ENHANCING FRUIT SET AND YIELD OF TOMATO (*Solanum lycopersicum* L.) IN POLYHOUSE USING ARTIFICIAL POLLINATION AND GROWTH REGULATORS.

by

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(2016-12-018)

THESIS

Submitted in partial fulfillment of the requirements for the degree of

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DECLARATION

I, hereby declare that this thesis entitled **"ENHANCING FRUIT SET AND YIELD OF TOMATO (*Solanum lycopersicum* L.) IN POLYHOUSE USING ARTIFICIAL POLLINATION AND GROWTH REGULATORS "** is a bonafide record of research work done by me during the course of research and the thesis has not previously formed the basis for the award of any degree, diploma, associateship, fellowship or other similar title, of any other University or Society.

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LIST OF ABBREVIATIONS

ANOVA	Analysis of variance
BARI	Bangladesh Agriculture Research Institute
CD	Critical difference
cm	Centimeter
DAT	Days after transplanting
et al	And co-workers/co-authors
Fig.	Figure
g	Gram
GA_3	Gibberellic acid
KAU	Kerala Agricultural University
Kg	Kilogram
Kgm^{-2}	Kilogram per meter square
m^2	Square meter
mg	Milligram
ml	Milliliter
NAA	Naphthalene acetic acid
NAOH	Sodium hydroxide
NHB	National Horticulture Board
NS	Non significant
PCPA	Para-chlorophenoxy acetic acid
PGB	Plant growth bioregulator
ppm	Parts per million
RBD	Randomized block design
SE(m)	Standard error mean
TSS	Total Soluble Solids
UV	Ultra violet
VBP	V-mount Battery Pinch
μg	Microgram
%	Per cent
4-CPA	4-Chlorophenoxy acetic acid

INTRODUCTION

1. INTRODUCTION

Tomato (*Solanum lycopersicum* L.) is a widely grown solanaceous vegetable crop around the world, both for fresh market and processing. India is the second largest producer of tomato with an area of 7.9 lakh ha, production of 193.77 lakh tons and productivity of 24.5 t ha^{-1} (NHB, 2017). Though tomato is sporadically cultivated in Kerala, extent of consumption is very high. Recently, many farmers have been trying for extensive cultivation of tomato under protected conditions expecting higher returns. However, these farmers are concerned about low fruit set under polyhouse conditions which limits productivity and profitability.

Fruit set in tomato is very sensitive to environmental conditions, especially to low or high temperatures and the temperature range in polyhouses of Kerala is obviously higher than the optimum range. The optimum temperature requirement for fruit set in tomato is 15°C to 32°C during day and 15°C to 21°C during night. Moreover, stigma exsertion which cause low fruit set, may be another limiting factor.

Fruit set in tomato was successfully improved by application of plant growth regulators. Shortage of auxin and gibberellins could cause reduction of fruit set under high temperature (Choudhury *et al.* 2013). Para-chlorophenoxyacetic acid /4-chlorophenoxyacetic acid (4-CPA/ PCPA) at concentration ranging from 20 –100 ppm is reported to be effective for improving fruit set in some foreign countries.

Gibberellic acid have effects on plant physiological systems including fruit setting, leaf expansion, germination, breaking dormancy, increasing fruit size, improving fruit quality and in many other aspects of plant growth and thereby increase crop production. Combination of PCPA and GA_3 may have synergistic influence on fruit set .

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The minimal movement of flowers that limits the amount of pollen reaching the stigma may also result in poor fruit set. Higher humidity in polyhouses of Kerala may hinder the release of pollen. Tapping or wind action in the field, moves the flower and agitates the pollen, resulting in more pollen reaching the stigma which may lead to increased fruit set. Mechanical vibration of tomato in a greenhouse may also promote fruit setting. Hence, assisted pollination measures alone or in combination with growth regulator application might improve fruit set and yield.

Considering the above mentioned facts, the present investigation was undertaken with the objective:

To enhance the fruit set and yield of tomato under poly house through artificial pollination and application of plant growth regulators.

REVIEW OF LITERATURE

2. REVIEW OF LITERATURE

Tomato (*Solanum lycopersicum* L.) is one of the most widely cultivated crops in the world. It is an important source of vitamins and an important crop for small-holders and medium scale commercial farmers. Tomato is emerging as one of the main tropical vegetable crops grown under protected cultivation. Though plant growth, fruit set, seed yield and seed quality were found better in polyhouse in comparison to open field by many researchers, varying environmental conditions in polyhouse may induce adverse effects. There was progressive decline in fruit set, seed yield and fruit quality as the temperature increased and RH decreased in tropical conditions.

Though self pollinated, the percentage of fruit set in tomato under polyhouse conditions is very poor which lead to the production of limited number of fruits, resulting low yield. This may be due to less or no movement of air in the polyhouse that affect the transfer of pollen to stigma. Sufficient pollination in tomato flowers do not occur in polyhouses unless they are disturbed either by natural or artificial means. Mechanical vibration of flowers can be an alternative to improve pollination under protected environment.

Growth regulators, like Para-chlorophenoxyaceticacid (PCPA) and Gibberellic acid (GA_3), have been used to improve fruit set in tomatoes. Therefore, assisted pollination measures alone or in combination with growth regulator application might improve fruit set and yield. Hence, the reviews, on these aspects is presented in this chapter.

2.1 Artificial Pollination

Pollination of flowers is very important and is needed for optimal fruit set and production of quality greenhouse vegetables (Sabir and Singh, 2013). Pollen is shed within the individual flowers during anthesis when there is a strong enough vibrating force, such as wind, to shake the plant and flower.

In the absence of naturally occurring wind in the greenhouse, tomato flowers have to be vibrated by some mechanical means to release the pollen. Kerr and Kribs (1955) observed that pollinating tomato flowers with the aid of electric vibrators showed good fruit set in the absence of wind under polyhouse conditions. Jones (1999) pointed out that physical vibration of flowers using mechanical means was important for complete pollination to take place and for production of well-formed symmetrical fruits. According to Nuez (2001), plant vibration helped to increase fruit set.

In an experiment conducted by Hanna (1995) on assisting natural wind pollination of field tomatoes, blowing air helped the anthers to release more pollen resulting in more efficient pollination and fertilization which enhanced seed number, fruit weight, fruit diameter and total yield. Influence of methods of pollination on cherry tomato cv. Pusa Selection-1 grown under different protected conditions was studied by Vidyadhar *et al.*(2015). Air blowing method recorded highest number of fruits per plant (67.46) compared to stick method (65.31) and vibratory pollination method (66.20). Air blowing method was superior in improving 100 seed weight (0.129 g) and seeds berry^{-1}(68.05) compared to other treatments. The yield of tomatoes grown under unfavorable conditions of high temperature was markedly improved by supplemental hand pollination (Shelby *et al* ., 1978).

2.1.1 Effect of artificial pollination methods on flowering and fruit set

According to Charles and Harris (1972) small electric vibrator, known as an 'electric bee', could be used to vibrate single clusters to improve the transfer of pollen from anthers to stigma. Smit and Combrink (2005) reported that there was improved fruit set percentage in tomatoes by cluster vibration treatment compared to those without vibration. Cluster vibration resulted in the release of more pollen and caused average increase in fruit set by 9.6 %, which directly influenced the final production. However, Vidyadhar *et al.*, (2015) noted maximum fruit set (64.19 %) in air blowing method followed by vibratory pollination and stick method (61.28 % and 61.26 %) respectively.

