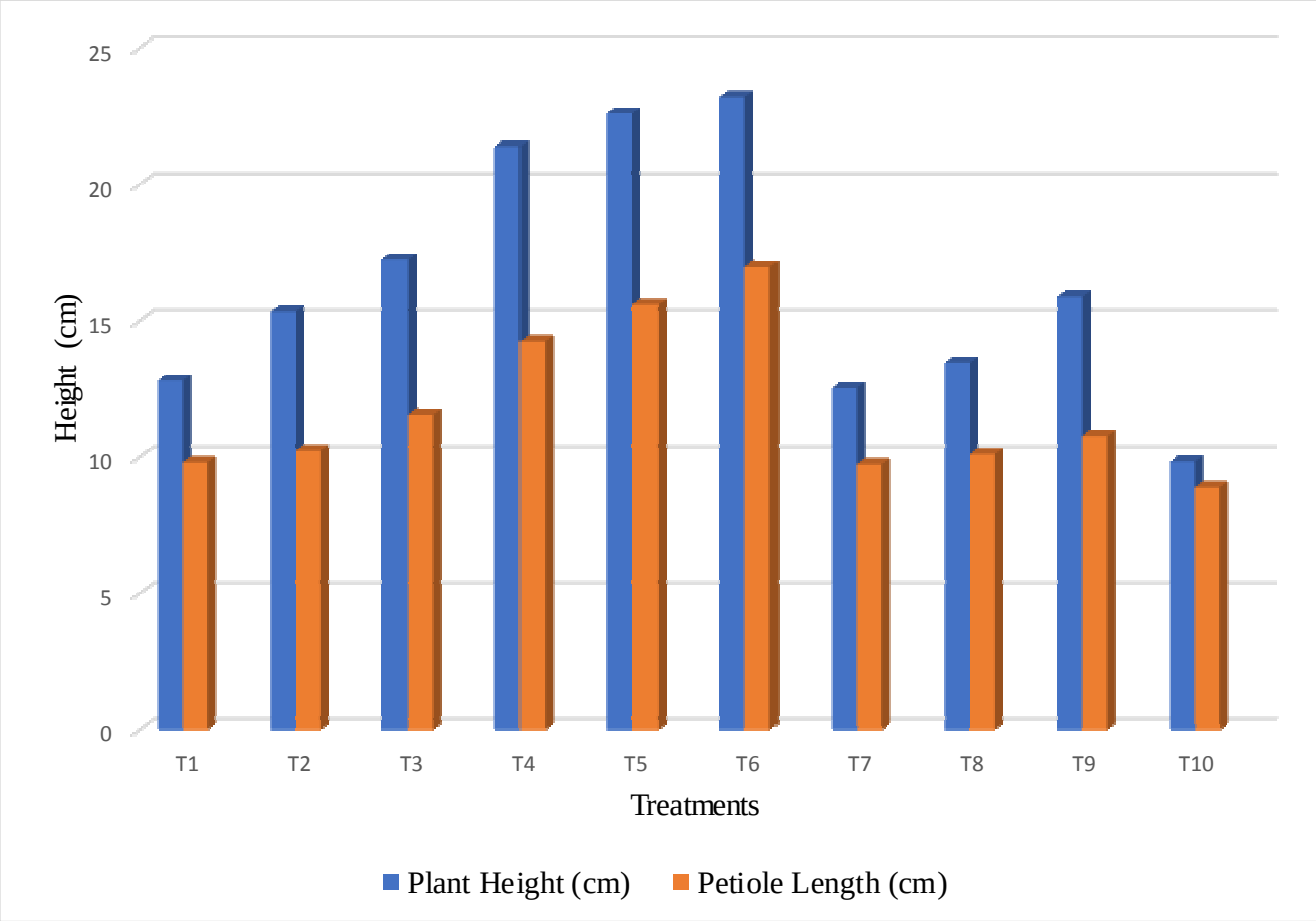


Figure 4.1 Effect of plant growth regulators on plant height and petiole length of strawberry cv. Camarosa

Table 4.2 Effect of plant growth regulators on number of leaves and leaf area of strawberry cv. Camarosa

Treatments	Number of Leaves	Leaf Area (cm^2)
T_1 NAA 5ppm	17.67	87.48
T_2 NAA 10ppm	19.00	89.00
T_3 NAA 15ppm	20.00	92.66
T_4 GA_3 25ppm	20.67	94.39
T_5 GA_3 50ppm	21.33	98.17
T_6 GA_3 75ppm	23.33	102.29
T_7 BA 5ppm	17.67	87.26
T_8 BA 10ppm	18.67	88.33
T_9 BA 15ppm	20.00	90.13
T_{10} Control	17.00	85.16
CD $_{(0.05)}$	**1.27**	**1.98**

4.1.4 Leaf Area

In Table 4.2, data on how different plant growth regulators affected average leaf area is shown. The average leaf area varied from 85.16 to 102.29 cm^2. Treatment T_6 (75 ppm GA_3) recorded highest leaf area (102.29 cm^2) which was followed by treatment T_5, 50 ppm GA_3 (98.17 cm^2). Whereas, lowest leaf area was recorded under treatment T_{10} (control) i.e., 85.16 cm^2.

The current study shows that the application of various growth regulators had a significant effect on the number of leaves and leaf area. This may be due to gibberellin stimulated cell division and cell expansion which is responsible for the increase in leaf area. Rapid division of cells in sub-epical meristem of shoots and expansion of parenchymatous and epidermal cells increases number of leaves per plant with GA_3 treatment (Singh *et al*., 2017b). Kumar and Tripathi (2009) found that application of gibberellic acid helps in increased number of leaves and leaf area in strawberry. Saima *et al.* (2014) also reported increase in number of leaves and leaf area with application of 75 ppm GA_3 application in strawberry. The results from the current study, which show increased leaf area and number of leaves per plant with GA_3 treatment closely match with the findings of Kumar *et al.* (2011), Uddin *et al*. (2012), Ikram and Qureshi (2016) and Mastuane *et al.* (2016).

4.1.5 Number of Crowns

Table 4.3, displays the observations relating to number of crowns as impacted by various concentrations of plant growth regulators. In this Table the number of crowns with

foliar application of GA_3 at 75 ppm (4.87) in treatment T_6 was observed higher which was statistically at par with 50 ppm GA_3 (4.73) and 25 ppm GA_3 (4.62) in treatment T_5 and T_4, respectively. While under control (T_{10}) the number of crowns were recorded lower i.e., 3.11. Kumar and Tripathi (2009) recorded maximum number of crowns with foliar application of gibberellic acid on strawberry plants. Similar results were also reported by Dubey *et al.* (2017), Rathod *et al.* (2021) and Kumari *et al.* (2018) in strawberry.

4.1.6 Number of Runners

In Table 4.3, the data regarding effect of various plant growth regulators doses on runner production is depicted. Runner production through application of different growth regulators varied from 3.97 to 5.53. Runner production was recorded maximum through foliar application of 75 ppm GA_3 (5.53) which was statistically at par with 50 ppm GA_3 (5.37). Whereas, minimum number of runners were observed in control (3.97). This may be due to increase in number of leaves per plant helps in synthesis of more photosynthates, which leads to formation of maximum number of crowns and runners per plant. Asadi *et al*. (2013) also found that GA_3 treatment helps to increase the runner production in strawberry. The present findings are similar with the results of Kumar and Tripathi (2009), Kumar *et al.* (2012), Eshghi *et al.* (2012), Palei *et al.* (2016) and Kumari *et al.* (2018).