2.1.2 Effect of artificial pollination methods on fruit characters and yield

Fruit size and total yield may be increased with efficient pollination and fertilization. Verkerk (1957) reported that more the number of pollen used in pollination resulting in more seed set, faster the growing fruit and a more profitable crop. Charles and Harris (1972) observed more number of seeds per fruit resulting in bigger fruit with vibratory pollination. The use of a wind blower increased fruit size, yield and the percentage of marketable fruits (Hanna, 1995). Higuti *et al.* (2010) conducted an experiment on the effect of plant vibration in five tomato hybrids and obtained more seeds per fruit .

2.1.3 Effect of artificial pollination methods on fruit quality

Heuvelink (2005) reported that incomplete pollination and differential growth of various parts of the fruit can produce misshapened fruit including cat facing, puffiness and non-characteristic shapes. Poor pollination can be a reason for fruits to grow misshapen.

2.2 Growth regulators

Gibberellin induces cell division, cell elongation, cell enlargement and ultimately leads to higher fruit length, girth and pulp-seed ratio as reported by Sanyal *et al.* (1995) and Shittu and Adeleke (1999). Gibberellic acid significantly increased growth characters of tomato (Pundir and Yadav, 2001). GA_3 application in tomato plant helped in synthesis of protein including various enzymes, increased rate of shoot elongation and photosynthetic capacity leading to total leaf area and leaf dry weight (Mostafa and Saleh, 2006).

Para chlorophenoxy acetic acid (PCPA) is found to be effective in improving tomato fruit set under higher temperature conditions (Kuo *et al.,* 1978). PCPA is an important plant growth regulator which increased fruit set and yield of tomato at high temperatures (Sasaki *et al.*, 2005). According to Paidi (2014), PCPA was effective in fruit retention of horticultural crops and thus increased the yield substantially.

2.2.1 Effect of application of growth regulators on vegetative characters

Negruckji (1960) reported that foliar application of GA_3 at 0.02 % enhanced the overall plant growth in tomatoes. Mehrotra *et al.* (1970) observed that GA_3 increased plant height over control in tomato cv. Pusa Ruby. Shittu and Adeleke (1999) investigated the effects of foliar application of GA_3 on growth and development of tomatoes in pot culture and found that plant height and number of leaves were significantly enhanced by GA_3 treatment. Plants treated with 250 ppm GA_3 were the tallest with the highest number of leaves. Gemici *et al.* (2000) noted that 10 ppm GA_3 treated tomato plants showed a 17 % increase in stem length compared to the control. The maximum number of primary branches (4.73) was recorded when treated with 25ppm GA_3 (Bokade, 2004). Meena (2008) found that application of 50 ppm GA_3 at 60 DAT recorded significant increase in plant height as well as plant spread. GA_3 applications promoted vegetative growth (Gelmesa *et al.*, 2012).

Ranjeet *et al.* (2014) reported that foliar sprays of GA_3 improved the plant height significantly. Highest plant height of 40.97 cm was recorded for GA_3 at 60 ppm concentration. Vandana and Verma (2014) reported that, spraying 50 ppm GA_3 at 30 DAT produced more plant height (30.15 cm) in chilli. Hasanuzzaman *et al.* (2015) revealed that application of 125 ppm GA_3 showed an increased plant height, number of leaves and branches per plant.

Shital *et al.* (2017) reported maximum plant height (79.69 cm) with 50 ppm GA_3 treatment compared to application of 500 ppm cycocel (77.65 cm) and 50 ppm Naphthalene acetic acid (76.86 cm) in tomato. The application of three levels of Tomatotone / 4-CPA (control, 1% , 2% and 3%) on summer tomato reported that 2% tomatotone application recorded the longest plant, maximum number of leaves and maximum number of flowers plant^{-1} compared to control (Shemu *et al.*, 2014). Karim *et al.* (2015) conducted a study to evaluate the influence of different levels of 4-chlorophenoxy acetic acid on growth of tomato during summer. Maximum plant height (85.57 cm) was noted with spray of 60 ppm 4-CPA over unsprayed plants (62.89 cm) in tomato.

Choudhury *et al.* (2013) reported that application of 20 ppm 4-CPA + 20 ppm GA_3 resulted in maximum plant height at 60 DAT (86.01cm)

2.2.2 Effect of application of growth regulators on flowering and fruit set

PCPA spray on flower cluster increased the fruit set as well as fruit production. However, Shital *et al.* (2017) revealed that the effect of plant growth regulators was non-significant for days to first flowering.

Rappaport (1957) reported higher fruit-set in tomato plants by gibberellin spray (1 to 500 ppm) but fruit size and development were unaffected. GA_3 gave the highest number of flowers cluster^{-1}, number of flower clusters plant^{-1} and number of flowers plant^{-1} (Saleh and Abdul,1980).

Habbasha *et al.* (1999) studied the effect of GA_3 on fruit yield and quality. They found that application of GA_3 increased fruit set percentage and total fruit yield compared to control. Bokade (2004) noted that the maximum number of flowers cluster^{-1} (7.73) was recorded for 50 ppm GA_3. Meena (2008) found that foliar application of GA_3 at 50 ppm exhibited higher number of flowers plant^{-1} than 75 ppm GA_3. Rahman *et al.* (2015) observed maximum number of flowers plant^{-1} and fruits plant^{-1} when sprayed with 50 ppm GA_3.

Randhawa and Thompson (1949) observed that flower clusters treated twice with PCPA at different stages of development, resulted in greater fruit set compared to untreated plants. Li *et al.* (1992) treated tomato plants with 30 ppm PCPA /4- CPA when 3 or 4 flowers were open, to obtain highest rate of fruit set and total yield. Baliyan *et al.* (2013) reported that tomato fruit set was increased by 9.28 %, 16.09% and 32.19% compared to control at 15, 45 and 75 ppm concentrations of 4-CPA respectively. Application of 75 ppm 4-CPA produced the highest fruit set in tomato followed by 45 ppm concentration. Sarkar *et al.* (2014) observed that flowers cluster^{-1} and total number of flowers plant^{-1} were increased by about 54% and 48% when 40 ppm 4-CPA was applied in BARI hybrid Tomato-4.

Kuo and Tsai (1984) reported that high temperature treatment decreased the levels of auxin and gibberellin, especially in floral buds and developing fruits of tomato. Therefore, shortage of auxin and gibberellins could cause the reduction of fruit set under high temperature. Treatments of the combination of 4-CPA and GAs reduced the high temperature inhibition of tomato fruit set. According to Sasaki *et al.* (2005) the treatment with the mixture of 4-CPA and GAs promoted the fruit set ratio to 88% compared to 4-CPA alone (67 %) and control (54 %.) This suggested that combination of growth regulators could induce more fruit set in tomato under rain shelter during summer season. A field experiment was carried out by Choudhury *et al.*, (2013) to assess the effect of different plant growth regulators on tomato during summer season where different plant growth regulators (20 ppm 4-CPA, 20 ppm GA_3 and 20 ppm 4-CPA + 20 ppm GA_3) were used. The maximum number of flower clusters per plant and number of flowers per plant were obtained when 20 ppm 4-CPA + 20 ppm GA_3 were applied.

2.2.3 Effect of application of growth regulators on fruit characters and yield

Sajeevkumar *et al.* (2016) observed that application of growth regulators like GA_3 and NAA tend to modify the plant morphological characters and help in getting higher seed yield coupled with better quality traits.

Coulombe and Rogers (1959) reported that foliar application of GA_3 hastened the physiological processes which resulted in early flowering, increased fruit weight and size. Singh and Choudhary (1966) revealed that GA_3 application in tomato var. Sioux improved the weight of fruits compared to other treatments. Tomar and Ramgiry (1997) found that plants treated with GA_3 recorded significantly higher number of fruits plant^{-1} and greater yield plant^{-1} than untreated controls. Damptey (1999) reported that exogenous application of 0.02% GA_3 increased the number of tomato fruits. According to Gemici *et al.* (2000), GA_3 treatment was quite effective in increasing fruit size. Pundir and Yadav (2001) sprayed 25 ppm GA_3 to improve growth characters, yield and yield components. Khan *et al.* (2006) indicated the significant role of GA_3 in tomato plant to increase fruit set, which led to larger number of fruits plant^{-1} and higher fruit size and final yield. Masroor *et al.* (2006) conducted a pot experiment to study the effect of four levels of gibberellic acid spray (0, 10^{-8}, 10^{-6} and 10^{-4} M GA_3) on the growth , yield and quality parameters of two tomato hybrids.

Irrespective of its concentration, spray of gibberellic acid proved beneficial for most of the parameters studied. Gelmesa *et al.* (2010) reported that the spray of GA_3 on blossom, increased the fruit set of tomato. Desai *et al.* (2012) studied the effect of different plant growth regulators and micronutrients on fruit characters and yield of tomato cv. Gujarat Tomato-3. Naphthalene acetic acid and Gibberellic acid gave the best results for fruit length, girth, pulp-seed ratio, fruit weight, yield plant^{-1} and yield hectare^{-1} than micronutrients. The maximum fruit length and girth was obtained with 75 ppm GA_3. Application of 100 ppm GA_3 recorded highest fruit yield plant^{-1} (1206.01g) over control (1101.69g). Shital *et al.* (2017) reported highest number of fruits plant^{-1} (31.06) with 50 ppm GA_3, compared to other growth regulators and control, in tomato. Application of 50 ppm GA_3 resulted in maximum length of fruit as well as diameter of fruit (4.32cm).

According to Yahaya and Gaya (2012), 300 ppm GA_3 significantly enhanced the growth, yield components as well as total yield of tomato. GA_3

applications improved number of fruits cluster^{-1}, fruit set, and marketable fruit plant^{-1} and extended maturity time and harvest (Gelmesa *et al.*, 2012). Prasad *et al.* (2013) observed that fruiting and yield parameters such as percent fruit set, number of fruits plant^{-1}, average fruit weight, length of fruit, fruit width and fruit yield ha^{-1} were increased with the application of GA_3 and NAA. Application of GA_3 and NAA checked the flower and fruit drop and ultimately increased the percent of fruit set and fruit yield hectare^{-1}. The maximum fruit yield (483.6 q/ha) was obtained with application of 80 ppm GA_3, closely followed by 1000 ppm NAA. The maximum number of fruit cluster^{-1} (4.62) was recorded from GA_3 at 40 ppm which was closely followed by 2, 4-D at 15 ppm, while the minimum numbers of fruits cluster^{-1}(3.42) was recorded from control (Verma *et al.*, 2014). Hasanuzzaman *et al.* (2015) revealed that application of 125 ppm GA_3, resulted in more fruits cluster^{-1}, fruits plant^{-1}, higher length and diameter of fruit, yield plant^{-1}, yield plot^{-1} and yield hectare^{-1}. Lutiel *et al.* (2015) recorded highest fruit length measured at 10 mgL^{-1} GA_3, but it was statistically similar to 15mg·L^{-1} GA_3 spray.

The highest fruit yield (12.29 kg/plot) was recorded for 30 ppm PCPA spray when three flowers in a cluster were opened, which was 28.6 % higher than control (Li *et al.*,1992). Tonder and Combrink (2003) observed that 4-CPA treatments produced higher truss weight and average fruit weight as well as larger number of tomatoes with greater diameters. Maximum fruit weight (38.88g) was observed for 50 ppm 4-CPA (Bokade, 2004). Poliquit and Diputandu (2007) noted that application of 4-CPA during anthesis period is more effective. Synthetic auxin 4-CPA reduced pre-harvest fruit drop, with increased number of fruits per plant and yield. Mahmood and Bahar (2008) noticed highest plant height, number of branches, number of fruits, fruit weight and dry matter with 100 mgL^{-1} 4-CPA, but the highest fresh weight and flower numbers were observed with 50 mg L^{-1} 4-CPA in two tomato cultivars, Binatomato-2 and Binatomato-3.

Tomato yield increased with the increase in the concentration of hormone applied in the range of 15 to 75 ppm in higher temperatures. Baliyan *et al.* (2013)

found that the total yield of tomato was the highest for 4-CPA at 75 ppm and 45 ppm followed by 15 ppm. 4-CPA at 75 ppm resulted in the highest fruit set (32.19 %). Shemu *et al.* (2014) observed that 2% tomatotone application resulted in the highest number of fruits plant^{-1}, length of fruit, weight of individual fruit, highest yield plant^{-1} and yield.

Two cherry type tomato cultivars when treated with 20 mgL^{-1} 4-CPA resulted in higher fruit set, and consequently higher marketable yield, in comparison with the control (Nandwani, 2015). Marketable fruit weight in treated plants increased by 60.1 % and 32.27 % respectively. Bhosle *et al.* (2002) obtained highest marketable yield from treatment with 25 ppm 4-CPA.

Sasaki *et al.* (2005) found that the mixture of 4-chlorophenoxyacetic acid and gibberellins in tomato increased the number of fruits. The maximum number of fruits plant^{-1}, single fruit weight, and yield were higher with the application of 20 ppm 4-CPA + 20 ppm GA_3 (Choudhury *et al.*, 2013).

2.2.4 Effect of application of growth regulators on fruit quality

Pundir and Yadav (2001) sprayed GA_3 at 25 ppm to improve the fruit quality of tomato cv. Punjab Chhuhara. Bokade (2004) indicated that the highest TSS was recorded for the treatment with application of GA_3 at 25 ppm. Application of GA_3 at 50 ppm recorded higher TSS (4.78°Bx) as well as Ascorbic acid content *i.e.* 26.15 mg 100 g^{-1} (Meena, 2008). In an experiment by Khan *et al.* (2006) to study the effect of four levels of GA_3 (0, 10^{-8}, 10^{-6} and 10^{-4} M GA_3) on the growth, yield and quality parameters of tomato hybrids, the interaction 10^{-8} M GA_3 x Hyb-SC-3 gave the maximum lycopene content compared to other treatments. Ghulam *et al.* (2006) treated tomato cv. Roma with foliar spray of GA_3 at 10^{-4} M exhibited higher productivity and performance in terms of nutrient content, plant height, plant vigour, dry weight and yield (1325.2 g). Higher total soluble solids was found in fruits obtained from 15mg L^{-1} GA_3 sprayed plants.

Graham and Ballesteros (2006) reported that GA_3 increased protein, soluble carbohydrates, ascorbic acid, starch and beta-carotene in tomato. Kataoka *et al*. (2009) reported that higher sugar content of tomato fruits was obtained from $50mg \cdot L^{-1}$ GA_3 treated plants. Maximum TSS (^{0}Bx) was found with 50 ppm GA_3 (4.95 ^{0}Bx) and minimum in control (Kumar *et al*., 2014). 4-CPA treatment significantly induced more abnormal fruits, especially puffy fruits than treatment with the mixture of 4-CPA and GA_3 (Sasaki *et al.*, 2005).