Table 4.3 Effect of plant growth regulators on number of crowns and runners of strawberry cv. Camarosa

Treatments	Number of Crowns	Number of Runners
T_1 NAA 5ppm	3.69	4.53
T_2 NAA 10ppm	3.85	4.70
T_3 NAA 15ppm	4.28	5.10
T_4 GA_3 25ppm	4.62	5.23
T_5 GA_3 50ppm	4.73	5.37
T_6 GA_3 75ppm	4.87	5.53
T_7 BA 5ppm	3.64	4.43
T_8 BA 10ppm	3.79	4.67
T_9 BA 15ppm	4.13	5.00
T_{10} Control	3.11	3.97
CD $_{(0.05)}$	**0.28**	**0.26**

4.2 Flowering and Fruiting Parameters

4.2.1 Initiation of flowering

Data regarding initiation of flowering is depicted in Table 4.4. Plant growth regulators had significant effect on initiation of flowering on strawberry cv. Camarosa and it was

concluded from the Table 4.4 i.e., minimum days to initiate flowering was observed in T_6 i.e., GA_3 75 ppm (96.67 days) which was superior among all the growth regulators application. This treatment was followed by T_5 i.e., 50 ppm GA_3 (99.00 days). However, in control (T_{10}) plants took maximum days to initiate flowering (113.33 days). GA_3 is also known to overcome endogenous dormancy factors and accelerate flowering by forcing the floral primordia to grow quickly. Sood *et al.* (2018) stated that application of GA_3 initiated early flowering in strawberry plants. Fan *et al.* (2008) reported that plants which were inoculated with AMF took minimum days to initiated flowering. The current study was in agreement with work of Tripathi and Shukla (2008), Sharma and Singh (2009), Jasrotia *et al.* (2014) and Ruchitha *et al.* (2020).

4.2.2 Duration of flowering

The following observations regarding effect on duration of flowering through foliar application of plant growth regulators in strawberry is shown in Table 4.4. Maximum duration of flowering was observed in treatment T_6 i.e., 75 ppm GA_3 (117.75 days) which was superior to all other treatments. This was followed by treatment T_5 (50 ppm GA_3) i.e., 112.67 days. However, minimum duration of flowering was reported in control (95.33 days). GA_3 application helps to increase the duration of flowering because gibberellin helps to improve the vegetative growth of plant so the accumulation of photosynthates were more which helps in increasing flower number and the duration of flowering. The results were similar with the findings of Tripathi and Shukla (2008), Sharma and Singh (2009) that with the application of gibberellic acid duration of flowering can be improved in strawberry.

Table 4.4 Effect of plant growth regulators on initiation and duration of flowering in strawberry cv. Camarosa

Treatments	Initiation of flowering	Duration of flowering
T_1 NAA 5ppm	112.96	97.00
T_2 NAA 10ppm	109.37	99.67
T_3 NAA 15ppm	106.00	106.33
T_4 GA_3 25ppm	102.33	110.00
T_5 GA_3 50ppm	99.00	112.67
T_6 GA_3 75ppm	96.67	117.75
T_7 BA 5ppm	113.00	98.00
T_8 BA 10ppm	111.40	101.66
T_9 BA 15ppm	108.00	104.38
T_{10} Control	113.33	95.33
$CD_{(0.05)}$	**1.86**	**1.72**

4.2.3 Number of Flowers

The observations collected on number of flowers were represented in Table 4.5. Application of different concentrations of plant growth regulators had significantly increased the number of flowers per plant and it varied from 21.47 to 29.33 and highest number of flowers per plant was recorded in 75 ppm GA_3 (29.33) which was statistically at par with 50 ppm GA_3 (28.30). Lowest number of flowers per plant was recorded in control (21.47). The higher number of flowers obtained with the spray of gibberellic acid in the current study might be attributed to enhanced inflorescence development, which could have led in increased flower production. Sharma and Singh (2009) recorded increased number of flowers with 75 ppm of GA_3 in strawberry. The results are in line with the findings of Uddin *et al*. (2012), Isam *et al*. (2012), Khalid *et al*. (2013), Asadi *et al.* (2013), Jasrotia *et al*. (2014) and Rathod *et al*. (2021) they found that application of gibberellic acid increase of number of flowers in strawberry plants.

4.2.4 Fruit Set

The results showing influence of plant growth regulators on strawberry cv. Camarosa is represented in Table 4.5. The given observations in Table shows the per cent fruit set from 73.41 to 89.44 %. Highest fruit set was reported from treatment T_6, 75 ppm GA_3 (89.44 %) and it was statistically at par with treatment T_5, 50 ppm GA_3 (86.27 %). However, lowest fruit set was reported in control i.e., treatment T_{10} (73.41 %). Gibberellic acid helps in increasing pollen germination which helps in improved fruit set (Paroussi *et al*., 2009). Gibberellic acid aids in the formation of numerous flowers and the quick elongation of the peduncle, which results in the full development of flower buds with all reproductive organs functioning thus increasing fruit set and berry yield per plant. Saima *et al*. (2014) reported increased fruit set in strawberry with foliar application of 75 ppm GA_3. The results were similar with the findings of Sharma and Singh (2009), Singh and Singh (2009), Al-madhagi *et al.* (2012) and Bhople *et al.* (2019).

NAA 15 ppm

GA_3 75 ppm

BA 15 ppm

Control

Plate 4.1 Effect of plant growth regulators on flowering

Table 4.5 Effect of plant growth regulators on number of flowers and fruit set of strawberry cv. Camarosa

Treatments	Number of Flowers	Fruit Set (%)
T_1 NAA 5ppm	24.00	76.67
T_2 NAA 10ppm	24.37	77.03
T_3 NAA 15ppm	25.90	78.15
T_4 GA_3 25ppm	27.43	84.48
T_5 GA_3 50ppm	28.30	86.27
T_6 GA_3 75ppm	29.33	89.44
T_7 BA 5ppm	22.53	75.63
T_8 BA 10ppm	24.13	76.93
T_9 BA 15ppm	25.20	77.37
T_{10} Control	21.47	73.41
CD $_{(0.05)}$	**0.83**	**4.72**

4.2.5 Number of fruits

Data pertaining to number of fruits per plant is depicted in Table 4.6. Number of fruits per plant was increased with application of different growth regulators and maximum number of fruits per plant was reported in plants treated with 75 ppm GA_3 (26.23) and it was superior to all other treatments. This treatment was followed by 50 ppm GA_3 (24.40). In case of control where growth regulators were not sprayed minimum number of fruits per plant was recorded (15.77). Fruit set in plants is heavily influenced by the endogenous amount of promoters and inhibitors. By activating enzymes needed during the post-fertilization stage, the exogenous injection of GA_3 may control this balance in favour of fruit-forming metabolic processes, improving the fruit setting and ultimately leading to the maximum number of fruits per plant (Rathod *et al.*, 2021). Increase in number of fruits per plant was recorded by treatment of plants with 75 ppm GA_3 in strawberry (Saima *et al*., 2014). Increase in number of fruits with inoculation of AMF was recorded by Bona *et al.* (2015) and Robinson *et al.* 2016. Results were matched with the findings of Rana (2001), Rajbhar *et al.* (2014), Barwary *et al.* (2018) and Bhople *et al.* (2019).

4.2.6 Fruit yield

Plant growth regulators had significant effect on increasing fruit yield per plant which was shown in Table 4.6. Results from Table revealed that increase in yield range from 171.48 g/plant to 388.03 g/plant. Highest yield was recorded in treatment T_6, 75 ppm GA_3 (388.03 g/plant). This treatment was followed by T_5, 50 ppm GA_3 (340.46 g/plant) and T_4, 25 ppm

GA_3 (319.49 g/plant). Lowest yield was observed from control 171.48 g/plant. Fruit yield (t/ha) given in Figure 4.2.

Gibberellin treated plants might have a higher fruit yield per plant due to increased vegetative development. The vegetative growth of plants throughout their life cycles determines the yield depending on the sink capacity of the crop and increased sink capacity is correlated with vigorous growth of plant. Larger leaves and a high rate of photosynthesis may have contributed to the higher yield by producing more metabolite (Ruchitha *et al.* 2020). The reason behind increased fruit yield may be increase in cell division and cell elongation by gibberellic acid and it increased the fruit weight and hence fruit yield also increased. AMF helps in solubilization of minerals and uptake of nutrients from the soil which results in good vegetative growth of plants and help in increased yield (Cekic and Yilmaz, 2011). The results are in agreement with findings of Rana (2001), Khokhar *et al.* (2004), Canli and Orhan (2009), Uddin *et al.* (2012), Kumar *et al*. (2012) and Thakur *et al.* (2015).