2.3 Combined effect of artificial pollination and application of growth regulators

Al-Attal *et al.* (2003) studied the effect of bumble bee pollination and plant growth regulator treatment on overall fruit set in tomato .The bumblebee pollination and PGR treatment recorded at par fruit set. Both bumblebee and PGR treatments gave significantly higher fruit set percentage than vibration and the control. Seed number per fruit was significantly higher in the bumblebee treatment (177.0) followed by vibration treatment (86.10). The lowest seed number was in the PGB treatment (61.8).

MATERIALS AND METHODS

3. MATERIALS AND METHODS

The present investigation "Enhancing fruit set and yield of tomato (*Solanum lycopersicum* L.) in polyhouse using artificial pollination and growth regulators" was carried out at the Department of Vegetable Science, College of Agriculture, Vellayani during 2017-2018.

The details of the materials used and methods adopted during the experiment are described in this chapter.

3.1. EXPERIMENTAL SITE

The experiment was conducted in a saw tooth type polyhouse of size 448 m^2 (28 m × 16 m) at to the Department of Vegetable Science, Vellayani. The framework was made of GI pipes and the roof was made of 200 micron UV stabilized polythene sheet.

3.2. EXPERIMENTAL PERIOD

The experiment was carried out during October 2017 to March 2018.

3.3. MATERIALS

The tomato variety "Akshaya" (semi determinate) was used for the experiment. Seeds were collected from the Department of Vegetable Science, College of Horticulture, Vellanikkara.

3.4. METHODS

3.4.1. Design and layout

The experiment was laid out as follows:

Design	: RBD
Replication	: 2
Treatment combinations	: 32
Spacing	: 60 cm x 60 cm
Plants/ plot	: 16
Plot size	: 5.76 m^2
Season	: October – March

3.4.2. Treatments

The experiment comprised of application of artificial pollination methods and growth regulators, either individually or in combination, as given in Table 1.

1) Artificial Pollination Methods (A)

1. A_1: Shaking
2. A_2: Air blowing
3. A_3: Vibratory pollination.
4. A_0: Control (No Artificial Pollination)

Artificial pollination methods were executed in morning hours daily, throughout the flowering period, by shaking the plant with hand or blowing air with the help of a blower (Plate 1) to the flower trusses or pollination through vibrating the flower truss with the help of an electrical vibrator (Plate 2).

Electric vibrator (VegiBee Garden Pollinators, model VBP-01) was used to vibrate flower clusters by touching the flower stalk for about two seconds. Air blower (Black & Decker model BPPT600) with an air volume of 3.5 m^3/minute with air outlet held 30 cm away from the tomato plant and operated by directing the air towards the flower clusters for ten seconds was used.

2) Application of Growth Regulators (G)

The two growth regulators used in the experiment were PCPA (Para chlorophenoxy acetic acid) and GA_3 (Gibberellic acid).

1. G_1: PCPA (10mgL^{-1})
2. G_2: PCPA (20 mgL^{-1})
3. G_3: PCPA (30 mgL^{-1})
4. G_4: GA_3 (20 mgL^{-1})
5. G_5: PCPA (10 mgL^{-1}) + GA_3 (20 mgL^{-1})
6. G_6: PCPA (20 mgL^{-1}) + GA_3 (20 mgL^{-1})
7. G_7: PCPA (30 mgL^{-1}) + GA_3 (20 mgL^{-1})
8. G_0: Control (No Spray)

Table 1. Treatment Combinations

A_1G_1	Shaking and application of PCPA (10 mgL^{-1})
A_1G_2	Shaking and application of PCPA (20 mgL^{-1})
A_1G_3	Shaking and application of PCPA (30 mgL^{-1})
A_1G_4	Shaking and application of GA_3 (20mgL^{-1})
A_1G_5	Shaking and application of PCPA (10 mgL^{-1}) + GA_3 (20 mgL^{-1})
A_1G_6	Shaking and application of PCPA (20 mgL^{-1}) + GA_3 (20 mgL^{-1})
A_1G_7	Shaking and application of PCPA (30 mgL^{-1}) + GA_3 (20 mgL^{-1})
A_1G_0	Shaking
A_2G_1	Air blowing and application of PCPA (10 mgL^{-1})
A_2G_2	Air blowing and application of PCPA (20 mgL^{-1})
A_2G_3	Air blowing and application of PCPA (30 mgL^{-1})
A_2G_4	Air blowing and application of GA_3 (20mgL^{-1})
A_2G_5	Air blowing and application of PCPA (10 mgL^{-1}) + GA_3 (20 mgL^{-1})
A_2G_6	Air blowing and application of PCPA (20 mgL^{-1}) + GA_3 (20 mgL^{-1})
A_2G_7	Air blowing and application of PCPA (30 mgL^{-1}) + GA_3(20 mgL^{-1})
A_2G_0	Air blowing
A_3G_1	Vibratory pollination and application of PCPA (10 mgL^{-1})
A_3G_2	Vibratory pollination and application of PCPA (20 mgL^{-1})
A_3G_3	Vibratory pollination and application of PCPA (30 mgL^{-1})
A_3G_4	Vibratory pollination and application of GA_3 (20mgL^{-1})
A_3G_5	Vibratory pollination and application of PCPA (10 mgL^{-1}) + GA_3 (20 mgL^{-1})
A_3G_6	Vibratory pollination and application of PCPA (20 mgL^{-1}) + GA_3 (20 mgL^{-1})
A_3G_7	Vibratory pollination and application of PCPA (30 mgL^{-1}) + GA_3(20 mgL^{-1})
A_3G_0	Vibratory pollination

A_0G_1	Application of PCPA (10 mgL^{-1})
A_0G_2	Application of PCPA (20 mgL^{-1})
A_0G_3	Application of PCPA (30 mgL^{-1})
A_0G_4	Application of GA_3 (20mgL^{-1})
A_0G_5	Application of PCPA (10 mgL^{-1}) + GA_3 (20 mgL^{-1})
A_0G_6	Application of PCPA (20 mgL^{-1}) + GA_3 (20 mgL^{-1})
A_0G_7	Application of PCPA (30 mgL^{-1}) + GA_3 (20 mgL^{-1})
A_0G_0	Control

3.4.3. Preparation of growth regulator solutions

The solutions of Gibberellic acid, GA_3 (20 mgL^{-1}) was prepared by dissolving 20 mg GA_3 in 10 ml 95% alcohol and then stirred with a glass rod, so that GA_3 would thoroughly mix and the volume was made up to 1000 ml in a volumetric flask.

Similarly Para chlorophenoxy acetic acid (10 mgL^{-1}, 20 mgL^{-1} and 30 mgL^{-1}) was prepared separately by dissolving 10 mg, 20 mg and 30 mg respectively, in distilled water and mixed thoroughly, the volume was made up to 1000 ml in a volumetric flask.

3.4.5. Time and method of spraying

Parachlorophenoxy acetic acid and Gibberellic acid, at specified concentrations were sprayed on to the flower trusses at fortnightly interval during the entire flowering period. Growth regulators were sprayed (six times) with the help of hand sprayer.

A spray volume of 3-5 ml per truss was applied. An interval of five hours was given on the same day between application of PCPA and GA_3 when both were applied to the same plant. Sprayer was washed thoroughly with distilled water after application of each treatment to avoid any contamination.

3.5. CULTURAL PRACTICES

3.5.1. Raising of seedlings

Tomato seedlings were raised in protrays (Plate 3) filled with potting mixture consisting of coir pith and vermicompost in 1:1 ratio. Thirty days old seedlings, with 4-5 true leaves and 10 cm height, were transplanted to the main field, at a spacing of 60 cm × 60 cm.