Table 4.6 Effect of plant growth regulators on number of fruits per plant and yield of strawberry cv. Camarosa

Treatments	Number of fruits per plant	Fruit yield (g/plant)	Fruit yield (t/ha)
T_1 NAA 5ppm	18.40	212.94	10.65
T_2 NAA 10ppm	18.77	232.01	11.60
T_3 NAA 15ppm	20.23	250.86	12.54
T_4 GA_3 25ppm	23.17	319.49	15.97
T_5 GA_3 50ppm	24.40	340.46	17.02
T_6 GA_3 75ppm	26.23	388.03	19.40
T_7 BA 5ppm	17.03	194.77	9.74
T_8 BA 10ppm	18.57	227.67	11.39
T_9 BA 15ppm	19.50	242.31	12.12
T_{10} Control	15.77	171.48	8.58
CD $_{(0.05)}$	**1.12**	**18.33**	**0.92**

4.3 Fruit Quality Parameters

4.3.1 Fruit Length

Table 4.7, demonstrates that foliar application of plant growth regulators significantly increased fruit length in comparison to control. Increase in fruit length was ranged from 30.25 mm to 42.44 mm. Fruit length was recorded maximum in plants treated with 75 ppm GA_3 (42.44 mm) and it was superior to all other treatments. This was closely followed by

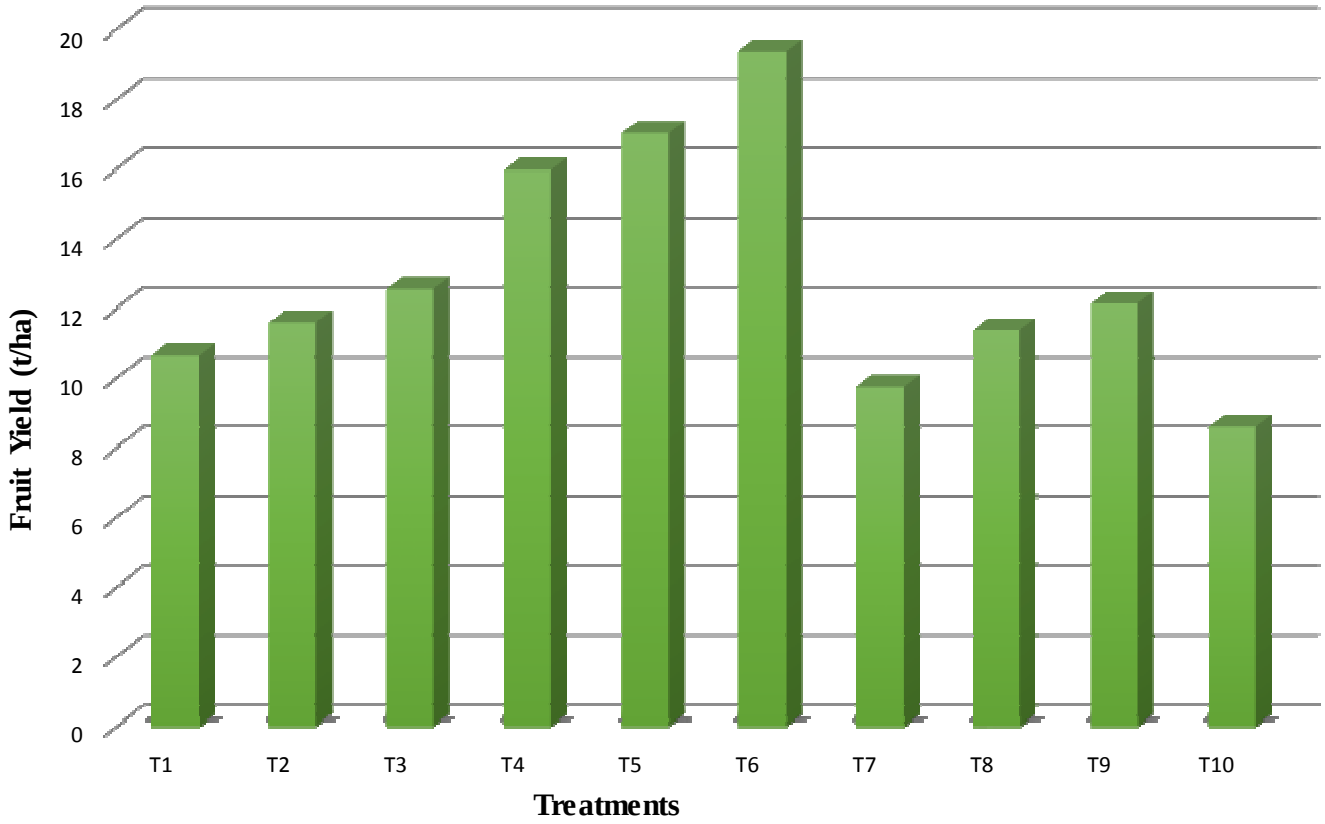


Figure 4.2 Effect of plant growth regulators on fruit yield of strawberry cv. Camarosa

treatment GA_3 50 ppm (40.02 mm). However, minimum fruit length was reported in control (30.25 mm).

4.3.2 Fruit Breadth

In Table 4.7, the information relating to fruit breadth and how plant growth regulators affect it by foliar spraying is shown. The data show that different growth regulator treatments considerably enhanced the fruit breadth in comparison to control. Fruit breadth range from 27.84 to 30.99 mm. Maximum fruit breadth was reported from treatment T_9, 15 ppm BA (30.99 mm) which was statistically at par with 75 ppm GA_3 (30.51 mm) and 50 ppm GA_3 (30.23 mm) i.e., T_6 and T_5, respectively. However, minimum fruit breadth was reported in treatment T_{10}, control (27.84 mm).

Table 4.7 Effect of plant growth regulators on fruit length and breadth of strawberry cv. Camarosa

Treatments	Length (mm)	Breadth (mm)
T_1 NAA 5ppm	33.26	28.42
T_2 NAA 10ppm	33.60	28.50
T_3 NAA 15ppm	34.58	28.63
T_4 GA_3 25ppm	37.67	29.92
T_5 GA_3 50ppm	40.02	30.23
T_6 GA_3 75ppm	42.44	30.51
T_7 BA 5ppm	33.00	28.38
T_8 BA 10ppm	34.19	29.66
T_9 BA 15ppm	35.26	30.99
T_{10} Control	30.25	27.84
$CD_{(0.05)}$	**0.97**	**0.78**

4.3.3 Fruit Weight

Table 4.8, presents the information regarding the impact of various growth regulator doses on fruit weight. Plant growth regulators significantly increased the weight of fruit as compared to control. Increase in fruit weight ranged from 10.87 g to 14.80 g by growth regulator treatments. The data presented in Table 4.8, depicted maximum fruit weight in treatment T_6, 75 ppm GA_3 (14.80 g) which was superior to all other growth regulators. This treatment was followed by T_5, 50 ppm GA_3 (13.95 g) and T_4, 25 ppm GA_3 (13.79 g). However, the minimum fruit weight was observed in T_{10}, control (10.87 g) where growth regulators were not applied.

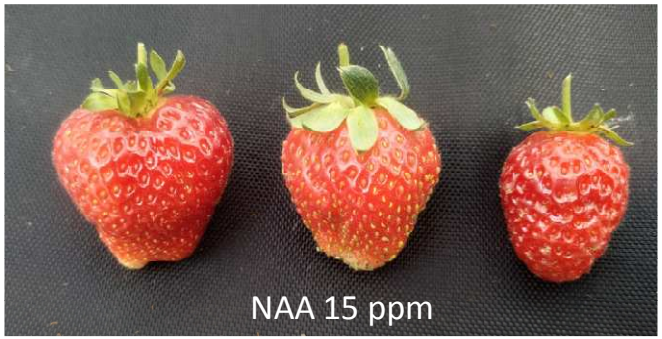
Plant growth regulators increase the fruit size and weight of fruit by active cell division and cell elongation by GA_3 and accumulation of carbohydrate content by increased photosynthetic rate. Gibberellic acid also regulates the movement of metabolites from source (foliage) to sink (developing fruits) (Iqbal *et al.,* 2011). Thakur *et al.* (2015) reported increase in fruit size (length and breadth) and weight by foliar application of 75 ppm GA_3. These results were similar with the work of Tripathi and Shukla (2008), Kumar and Tripathi (2009), Uddin *et al.* (2012), Saima *et al.* (2014) and Ruchitha *et al.* (2020) that GA_3 treated plants improved the size (length, breadth) and weight of strawberry fruit. Stern and Flaishman (2003) reported increased in fruit size with application of BA which is due to increased cell division by cytokinin in fruit cortex. Similar results were also reported by (Dussi and Sugar, 2010).