3.5.2. Preparation of land

The experimental area inside the polyhouse was ploughed thoroughly using tiller and brought to a fine tilth. Raised beds of size 23 m length and 1m width were prepared and incorporated with 100 kg cowdung,100 kg vermicompost and 2 ½ kg Rock Phosphate per m^2. The beds were levelled and covered with yellow coloured polythene mulch of 30 micron thickness (Plate 4). Holes were punched on the mulch, as per the spacing for transplanting seedlings.

The seedlings were transplanted on prepared beds in two rows (Plate 5). Sixteen plants were maintained in each plot.

3.6. CROP MANAGEMENT

3.6.1. Manures and fertilizers

Fertilizers were applied by fertigation once in three days from planting till the end of the crop. Fertigation schedule as recommended in KAU, (2013) was practiced and the schedule is attached as Appendix I.

3.6.2. Irrigation and climate control

Drip system of irrigation was followed in polyhouse. Misting was also adopted periodically.

3.6.3. Training and Pruning

Staking of plants was done to support the plants and to permit easier training operations (Plate 6). The plants were trained by plastic twine loosely anchored at the base of the plants with the help of the plastic clips and to overhead support wires running all along the length of the rows of the bed at gutter height.

3.6.4. Plant Protection

Following plant protection chemicals were sprayed on the plants when the incidence of pest and diseases was observed. Fruits were harvested at ripe stage

Dimethoate (Rogor) – 2.2 ml /L	Against thrips (vector for Tomato spotted wilt virus)
Thiamethoxam (Actara) – 4 g /10 L.	
Quinalphos (Ekalux) – 2ml/L	Against spodoptera incidence

Plate 1. Air blower

Plate 2. Electric vibrator

Plate 3. Protray seedlings ready for transplanting

Plate 4. Beds covered with mulch sheet

Plate 5. Transplanted seedlings

Plate 6. Staking in plants

Plate 7. Field View

Plate 8. Stages of experiment

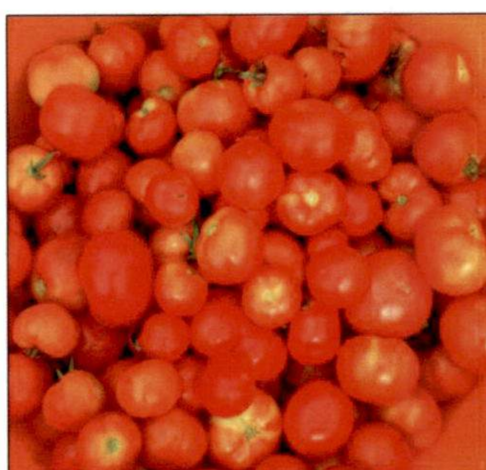
Flowering stage

Pollination using vibrator

Fruit set

Mature green stage

Harvest Stage



Harvested fruits

3.6.5. Harvesting

Fruits were harvested at ripe stage (Plate 8).

3.7 MAIN ITEMS OF OBSERVATION

Five plants from each plot were selected randomly for recording the observations on following aspects.

3.7.1. Vegetative Characters

3.7.1.1 Plant height (cm)

Height of the observational plants from the ground level to the top most leaf bud at the time of final harvest was recorded.

3.7.1.2. Height at flowering (cm)

Height of the observational plants from the ground level to the first flower bud at the time of first flowering was recorded.

3.7.1.3. Primary branches plant^{-1}

The total numberof primary branches of observational plants were counted and the average was worked out at the time of final harvest.

3.7.1.4. Leaf length (cm)

The fifth leaf from the top of the selected plants was used for recording the observation. The length was measured as the distance from the base of the petiole to the top of the leaf and expressed in centimeters.

3.7.1.5 Leaf width (cm)

The width of the same leaf that was used for recording the length was taken, at the region of maximum width.

3.7.2. Flowering Characters

3.7.2.1 Days to first flowering

Number of days from the date of transplanting to the first flowering of the observational plants was recorded and the average was worked out.

3.7.2.2 Days to fruit set

Three inflorescences were selected randomly and tagged from each observational plant and number of days taken from flowering to emergence of young fruits was noted and the average was worked out.

3.7.2.3 Flowers cluster^{-1}

Number of flowers per cluster was recorded from the same cluster tagged for making observations on days to fruit set and the average was recorded.

3.7.2.4 Inflorescences plant^{-1}

Total number of inflorescences per plant was recorded.

3.7.2.5 Fruit set (%)

Number of fruits present per cluster at fortnightly intervals after two weeks of flowering were recorded. Percentage fruit set was calculated and the average was worked out.

3.7.2.6 Pollen viability (%)

Pollen viability of tomato flowers was analysed using acetocarmine dye method and expressed in percentage (Shivanna and Rangaswamy, 1992).

3.7.2.7. Flowers with exserted stigma cluster^{-1} (%)

Number of flowers with stigma protruding outside the anther cone were counted and divided with total number of flowers per cluster to get percentage of flowers with exserted stigma.

3.7.3. Fruit Characters and Yield

3.7.3.1. Fruits plant^{-1}

Total number of fruits harvested per plant till last harvest was recorded and the average was calculated.

3.7.3.2. Fruits cluster^{-1}

Number of fruits per cluster was recorded from observational plants and the average was worked out .

3.7.3.3. Fruit length (cm)

Length of fruits was measured as the distance from pedicel attachment of the fruit to the apex using a digital Vernier Calipers.

3.7.3.4 Fruit girth (cm)

Fruit girth was taken from the same fruits used for recording the fruit length. Diameter was measured at the maximum width of the fruit using a digital Vernier Calipers. The average was worked out and expressed in centimeters.

3.7.3.5. Fruit weight (g)

Weight of fruits used for recording fruit length and girth was measured using an electronic balance and expressed in grams.

3.7.3.6. Yield plant^{-1} (g)

Weight of all fruits harvested from each observation plant per harvest was recorded and the total worked out and expressed in grams.

3.7 .3.7. Yield plot^{-1} (kg/m^2)

Total weight of all the fruits from each plot (5.76 m^2) per harvest was recorded and expressed as kilogram per square meter.

3.7.3.8. Number of seeds fruit^{-1}

Ten fruits were randomly selected from the tagged plants in each plot within the harvesting period. A sharp knife was used to divide each fruit and the seeds were removed, counted and the average was worked out.

3.7.3.9. Thousand seed weight (g)

The extracted seeds from ten fruits in each plot were dried under sun for three days and the weight of 1000 seeds were determined using an electronic balance.

3. 7. 4. Quality Characters

3.7.4.1. Abnormal fruits plant^{-1} (%)

Number of abnormal fruits present per plant was recorded. Percentage of abnormal fruits per plant was calculated as

$$\text{Abnormal fruits plant}^{-1}(\%) = \frac{\text{Number of abnormal fruits plant}^{-1}}{\text{Total number of fruits plant}^{-1}} \times 100$$

3.7.4.2. Titrable Acidity (%)

Total acids were estimated by the method of Ranganna (1986).

***Preparation of sample*:**

Sample was pulped in a blender or in mortar and mixed thoroughly. To the weighed pulped material, water was added and boiled for 1 hr. replacing the water lost by evaporation. It was cooled, filtered and transferred to a 250 ml volumetric flask and made volume.