Table 4.8 Effect of plant growth regulators on fruit weight and firmness of strawberry cv. Camarosa

Treatments	**Weight (g)**	**Firmness (Kg/cm^2)**
T_1 NAA 5ppm	11.57	0.67
T_2 NAA 10ppm	12.37	0.73
T_3 NAA 15ppm	12.40	0.77
T_4 GA_3 25ppm	13.79	0.79
T_5 GA_3 50ppm	13.95	0.81
T_6 GA_3 75ppm	14.80	0.82
T_7 BA 5ppm	11.43	0.69
T_8 BA 10ppm	12.27	0.77
T_9 BA 15ppm	12.43	0.83
T_{10} Control	10.87	0.65
CD $_{(0.05)}$	**0.75**	0.05

4.3.4 Fruit Firmness

Plant growth regulators had significantly affected the fruit firmness which is shown in Table 4.8. Fruit firmness ranged from 0.65 to 0.83 Kg/cm^2. Maximum fruit firmness was recorded in treatment T_9, 15 ppm BA (0.83 Kg/cm^2) which was statistically at par with T_6, 75 ppm GA_3 (0.82 Kg/cm^2), T_5, 50 ppm GA_3 (0.81 Kg/cm^2) and T_4, 25 ppm GA_3 (0.79 Kg/cm^2). However, minimum fruit firmness was noted in T_{10}, control (0.65 Kg/cm^2). The present study is in line with work of Choi *et al.* (2002), Jayachandran *et al.* (2005) and Abdel and Kamel (2015).



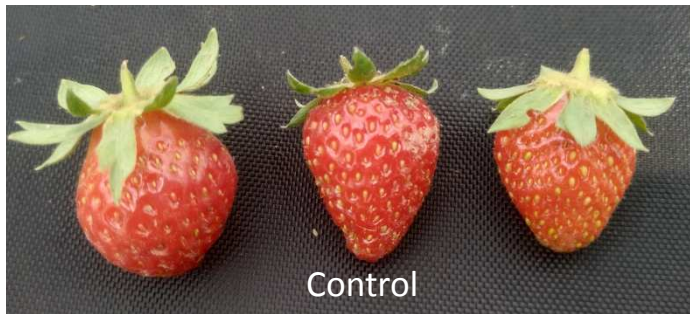


Plate 4.2 Effect of plant growth regulators on fruit size

4.3.5 Total Soluble Solids (TSS)

Table 4.9, demonstrates that each treatment had a considerable impact on fruit TSS. Plant growth regulators had positive impact on fruit TSS and it ranged from 6.07 to 10.03 °B. Maximum fruit TSS was recorded in 75 ppm GA_3 (10.03 °B) which was statistically at par with 50 ppm GA_3 (9.83 °B). However, in control minimum fruit TSS was observed (6.07 °B). TSS may have increased as a result of the use of plant growth regulators, which affected physiological processes that hydrolyzed starch and assisted in metabolic activity during the conversion of available starch to sugar. The rise in total soluble solids can be explained by the hydrolysis of polysaccharides, the transformation of organic acids into soluble sugars, and the improved solubilization of insoluble starch and pectin found in cell walls and middle lamella (Paikra *et al*., 2018). Similarly, Rana (2001) and Ozguven and Yilmaz (2002) sprayed GA_3 on strawberry plants and observed increased fruit TSS. The current study is similar with results of Uddin *et al.* (2012), Khunte *et al*. (2014), Thakur *et al.* (2015) and Gaikwad and Ahire (2017) also stated that application of GA_3 resulted in increased fruit TSS. Kumar *et al.* (2013) reported increased fruit TSS with partial deblossoming and 50 ppm GA_3 application. Cordeiro *et al.* (2019) and El-Gould and Amal (2020) recorded maximum soluble solids with inoculation of strawberry with AMF.

4.3.6 Titratable Acidity

Influence of different plant growth regulators on titratable acidity of fruit was depicted in Table 4.9. It is clear from the Table that data varied from to 0.56 to 0.76 per cent. Highest titratable acidity was recorded under treatment T_{10} i.e., control (0.76 %). Whereas, lowest titratable acidity was reported in treatment T_6, 75 ppm GA_3 (0.56 %) which was statistically at par with treatment T_5, 50 ppm GA_3 (0.59 %) and T_4, 25 ppm GA_3 (0.61 %). The use of GA_3 considerably lowered the acidity of the fruit. The decrease in acidity could be attributed to metabolic alterations that result in the rapid conversion of organic acids into sugars and their derivatives. Application of 75 ppm GA_3 lowers the titratable acidity of strawberry fruit reported by Paikra *et al.* (2018). Similar results were observed by Thakur *et al*. (2015) when plants were treated with 75 ppm GA_3.

Table 4.9 Effect of plant growth regulators on total soluble acid (TSS) and titratable acidity of strawberry cv. Camarosa

Treatments	TSS (°B)	Titratable Acidity (%)
T_1 NAA 5ppm	7.67	0.73
T_2 NAA 10ppm	8.10	0.69
T_3 NAA 15ppm	8.30	0.66
T_4 GA_3 25ppm	8.90	0.61
T_5 GA_3 50ppm	9.83	0.59
T_6 GA_3 75ppm	10.03	0.56
T_7 BA 5ppm	7.50	0.74
T_8 BA 10ppm	7.83	0.72
T_9 BA 15ppm	8.17	0.68
T_{10} Control	6.07	0.76
CD $_{(0.05)}$	**1.03**	**0.05**

4.3.7 TSS: acid ratio

In Table 4.10, data presented on positive impact of different growth regulators on TSS: acid ratio was depicted. The observations recorded were ranged from 8.01 to 17.85. It is clear from the observations that maximum TSS: acid ratio was observed in 75 ppm GA_3 (17.85) which was statistically at par with 50 ppm GA_3 (16.78). Whereas, minimum TSS: acid ratio was reported in control (8.01). Paikra *et al*. (2018) reported that foliar application of 75 ppm GA_3 helps to increase the TSS: acid ratio of strawberry. The present results are in agreement with work of Thakur *et al*. (2015) in strawberry. Singh *et al.* (2018) recorded maximum TSS: acid ratio in kinnow with gibberellin application. Cordeiro *et al.* (2019) found maximum TSS: acid ratio with AMF inoculation in strawberry.

4.3.8 Total Sugars

The information recorded on the impact of plant growth regulators on strawberry cv. Camarosa is shown in Table 4.10 and Figure 4.3. The values of total sugar varied from 5.11 to 8.43 per cent. Plants treated with 75 ppm GA_3 (8.43 %) recorded maximum total sugars and it was superior to all other treatments. Which was followed by 50 ppm GA_3 (8.22 %) application. While minimum total sugar was reported in control (5.11 %). Gibberellins promote the synthesis of α-amylase, which convert starch into sugars in fruits which is responsible in increasing total sugars. Singh and Singh (2009) recorded highest total sugars with application of GA_3 in strawberry plants. Kong *et al.* (2019) recorded increased sugar

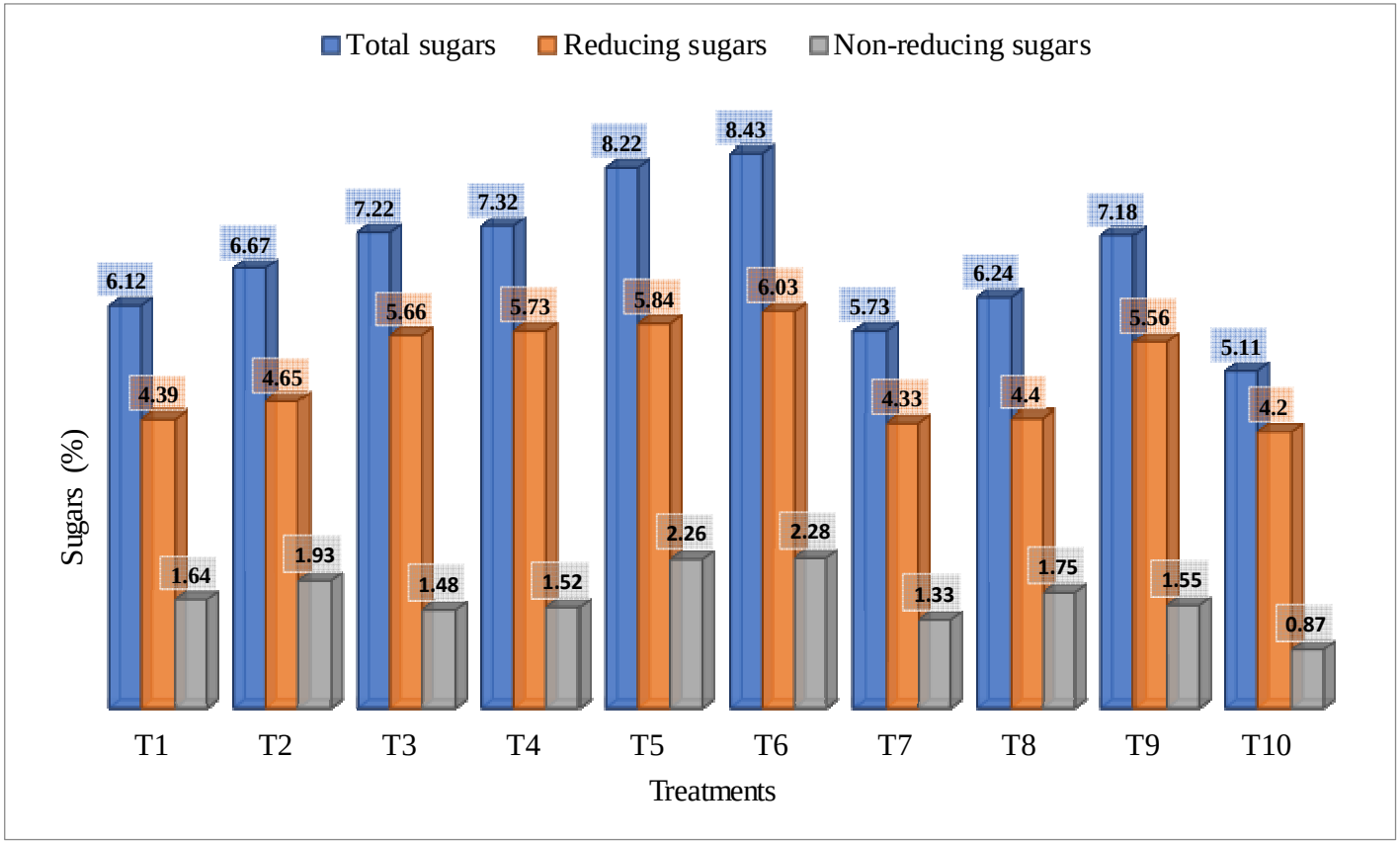


Figure 4.3 Effect of plant growth regulators on total sugars, reducing sugars and non-reducing sugars of strawberry cv. Camarosa

content of tomato by inoculation of AMF. The results are in line with work of Singh and Tripathi (2010), Thakur *et al.* (2015) and Paikra *et al.* (2018).

Table 4.10 Effect of plant growth regulators on TSS: acid ratio and total sugars of strawberry cv. Camarosa

Treatments	TSS: acid ratio	Total Sugars (%)
T_1 NAA 5ppm	10.45	6.12
T_2 NAA 10ppm	11.73	6.67
T_3 NAA 15ppm	12.64	7.22
T_4 GA_3 25ppm	14.50	7.32
T_5 GA_3 50ppm	16.78	8.22
T_6 GA_3 75ppm	17.85	8.43
T_7 BA 5ppm	10.11	5.73
T_8 BA 10ppm	10.94	6.24
T_9 BA 15ppm	11.99	7.18
T_{10} Control	8.01	5.11
CD $_{(0.05)}$	**1.89**	**0.09**

4.3.9 Reducing Sugars

Influence of plant growth regulators on reducing sugar was demonstrated in Table 4.11 and Figure 4.3. The reducing sugars values ranged from 4.20 to 6.03 per cent. The maximum value of reducing sugars was recorded with application of 75 ppm GA_3 (6.03 %) and it was statistically at par with 50 ppm GA_3 (5.84 %). The minimum reducing sugars was observed in control (4.20 %). Increase in fruit TSS and lower acidity might be attributed to the fast conversion of starch into sugars (reducing and non-reducing sugars) during the quick ripening process. Paikra *et al.* (2018) applied 75 ppm GA_3 on strawberry cv. Sabrina and observed increased reducing sugars content in strawberry fruits. Similarly, Sehkar (2013) reported increase in reducing sugars with 75 ppm GA_3 application in strawberry. El-Gould and Amal (2020) reported increased reducing sugars with inoculation of arbuscular mycorrhizal fungi in strawberry.

4.3.10 Non-reducing Sugars

It is evident from observations recorded in Table 4.11 and Figure 4.3 that growth regulators had significant impact on non-reducing sugar. It ranged from 0.87 to 2.28 per cent. The highest value was recorded in 75 ppm GA_3 (2.28 %) treatment which was statistically at par with 50 ppm GA_3 (2.26 %). Lowest values were observed in control (0.87 %). The rise in non-reducing sugar content in GA_3 treated plants may be attributed to quick fruit ripening

caused by hydrolytic enzyme, which is coupled with significant metabolic changes in fruit, leading to the conversion of complex polysaccharides and organic acid into simple sugars via high respiration. The present results are similar with work of Thakur *et al*. (2015) and Paikra *et al.* (2018) in strawberry and Saleem *et al*. (2008) and Hazarika *et al.* (2015), El-Gould and Amal (2020) in other fruit crops.

Table 4.11 Effect of plant growth regulators on reducing and non-reducing sugars of strawberry cv. Camarosa

Treatments	Reducing Sugars (%)	Non-Reducing Sugars (%)
T_1 NAA 5ppm	4.39	1.64
T_2 NAA 10ppm	4.65	1.93
T_3 NAA 15ppm	5.66	1.48
T_4 GA_3 25ppm	5.73	1.52
T_5 GA_3 50ppm	5.84	2.26
T_6 GA_3 75ppm	6.03	2.28
T_7 BA 5ppm	4.33	1.33
T_8 BA 10ppm	4.40	1.75
T_9 BA 15ppm	5.56	1.55
T_{10} Control	4.20	0.87
$CD_{(0.05)}$	**0.23**	**0.25**

4.3.11 Ascorbic acid content

Table 4.12, provides information on impact of growth regulators on ascorbic acid. The values of ascorbic acid varied from 47.00 to 65.67 mg/100g. Higher ascorbic acid content was reported in treatment T_6, 75 ppm GA_3 (65.67 mg/100g) treated plants and it was statistically at par with T_5, 50 ppm GA_3 (63.33 mg/100g). The lower values of ascorbic acid content was recorded in T_{10}, control (47.00 mg/100g). Gibberellic acid may have a catalytic effect on the biosynthesis of ascorbic acid from its precursor glucose-6-phosphate or ascorbic acid may have an inhibitory effect on its conversion to dehydro-ascorbic acid or both causing the perceptible rise in ascorbic acid with gibberellic acid. Kumar and Tripathi (2009) reported increase in ascorbic acid of strawberry cv. Chandler with foliar application of 75 ppm GA_3.The present results were similar with findings of Ingle *et al.* (2001), Singh and Singh (2009), Kumar *et al*. (2012), Tiwari *et al*. (2017), Paikra *et al*. (2018), Kong *et al.* (2019) and Bairwa *et al.* (2020).