Procedure:

An aliquot of sample prepared as above was diluted with recently boiled distilled water. It was then titrated with 0.1 N NaOH using a few drops of 1 per cent phenolphthalein solution as indicator. Titre value was noted and the results were calculated as percent citric acid.

$$\text{Titratable acidity (\%)} = \frac{\text{Titre x Normality of alkali x Vol. made up x Eq. Wt. of acid x 100}}{\text{Vol. of sample taken x Wt. or vol. of sample taken x 1000}}$$

3.7.4.3. Total Soluble Solids (°Bx)

Total soluble solids of tomato fruits was recorded using a Hand Refractometer (Erma Japan) (0-32°Brix). A drop of tomato juice was used to determine TSS and the value was expressed in °Bx.

3.7.4.4. Lycopene (µg/100g)

Lycopene content of the fruits was estimated at the full ripe stage by the following method of Srivastava and Kumar (1994) .

Reagents

Acetone, petroleum ether (40-60 degree celcius), anhydrous sodium sulphate and five percent sodium sulphate

Procedure

Tomato fruits were crushed with the help of pestle and mortar and pulped it well to a smooth consistency in a blender. Five to ten grams of this pulp was weighed and the pulp was extracted repeatedly with acetone using pestle and mortar until the residue became colourless. The acetone extracts were pooled and transferred to a separating funnel containing about 20 ml petroleum ether and gently mixed. About 20 ml of 5% sodium sulphate solution were added and the separating funnel shaken gently. Volume of petroleum ether was reduced during the process because of its evaporation hence 20 ml more of petroleum ether was added to the separating funnel for the clear separation of two layers. Most of the colour was noticed in the upper petroleum ether layer. The two phases were separated and the lower aqueous phase was re-extracted with additional 20 ml petroleum ether until the aqueous phase changed colourless. The petroleum ether extracts was pooled and washed once with little distilled water. The washed petroleum extracts containing carotenoids was poured into a brown bottle containing about ten gram anhydrous sodium sulphate and kept it aside for 30 minutes. The petroleum ether extracts was decanted into a 100 ml volumetric flask through a funnel containing cotton wool .

Sodium sulphate slurry was washed with petroleum ether until it was colourless and the washings were transferred to the volumetric flask. The volume was made up and absorbance was measured in a spectrophotometer at 503 nm using petroleum ether as blank.

$$\text{Lycopene } (\mu g/100g) = \frac{31.06 \times \text{Absorbance}}{\text{Weight of sample (g)}} \times 1000$$

3.7.4.5. Vitamin C / Ascorbic Acid (mg/100g)

Ascorbic acid content of fruit was estimated by 2,6 – dichlorophenol indophenol dye method (Sadasivam and Manickam, 1996) .

Reagents

1. Oxalic acid
2. Ascorbic acid (standard)

Stock solution was prepared by dissolving 100 mg ascorbic acid in 100 ml of 4% oxalic acid. Ten millilitre of this stock solution was diluted to 100 ml with 4% oxalic acid to get working standard solution

3. 2,6-dichloropheno indophenol dye.

Forty two milligram sodium bicarbonate was dissolved in a small volume of distilled water fifty two milligram of 2,6 dichlorophenol indophenol dye was added into this and made up to 200ml with distilled water.

4. Working standard

Ten millilitre of stock solution was diluted to 100 ml with four per cent oxalic acid .The concentration of working standard was 100 mg per ml.

Procedure

Five ml of working standard solution was pippeted out into a 100 ml conical flask and 10 ml 4% oxalic acid was added. This was titrated against the dye (V_1). End point was the appearance of pink colour which persisted for atleast five seconds.
Five grams of fresh fruits was extracted in four per cent oxalic acid medium, the extract was filtered and volume was made up to 100 ml using oxalic acid. From this five ml of aliquot was taken ,10 ml 4% oxalic was added and titrated as above against the dye and the end point (V_2) was determined.

Ascorbic acid content of the sample was calculated using the formula

$$\text{Amount of ascorbic acid (mg/100g)} = \frac{0.5 \times V_2 \times 100}{V_1 \times 5 \times \text{weight of sample}} \times 100$$

3.8. STATISTICAL ANALYSIS

Data collected were statistically analysed using OPSTAT for Two factorial ANOVA.

RESULTS

4. RESULTS

The experiment entitled "Enhancing fruit set and yield of tomato (*Solanum lycopersicum* L.) in polyhouse using artificial pollination and growth regulators" was carried out at the Department of Vegetable Science, College of Agriculture, Vellayani during 2017-2018. The results of observations taken during vegetative , flowering and fruiting stages along with yield and fruit quality characters of tomato variety "Akshaya" as influenced by different methods of artificial pollination, growth regulators and their interactions are presented in this chapter.

4.1 Vegetative characters

Effect of artificial pollination methods, growth regulators and their interaction on vegetative characters are depicted in tables 2, 3 and 4 respectively.

4.1.1 Plant Height (cm)

Artificial pollination methods did not influence plant height. Among growth regulators, application of PCPA 30 mgL^{-1} + GA_3 20 mgL^{-1} produced tallest plant (324.90 cm) which was statistically similar to PCPA 10 mgL^{-1} + GA_3 20 mgL^{-1} (303.10 cm) and PCPA 20 mgL^{-1} + GA_3 20 mgL^{-1} (296.72 cm). The lowest plant height (231.90 cm) was observed when PCPA 20 mgL^{-1} was sprayed which was on par with control (248.05 cm). Interaction effect of artificial pollination and growth regulators was non significant.

4.1.2. Height at flowering (cm)

Artificial pollination was executed after flowering. Application of growth regulators at various concentrations and their interactions with artificial pollination methods did not influence height at flowering. Average height of the plant at flowering was 48.38 cm.

Table 2. Effect of artificial pollination on vegetative characters

Pollination Methods	Plant height (cm)	Primary branches $plant^{-1}$	Leaf length (cm)	Leaf width (cm)
Shaking (A_1)	271.39	4.22	34.04	21.74
Air blowing (A_2)	257.01	4.38	34.20	21.64
Vibratory pollination (A_3)	273.69	4.25	33.92	21.65
Control (A_0)	272.79	4.12	34.39	21.95
Mean	268.72	4.24	34.14	21.74
SE(m)	9.61	0.07	0.21	0.23
C D (0.05)	NS	NS	NS	NS

*NS – Non significant

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Table 3. Effect of growth regulators on vegetative characters

Pollination Methods	Plant height (cm)	Height at flowering (cm)	Primary branches $Plant^{-1}$	Leaf length (cm)	Leaf width (cm)
PCPA (10 mgL^{-1}) (G_1)	249.55	48.11	4.17	32.96	21.21
PCPA (20 mgL^{-1}) (G_2)	231.90	48.57	4.17	33.25	20.97
PCPA (30 mgL^{-1}) (G_3)	251.95	47.92	4.22	33.01	21.12
GA_3 (20 mgL^{-1}) (G_4)	243.58	48.59	4.35	33.92	21.23
PCPA (10 mgL^{-1}) + GA_3 (20 mgL^{-1}) (G_5)	303.10	48.75	4.10	34.32	21.56
PCPA (20 mgL^{-1}) + GA_3 (20 mgL^{-1}) (G_6)	296.72	48.29	4.35	35.17	22.56
PCPA (30 mgL^{-1}) + GA_3 (20 mgL^{-1}) (G_7)	324.90	49.08	4.17	37.85	23.65
Control (G_0)	248.05	47.70	4.40	32.64	21.65
Mean	268.72	48.37	4.24	34.14	21.74
SE(m)	13.60	0.48	0.10	0.30	0.33
C D(0.05)	39.40	NS	NS	0.87	0.95

*NS – Non significant

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Table 4. Interaction effect of artificial pollination and growth regulators on vegetative characters

Interaction treatments	Plant height (cm)	Height at flowering (cm)	Primary branches plant^{-1}	Leaf length (cm)	Leaf width (cm)
A_1G_1	231.30	48.67	4.00	31.98	21.02
A_1G_2	209.20	48.80	4.30	33.94	20.09
A_1G_3	268.70	46.98	4.10	32.79	21.51
A_1G_4	257.00	48.44	4.20	34.89	21.11
A_1G_5	310.30	46.61	4.10	35.59	21.65
A_1G_6	310.30	50.39	4.10	32.86	22.47
A_1G_7	325.00	48.51	4.40	37.98	24.25
A_1G_0	259.30	46.01	4.60	32.33	21.83
A_2G_1	220.50	48.36	4.70	33.41	21.43
A_2G_2	260.30	47.87	4.00	33.02	20.47
A_2G_3	245.30	48.35	4.30	33.05	21.07
A_2G_4	234.80	48.54	4.40	33.61	21.00
A_2G_5	267.90	50.04	4.10	33.72	21.13
A_2G_6	279.20	47.27	4.40	36.51	22.28
A_2G_7	301.00	49.46	4.50	37.53	23.77
A_2G_0	247.10	49.15	4.60	32.80	21.99
A_3G_1	263.20	47.39	4.00	32.52	21.19
A_3G_2	218.80	48.27	4.30	33.76	21.05
A_3G_3	248.60	46.72	4.20	33.10	21.43
A_3G_4	248.30	48.84	4.90	34.19	22.06
A_3G_5	303.40	49.93	4.00	33.59	21.08
A_3G_6	307.00	47.48	4.60	35.47	21.73
A_3G_7	338.90	48.66	3.80	36.09	22.96
A_3G_0	261.30	48.72	4.20	32.64	21.68
A_0G_1	283.20	48.03	4.00	33.92	21.23
A_0G_2	239.30	49.33	4.10	32.28	22.28
A_0G_3	245.20	49.63	4.22	33.11	20.48

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A_0G_4	234.20	48.56	4.35	32.98	20.76
A_0G_5	330.80	48.44	4.10	34.40	22.38
A_0G_6	290.40	48.03	4.35	35.86	23.76
A_0G_7	334.70	49.69	4.17	39.79	23.62
A_0G_0	224.50	46.9	4.40	32.80	21.65
Mean	268.72	48.37	3.9	34.14	21.7
SE(m)	27.20	0.96	0.21	0.60	0.66
CD(0.05)	NS	NS	NS	NS	NS

*NS – Non significant

4.1.3. Primary branches plant^{-1}

Artificial pollination methods, application of growth regulators and their interactions did not induce any significant difference on number of primary branches per plant. Average number of primary branches plant^{-1} were 3.90.

4.1.4. Leaf length (cm)

The effect of artificial pollination method was not significant for leaf length. However, various concentrations of growth regulators influenced leaf length and the longest leaf (37.85 cm) was observed for the combination of PCPA 30 mgL^{-1} + GA_3 20 mgL^{-1}.Untreated plants exhibited the shortest leaf (32.64 cm) and individual application of PCPA could not make significant improvement in leaf length irrespective of concentrations. Interaction of artificial pollination and growth regulator application did not significantly influence leaf length.

4.1.5. Leaf width (cm)

Artificial pollination methods did not influence leaf width. PCPA 30 mgL^{-1} + GA_3 20 mgL^{-1} exhibited maximum leaf width (23.65 cm). Other treatments did not exert any significant change in leaf width compared to control. The minimum leaf width was observed for PCPA at 20 mgL^{-1} (20.97 cm) as given in Table 3. Interaction of artificial pollination and growth regulator application did not significantly influence leaf length (Table 4).

4.2 Flowering Characters

Effect of artificial pollination methods growth regulators and their interactions on flowering characters are depicted in tables 5, 6 and 7 respectively.

4.2.1. Days to first flowering

None of the treatments or its interactions influenced days to first flowering. The plants started to flower 24 days after transplanting.

4.2.2.Days to fruit set

Artificial pollination method, application of growth regulators and their interactions did not influence days to fruit set. Average number of days taken for fruit set was 8.41.

4.2.3 Flowers cluster^{-1}

The effect of artificial pollination, growth regulators and their interaction on flowers cluster^{-1} was non significant. The mean number of flowers per cluster was 7.53 as shown in the Table 7.

4.2.4 Inflorescence plant^{-1}

Artificial pollination did not influence the number of inflorescence in a plant. Application of PCPA 30 mgL^{-1} + GA_3 20 mgL^{-1} recorded more inflorescence plant^{-1} (17.27) which was on par with PCPA 20 mgL^{-1} + GA_3 20 mgL^{-1} (15.57) and GA_3 20mgL^{-1}(15.17). Minimum number of inflorescence (12.85) was observed when PCPA at 10 mgL^{-1} was sprayed which was on par with PCPA 20 mgL^{-1}(13.80), PCPA 30 mgL^{-1}(14.97)and PCPA 10 mgL^{-1} + GA_3 20 mgL^{-1} (14.55) as given in Table 6. Interaction of artificial pollination and growth regulator could not produce significant changes in number of inflorescences in a plant.

4.2.5.Fruit set (%)

Vibratory pollination produced the maximum fruit set (67.35 %) . Minimum fruit set percent (59.29 %) was recorded for control. Shaking or air blowing could not improve fruit set.

Application of PCPA 30 mgL^{-1} resulted in maximum fruit set percent (66. 34 %) and it was on par with PCPA 10 mgL^{-1} + GA_3 20 mgL^{-1} (65.40 %) and PCPA 30 mgL^{-1} + GA_3 20 mgL^{-1} (65.04 %) and PCPA 20 mgL^{-1} + GA_3 20 mgL^{-1} (62.25 %) as given in Table 6. The minimum fruit set percent (58.41 %) was observed in control and application of PCPA 10 mgL^{-1}, PCPA 20 mgL^{-1} and GA_3 20 mgL^{-1} could not improve fruit set. Interaction of artificial pollination methods and growth regulators could not induce any significant difference (Table 7).

4.2.6. Pollen viability (%)

Artificial pollination methods did not significantly influence pollen viability. Application of PCPA 30 mgL^{-1} produced maximum viable pollen (64.19 %) . Similar increase in pollen viability was shown by PCPA 20 mgL^{-1} (63.34 %), PCPA 10 mgL^{-1} + GA_3 20 mgL^{-1} (63.08 %) and PCPA 20 mgL^{-1} + GA_3 20 mgL^{-1} (61.66 %), which were at par. Application of PCPA 10 mgL^{-1}, PCPA 30 mgL^{-1}+ GA_3 20 mgL^{-1} could not improve pollen viability. Untreated plants recorded minimum pollen viability (57.39 %). Interaction between artificial pollination methods and growth regulator applications did not influence pollen viability (Table 7 and Plate 9).

4.2.7. Flowers with exserted stigma cluster^{-1} (%)

Artificial pollination methods could not influence the number of flowers with exserted stigma. Minimum number of flowers with exserted stigma (25.72 %) was produced by application of PCPA 20 mgL^{-1} + GA_3 20 mgL^{-1} which was on par with PCPA 30 mgL^{-1} (28.56 %) , GA_3 20 mgL^{-1} (28.65%) and PCPA 10 mgL^{-1} + GA_3 20 mgL^{-1} (29.33%). Application of PCPA 10 mgL^{-1}, PCPA 20 mgL^{-1}, PCPA 30 mgL^{-1} + GA_3 20 mgL^{-1} did not reduce the number of flowers with exserted stigma in comparison to control (39.11%). Interaction effect was non significant as depicted in Table 7 and Plate 10.