4.3.12 Anthocyanin

The information on the impact of growth regulator treatments on anthocyanin content of strawberry fruit is shown in Table 4.12. It is evident from Table that highest value of anthocyanin content was recorded in treatment T_6 i.e., 75 ppm GA_3 (0.23) and it was statistically at par with 50 ppm GA_3 (0.22) and 15 ppm BA (0.21) in treatments T_5 and T_9, respectively. The lowest values were recorded in T_{10} i.e., control (0.11). Schwab and Raab (2004) reported significantly increase in anthocyanin content by GA_3 application in strawberry. Gibberellic acid may be involved in the production of anthocyanin pigments or their precursors as well as the movement of their precursors. The increase in anthocyanin content of fruits observed in the current study may also be related to a higher accumulation of carbohydrates by increase in photosynthetic rate with foliar application of plant growth regulators. The higher anthocyanin levels represent in the current study may also be related to a higher buildup of carbohydrates brought on by increased photosynthesis under the control of plant growth regulators. Similar results were obtained from the work of Montero *et al.* (1998), Khokhar *et al*. (2004) and Khandaker *et al.* (2017) and Emami *et al*. (2011). This increased anthocyanin content in fruits can also due to mycorrhizal colonisation activating a host defence response (Rouphael *et al.,* 2015). Chiomento *et al*. (2019) inoculate plants with AMF and recorded maximum anthocyanin content.

Table 4.12 Effect of plant growth regulators on ascorbic acid and anthocyanin content of strawberry cv. Camarosa

Treatments	**Ascorbic acid content (mg/100g)**	**Anthocyanin content (A_{530})**
T_1 NAA 5ppm	50.67	0.12
T_2 NAA 10ppm	54.67	0.13
T_3 NAA 15ppm	58.67	0.15
T_4 GA_3 25ppm	60.00	0.20
T_5 GA_3 50ppm	63.33	0.22
T_6 GA_3 75ppm	65.67	0.23
T_7 BA 5ppm	51.33	0.15
T_8 BA 10ppm	54.33	0.17
T_9 BA 15ppm	54.67	0.21
T_{10} Control	47.00	0.11
CD $_{(0.05)}$	**4.20**	**0.02**

4.4 Bio-Chemical Parameter

4.4.1 Chlorophyll Content

The data pertaining influence of growth regulators on chlorophyll content was presented in Table 4.13. The value of chlorophyll content ranged from 1.97 to 3.31 mg/g. It is clear from the Table that maximum value of chlorophyll was noted in 75 ppm GA_3 (3.31 mg/g) application which was statistically at par with 50 ppm GA_3 (3.04 mg/g). The minimum value of chlorophyll content was recorded in control (1.97 mg/g). Similar results were obtained by application of 75 ppm GA_3 in strawberry by Kumari *et al.* (2008), Sehkar (2013) and Zang *et al.* (2016). Mikiciuk *et al.* (2019) and Turhan (2021) also observed increased chlorophyll content with inoculation of plants with AMF.

Table 4.13 Effect of plant growth regulators on chlorophyll content of strawberry cv. Camarosa

Treatments	**Chlorophyll content (mg/g fresh weight)**
T_1 NAA 5ppm	2.13
T_2 NAA 10ppm	2.25
T_3 NAA 15ppm	2.44
T_4 GA_3 25ppm	2.78
T_5 GA_3 50ppm	3.04
T_6 GA_3 75ppm	3.31
T_7 BA 5ppm	2.08
T_8 BA 10ppm	2.20
T_9 BA 15ppm	2.37
T_{10} Control	1.97
CD $_{(0.05)}$	**0.44**

4.5 Physiological Parameters

4.5.1 Photosynthesis

Data related to photosynthesis was presented in Table 4.14. It is evident from the data recorded in table that growth regulators had positive impact on photosynthesis in strawberry plants as compare to control. Photosynthesis value varied from 7.01 to 8.30 µmol $CO_2/m^2/s$. The maximum value of photosynthesis was recorded in treatment T_6, 75 ppm GA_3 (8.30 µmol $CO_2/m^2/s$) and it was statistically at par with T_5, 50 ppm GA_3 (8.24 µmol $CO_2/m^2/s$). However, the minimum value of photosynthesis was observed in treatment T_{10}, control (7.01 µmol $CO_2/m^2/s$).

4.5.2 Stomatal Conductance

Plant growth regulators had significantly increased the stomatal conductance of strawberry cv. Camarosa and the data is demonstrated in Table 4.14. It varied from 0.32 to 0.54 mol $H_2O/m^2/s$. Higher stomatal conductance was recorded in treatment T_6, 75 ppm GA_3 (0.54 mol $H_2O/m^2/s$) which was statistically at par with treatment T_5, 50 ppm GA_3 (0.51 mol $H_2O/m^2/s$). While, lower stomatal conductance was recorded in treatment T_{10}, control (0.32 mol $H_2O/m^2/s$).

Table 4.14 Effect of plant growth regulators on photosynthesis, stomatal conductance and transpiration of strawberry cv. Camarosa

Treatments	Photosynthesis (µmol $CO_2/m^2/s$)	Stomatal conductance (mol $H_2O/m^2/s$)	Transpiration (mmol $H_2O/m^2/s$)
T_1 NAA 5ppm	7.19	0.35	16.71
T_2 NAA 10ppm	7.23	0.40	18.14
T_3 NAA 15ppm	7.54	0.43	18.36
T_4 GA_3 25ppm	8.21	0.48	18.77
T_5 GA_3 50ppm	8.24	0.51	19.11
T_6 GA_3 75ppm	8.30	0.54	19.42
T_7 BA 5ppm	7.10	0.33	16.64
T_8 BA 10ppm	7.52	0.36	17.48
T_9 BA 15ppm	7.74	0.41	18.31
T_{10} Control	7.01	0.32	16.32
CD $_{(0.05)}$	**0.06**	**0.05**	**1.21**

4.5.3 Transpiration

Data pertaining to influence of growth regulator on transpiration is shown in Table 4.14. The values of transpiration varied from 16.32 to 19.42 mmol $H_2O/m^2/s$. Maximum transpiration value was recorded in 75 ppm GA_3 (19.42 mmol $H_2O/m^2/s$) which was statistically at par with 50 ppm GA_3 (19.11 mmol $H_2O/m^2/s$), 25 ppm GA_3 (18.77 mmol $H_2O/m^2/s$), 15 ppm NAA (18.36 mmol $H_2O/m^2/s$) and 15 ppm BA (18.31 mmol $H_2O/m^2/s$). However minimum value of transpiration was reported in control (16.32 mmol $H_2O/m^2/s$).

Increased leaf area, higher chlorophyll content and a strong source-sink connection are all responsible for the rise in photosynthesis, stomatal conductance, and transpiration rate. Styliandis *et al*. (2004) reported increased photosynthetic rate, stomatal conductance and transpiration with 75 ppm GA_3 application in apple. Guo *et al*. (2006) reported that transpiration rate increased with application of benzyladenine in strawberry plants. Wu and

Xia (2006) reported that inoculation of plants with arbuscular mycorrhizal fungi helps in improved photosynthetic rate, stomatal conductance and transpiration. Kumari *et al.* (2018) reported maximum photosynthetic rate, stomatal conductance and transpiration with application of gibberellic acid in strawberry.

Chapter-5

SUMMARY AND CONCLUSION

The present studies entitled **"Influence of plant growth regulators on growth, yield and fruit quality of strawberry (*Fragaria × ananassa*) cv. Camarosa"** was carried out at Horticultural Research & Training Station and Krishi Vigyan Kendra, Solan at Kandaghat during the year 2021-2022. The results obtained and conclusion drawn from present investigation are summarized as under:

5.1 VEGETATIVE PARAMETERS

5.1.1 The application of different growth regulators showed significant increase in plant height and petiole length. Maximum plant height (23.17 cm) and petiole length (16.93 cm) was recorded with foliar application of 75 ppm GA_3 which was closely followed by the application of 50 ppm GA_3. While minimum plant height (9.83 cm) and petiole length (8.87 cm) was recorded in control.

5.1.2 The highest number of leaves (23.33) and leaf area (102.29 cm^2) was recorded in plants treated with 75 ppm GA_3 while lowest number of leaves (17.00) and leaf area (85.16 cm^2) was recorded under control.

5.1.3 The foliar application of 75 ppm GA_3 resulted in increased runner production per plant (5.53) and it was closely followed by 50 ppm GA_3. The maximum number of crowns per plant (4.87) was observed in 75 ppm GA_3 treated plants and it was closely followed by 50 ppm and 25 ppm GA_3. The minimum number of runners (3.97) and crowns (3.11) per plant was observed in control.

5.2 FLOWERING AND FRUITING PARAMETERS

5.2.1 Application of plant growth regulators had significant effect on flowering. Plants treated with 75 ppm GA_3 took minimum days to initiate flowering (96.67 days) and in control plants took maximum days to initiate flowering i.e., 113.33 days. The duration of flowering (117.75 days) was also recorded maximum in 75 ppm GA_3 treated plants and minimum duration of flowering was noted under control (95.33 days).

5.2.2 Application of 75 ppm GA_3 increased number of flowers per plant (29.33) and also fruit set (89.44 %) and followed by 50 ppm GA_3 i.e., treatment T_5. However,

minimum number of flowers per plant (21.47) and fruit set (73.41 %) was recorded under control.

5.2.3 Foliar application of 75 ppm GA_3 resulted in highest number of fruits (26.23) and yield per plant (388.03 g) while, lowest number of fruit (15.77) and yield (171.48 g) was recorded in control.

5.3 FRUIT QUALITY PARAMETERS

5.3.1 Plant growth regulators had significant effect on fruit size and weight. Application of 75 ppm GA_3 registered maximum fruit length (42.44 mm) and weight (14.80 g). However, maximum fruit breadth (30.99 mm) was recorded in 15 ppm BA and it was closely followed by 75 ppm and 50 ppm GA_3. The minimum fruit length (30.25 mm), breadth (27.84 mm) and weight (10.87 g) were recorded under control.

5.3.2 The maximum fruit firmness (0.83 Kg/cm^2) was reported in plants treated with 15 ppm BA and it was closely followed by 75 ppm, 50 ppm and 25 ppm GA_3 respectively. While, minimum fruit firmness was recorded in control (0.65 Kg/cm^2).

5.3.3 The maximum total soluble solids (10.03 °B) were recorded in 75 ppm GA_3 treatment and it was closely followed by 50 ppm GA_3. The minimum total soluble solids (6.07 °B) were recorded in control.

5.3.4 Application of 75 ppm GA_3 recorded minimum titratable acidity (0.56 %) and it was followed by 50 ppm and 25 ppm GA_3, respectively. The maximum titratable acidity (0.76 %) was noted under control.

5.3.5 TSS: acid ratio was found maximum (17.85) in 75 ppm GA_3 treatment and it was closely followed by 50 ppm GA_3. The minimum TSS: acid ratio (8.01) was recorded in control.

5.3.6 Plant growth regulators had significant impact on total sugars, reducing sugars, non-reducing sugars and ascorbic acid content. Application of 75 ppm GA_3 registered maximum total sugars (8.43 %), reducing sugars (6.03 %), non- reducing sugars (2.28 %) and ascorbic acid contents (65.67 mg/100g). In case of reducing sugars, non-reducing sugars and ascorbic acid it was closely followed by 50 ppm GA_3. While minimum total sugars (5.11 %), reducing sugars (4.20 %), non-reducing sugars (0.87 %) and ascorbic acid (47.00 mg/100g) were recorded under control.

5.3.7 Treatment T6, GA_3 73 ppm resulted maximum anthocyanin content (0.23) and followed by 50 ppm GA_3 and 15 ppm BA, respectively. The minimum anthocyanin content (0.11) was observed in control.

5.4 BIO-CHEMICAL PARAMETER

5.4.1 The maximum chlorophyll content (3.31 mg/g fresh weight) was reported in plants treated with 75 ppm GA_3 and it was followed by 50 ppm GA_3 and minimum chlorophyll content (1.97 mg/g fresh weight) was recorded in control.

5.5 PHYSIOLOGICAL PARAMETERS

5.5.1 Application of 75 ppm GA_3 resulted in increased photosynthesis (8.30 µmol CO_2/m^2 /s), stomatal conductance (0.54 mol $H_2O/m^2/s$) and transpiration (19.42 mmol $H_2O/m^2/s$). In case of photosynthesis and stomatal conductance it was followed by 50 ppm GA_3 while, transpiration was followed by 50 ppm, 25 ppm GA_3, 15 ppm NAA and 15 ppm BA. The minimum photosynthesis (7.01 µmol $CO_2/m^2/s$), stomatal conductance (0.32 mol $H_2O/m^2/s$) and transpiration (16.32 mmol $H_2O/m^2/s$) was recorded under control.

CONCLUSION

On the basis of study, it may be concluded that, various plant growth regulators resulted significant increase in vegetative growth, fruit set, fruit yield and quality along with physiological and bio-chemical parameters. Therefore, treatment T_6 i.e., application of GA_3 at 75 ppm was found best for improving growth, yield and fruit quality of strawberry which was statistically at par with 50 ppm GA_3 i.e., treatment T_5. Thus, it can be concluded that application of GA_3 75 ppm (T_6) is recommended for better growth, yield and fruit quality of strawberry followed by treatment T_5, 50 ppm GA_3.

Hence, the treatment with 50 ppm GA_3 suggested as a cost effective module for getting higher yield and quality with 25 per cent net savings of growth regulators in strawberry on sustainable basis.

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APPENDIX- I

Mean monthly meteorological data of Horticulture Research & Training Station and Krishi Vigyan Kendra Kandaghat, Solan (HP) with effect from October' 2021 to June' 2022

Months	Temperature (°C)			Relative Humidity (%) (Mean)	Rainfall (mm)
	Maximum	Minimum	Mean		
October, 2021	25	11	18	9.5	59
November, 2021	21	6	13.5	0	42
December, 2022	17	2	9.5	3.4	39
January, 2022	13	2	7.5	51.2	62
February, 2022	16	2	9	18.7	58
March, 2022	28	11	19.5	0.3	32
April, 2022	34	14	24	1.2	21
May, 2022	35	16	25.5	11	30
June, 2022	33	18	25.5	15	35

APPENDIX-II

ANALYSIS OF VARIANCE FOR DIFFERENT PARAMETERS

1. Analysis of variance for plant height (cm)

Source of Variation	DF	SS	MSS	F-Calculated	Significance
Replication	2	0.194			
Treatment	9	571.543	63.505	141.599	0
Error	18	8.073	0.448		
Total	29	579.809			

2. Analysis of variance for petiole length (cm)

Source of Variation	DF	SS	MSS	F-Calculated	Significance
Replication	2	0.132			
Treatment	9	210.121	23.347	46.311	0
Error	18	9.074	0.504		
Total	29	219.327			

3. Analysis of variance for number of leaves

Source of Variation	DF	SS	MSS	F-Calculated	Significance
Replication	2	0.267			
Treatment	9	101.467	11.274	20.849	0
Error	18	9.733	0.541		
Total	29	111.467			

4. Analysis of variance for leaf area (cm^2)

Source of Variation	DF	SS	MSS	F-Calculated	Significance
Replication	2	1.43			
Treatment	9	789.755	87.751	66.716	0
Error	18	23.675	1.315		
Total	29	814.86			

5. Analysis of variance for number of crowns

Source of Variation	DF	SS	MSS	F-Calculated	Significance
Replication	2	0.114			
Treatment	9	8.359	0.929	34.73	0
Error	18	0.481	0.027		
Total	29	8.954			

6. Analysis of variance for number of runners

Source of Variation	DF	SS	MSS	F-Calculated	Significance
Replication	2	0.009			
Treatment	9	6.228	0.692	29.805	0
Error	18	0.418	0.023		
Total	29	6.655			

7. Analysis of variance for initiation of flowering

Source of Variation	DF	SS	MSS	F-Calculated	Significance
Replication	2	0.73			
Treatment	9	992.306	110.256	95.038	0
Error	18	20.882	1.16		
Total	29	1,013.92			

8. Analysis of variance for duration of flowering

Source of Variation	DF	SS	MSS	F-Calculated	Significance
Replication	2	2.905			
Treatment	9	1,468.29	163.144	165.305	0
Error	18	17.765	0.987		
Total	29	1,488.96			

9. Analysis of variance for number of flowers

Source of Variation	DF	SS	MSS	F-Calculated	Significance
Replication	2	2.945			
Treatment	9	169.347	18.816	81.516	0
Error	18	4.155	0.231		
Total	29	176.447			

10. Analysis of variance for fruit set (%)

Source of Variation	DF	SS	MSS	F-Calculated	Significance
Replication	2	0.263			
Treatment	9	745.717	82.857	11.115	0.00001
Error	18	134.179	7.454		
Total	29	880.159			

11. Analysis of variance for number of fruits

Source of Variation	DF	SS	MSS	F-Calculated	Significance
Replication	2	1.604			
Treatment	9	302.934	33.659	80.538	0
Error	18	7.523	0.418		
Total	29	312.061			

12. Analysis of variance for fruit yield (g/plant)

Source of Variation	DF	SS	MSS	F-Calculated	Significance
Replication	2	86.874			
Treatment	9	128682.751	14,298.08	127.216	0
Error	18	2,023.06	112.392		
Total	29	130792.682			

13. Analysis of variance for fruit yield (t/ha)

Source of Variation	DF	SS	MSS	F-Calculated	Significance
Replication	2	0.219			
Treatment	9	321.583	35.731	127.191	0
Error	18	5.057	0.281		
Total	29	326.859			

14. Analysis of variance for fruit length (mm)

Source of Variation	DF	SS	MSS	F-Calculated	Significance
Replication	2	0.25			
Treatment	9	354.65	39.406	124.737	0
Error	18	5.686	0.316		
Total	29	360.587			

15. Analysis of variance for fruit breadth (mm)

Source of Variation	DF	SS	MSS	F-Calculated	Significance
Replication	2	1.244			
Treatment	9	31.626	3.514	17.092	0
Error	18	3.701	0.206		
Total	29	36.571			

16. Analysis of variance for fruit weight (g)

Source of Variation	DF	SS	MSS	F-Calculated	Significance
Replication	2	0.125			
Treatment	9	41.24	4.582	24.641	0
Error	18	3.347	0.186		
Total	29	44.713			

17. Analysis of variance for fruit firmness (Kg/cm^2)

Source of Variation	DF	SS	MSS	F-Calculated	Significance
Replication	2	0.001			
Treatment	9.00	0.11	0.01	12.70	0.00
Error	18	0.017	0.001		
Total	29	0.128			

18. Analysis of variance for total soluble solids (°B)

Source of Variation	DF	SS	MSS	F-Calculated	Significance
Replication	2	0.542			
Treatment	9	35.952	3.995	11.239	0.00001
Error	18	6.398	0.355		
Total	29	42.892			

19. Analysis of variance for titratable acidity (%)

Source of Variation	DF	SS	MSS	F-Calculated	Significance
Replication	2	0.00			
Treatment	9	0.12	0.014	14.291	0
Error	18	0.02	0.001		
Total	29	0.14			

20. Analysis of variance for TSS: acid ratio

Source of Variation	DF	SS	MSS	F-Calculated	Significance
Replication	2	0.85			
Treatment	9	252.668	28.074	23.393	0
Error	18	21.602	1.2		
Total	29	275.12			

21. Analysis of variance for total sugars (%)

Source of Variation	DF	SS	MSS	F-Calculated	Significance
Replication	2	0.007			
Treatment	9	30.136	3.348	1,352.36	0
Error	18	0.045	0.002		
Total	29	30.187			

22. Analysis of variance for reducing sugars (%)

Source of Variation	DF	SS	MSS	F-Calculated	Significance
Replication	2	0.016			
Treatment	9	14.769	1.641	94.708	0
Error	18	0.312	0.017		
Total	29	15.097			

23. Analysis of variance for non-reducing sugars (%)

Source of Variation	DF	SS	MSS	F-Calculated	Significance
Replication	2	0.018			
Treatment	9	4.864	0.54	26.498	0
Error	18	0.367	0.02		
Total	29	5.25			

24. Analysis of variance for ascorbic acid content (mg/100g)

Source of Variation	DF	SS	MSS	F-Calculated	Significance
Replication	2	8.867			
Treatment	9	923.633	102.626	17.351	0
Error	18	106.467	5.915		
Total	29	1,038.97			

25. Analysis of variance for anthocyanin content

Source of Variation	DF	SS	MSS	F-Calculated	Significance
Replication	2	0			
Treatment	9	0.051	0.006	40.25	0.00
Error	18	0.003	0		
Total	29	0.054			

26. Analysis of variance for chlorophyll content (mg/g fresh weight)

Source of Variation	DF	SS	MSS	F-Calculated	Significance
Replication	2	0.025			
Treatment	9	5.314	0.59	9.322	0.00004
Error	18	1.14	0.063		
Total	29	6.479			

27. Analysis of variance for photosynthesis (µmol $CO_2/m^2/s$)

Source of Variation	DF	SS	MSS	F-Calculated	Significance
Replication	2	0.002			
Treatment	9	6.631	0.737	650.861	0
Error	18	0.02	0.001		
Total	29	6.653			

28. Analysis of variance for stomatal conductance (mol $H_2O/m^2/s$)

Source of Variation	DF	SS	MSS	F-Calculated	Significance
Replication	2	0.002			
Treatment	9	0.161	0.018	19.716	0
Error	18	0.016	0.001		
Total	29	0.18			

29. Analysis of variance for transpiration (mmol $H_2O/m^2/s$)

Source of Variation	DF	SS	MSS	F-Calculated	Significance
Replication	2	0.509			
Treatment	9	31.917	3.546	7.193	0.00021
Error	18	8.875	0.493		
Total	29	41.3			

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Title of Thesis	:	**"Influence of plant growth regulators on growth, yield and fruit quality of strawberry (*Fragaria* × *ananassa*) cv. Camarosa"**
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ABSTRACT

The present study entitled, **"Influence of plant growth regulators on growth, yield and fruit quality of strawberry (*Fragaria* × *ananassa*) cv. Camarosa"** was carried out at Horticultural Research & Training Station and Krishi Vigyan Kendra, Solan at Kandaghat during the year 2021-2022.The experiment was laid out in Randomized Block Design (RBD) with three replications having ten treatments of different plant growth regulators viz; T_1: 5 ppm NAA, T_2: 10 ppm NAA, T_3: 15 ppm NAA, T_4: 25 ppm GA_3, T_5: 50 ppm GA_3, T_6: 75 ppm GA_3, T_7: 5 ppm BA, T_8: 10 ppm BA, T_9: 15 ppm BA and T_{10}: Control.The observations were recorded on plant height, petiole length, number of leaves per plant, leaf area, number of crowns and runners per plant, initiation and duration of flowering, number of flowers, fruit set, number of fruits, yield, fruit size, weight, firmness, total soluble soilds, titratable acidity, TSS: Acid ratio, total sugars, reducing sugars, non-reducing sugars, ascorbic acid content, anthocyanin content, chlorophyll content, photosynthesis, stomatal conductance and transpiration. From present investigation, it can be concluded that treatment T_6 recorded higher growth, yield and fruit quality. Among different plant growth regulators T_6: 75 ppm GA_3 had maximum plant height (23.17 cm), petiole length (16.93 cm), number of leaves per plant (23.33), leaf area (102.29 cm^2), number of crowns (4.87) and runners (5.53) per plant, initiation (96.67 days) and duration (117.75 days) of flowering, number of flowers (29.33), fruit set (89.44 %), number of fruits (26.23), yield (388.03 g/plant), fruit length (42.44 mm),weight (14.80 g),total soluble soilds (10.03 °B), titratable acidity (0.56 %), TSS: Acid ratio (17.85), total sugars (8.43 %), reducing sugars (6.03 %), non-reducing sugars (2.28 %), ascorbic acid content (65.67 mg/100g), anthocyanin content (0.23), chlorophyll content (3.31 mg/g fresh weight), photosynthesis (8.30 µmol $CO_2/m^2/s$), stomatal conductance (0.54 mol $H_2O/m^2/s$) and transpiration (19.42 mmol $H_2O/m^2/s$). While fruit breadth (30.99 mm) and firmness (0.83 Kg/cm^2) were recorded maximum in T_9: 15 ppm BA.

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