Table 5. Effect of artificial pollination on flowering characters

Pollination Methods	Days to first flowering	Days to fruit set	Flowers Cluster^{-1}	Inflorescence Plant^{-1}	Fruit set (%)	Pollen viability (%)	Flowers with exserted stigma cluster^{-1} (%)
Shaking (A_1)	24.00	8.35	7.30	14.96	60.81	59.78	25.11 (5.71)
Air blowing (A_2)	24.10	8.51	7.69	14.94	61.33	61.79	31.46 (5.70)
Vibratory Pollination (A_3)	24.11	8.41	7.43	14.77	67.35	60.83	33.36 (5.86)
Control (A_0)	23.75	8.39	7.70	14.41	59.29	62.73	29.38 (5.51)
Mean	24.00	8.41	7.53	14.77	62.19	61.28	31.49 (5.70)
SE(m)	0.17	0.09	0.15	0.53	1.16	1.03	(0.15)
C D(0.05)	NS	NS	NS	NS	3.37	NS	NS

*Values in parenthesis are square root transformed value *NS – Non significant

Table 6. Effect of growth regulators on flowering characters

Growth Regulators	Days to first flowering	Days to Fruit set	Flowers $Cluster^{-1}$	Inflorescence $Plant^{-1}$	Fruit set (%)	Pollen viability (%)	Flowers with exserted stigma $cluster^{-1}$ (%)
PCPA (10 mgL^{-1}) (G_1)	23.97	8.20	7.72	12.85	59.72	60.56	32.79 (5.81)
PCPA (20 mgL^{-1}) (G_2)	23.77	8.50	7.40	13.80	60.71	63.34	35.30 (6.02)
PCPA (30 mgL^{-1}) (G_3)	23.95	8.57	8.00	14.97	66.34	64.19	28.56 (5.43)
GA_3 (20 mgL^{-1}) (G_4)	24.00	8.30	7.32	15.17	59.68	59.77	28.65 (5.44)
PCPA(10mgL^{-1})+ GA_3 (20mgL^{-1}) (G_5)	24.10	8.62	7.65	14.55	65.40	63.08	29.33 (5.50)
PCPA(20mgL^{-1})+ GA_3 (20 mgL^{-1}) (G_6)	24.00	8.45	7.20	15.57	62.25	61.66	25.72 (5.17)
PCPA(30mgL^{-1})+ GA_3 (20 mgL^{-1}) (G_7)	24.12	8.22	7.65	17.27	65.04	60.27	33.03 (5.83)
Control (G_0)	24.00	8.45	7.30	13.97	58.41	57.39	39.11 (6.33)
Mean	24.00	8.41	7.53	14.78	62.20	61.30	31.49 (5.70)
SE(m)	0.25	0.13	0.15	0.75	1.64	1.46	(0.21)
C D(0.05)	NS	NS	NS	2.18	4.76	4.25	(0.63)

*Values in parenthesis are square root transformed value *NS – Non significant

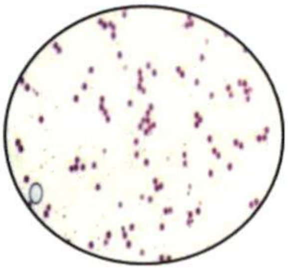
Table 7. Interaction effect of artificial pollination and growth regulators on flowering character

Interaction treatments	Days to first flowering	Days to fruit set	Flowers Cluster^{-1}	Inflorescence Plant^{-1}	Fruit set (%)	Pollen viability (%)	Flowers with exserted stigma cluster^{-1} (%)
A_1G_1	24.10	8.10	7.00	13.50	56.63	59.50	32.65 (5.80)
A_1G_2	23.60	8.50	6.90	13.80	53.94	62.35	29.45 (5.52)
A_1G_3	24.00	8.60	7.40	11.30	63.46	59.49	28.58 (5.71)
A_1G_4	24.60	8.30	7.00	17.70	62.08	53.36	27.82 (5.36)
A_1G_5	24.90	8.40	7.40	16.50	64.25	61.25	39.80 (6.38)
A_1G_6	23.00	8.20	7.40	15.00	61.65	65.07	25.45 (5.14)
A_1G_7	24.10	8.40	7.60	18.00	65.53	63.83	30.34 (5.59)
A_1G_0	23.70	8.30	7.70	13.90	59.00	53.43	36.92 (6.15)
A_2G_1	23.70	8.50	8.40	11.90	57.26	59.68	29.47(5.52)
A_2G_2	24.10	8..50	7.20	14.30	62.34	65.83	37.15(6.17)
A_2G_3	23.70	8.50	9.40	16.70	65.63	64.85	30.40 (5.60)
A_2G_4	24.10	8.50	7.40	15.60	55.56	59.46	24.49 (5.04)
A_2G5	23.90	8.60	7.80	14.00	68.04	66.16	29.00 (5.47)
A_2G_6	24.60	8.90	6.70	16.10	60.81	58.08	31.26 (5.6)
A_2G_7	24.40	8.40	6.80	16.80	66.77	66.11	40.26 (6.42)
A_2G_0	24.30	8.20	7.80	14.100	54.26	54.17	30.95 (5.65)
A_3G_1	24.50	7.90	7.10	13.10	68.82	63.46	33.75 (5.89)
A_3G_2	23.70	8.40	7.70	14.20	69.35	61.20	42.34 (6.58)
A_3G_3	24.60	8.60	7.40	16.80	72.44	64.86	31.60 (5.71)
A_3G_4	23.40	8.50	7.50	15.40	61.90	60.87	31.02 (5.65)
A_3G_5	23.70	8.90	7.70	13.50	68.07	61.46	21.44 (4.73)
A_3G_6	24.80	7.90	7.00	15.50	65.88	61.96	24.44 (5.04)
A_3G_7	24.40	8.60	8.10	16.50	66.53	53.28	37.31 (6.19)

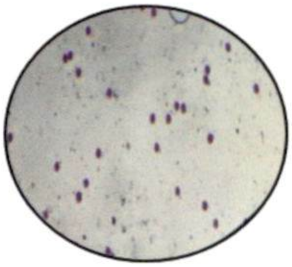
A_3G_0	23.80	8.30	7.00	13.20	65.78	59.59	49.06 (7.07)
A_0G_1	23.60	8.60	8.40	12.90	56.20	59.62	35.44 (6.03)
A_0G_2	23.70	8.60	7.80	12.90	57.22	64.34	32.86 (5.81)
A_0G_3	23.50	7.90	7.80	15.10	63.83	64.19	21.25 (4.71)
A_0G_5	23.90	8.20	7.70	14.20	61.25	63.08	28.45 (5.42)
A_0G_6	23.60	8.20	7.70	15.70	60.69	61.66	22.15 (4.81)
A_0G_7	23.60	8.20	8.10	17.80	61.33	60.27	25.23 (5.12)
A_0G_0	24.20	8.70	6.70	14.70	54.61	57.39	40.60 (6.45)
Mean	24.00	8.41	7.53	14.77	62.20	61.29	29.36 (5.51)
SE(m)	0.50	0.27	0.21	1.50	3.30	2.93	(0.43)
CD(0.05)	NS	NS	NS	NS	NS	NS	NS

*Values in parenthesis are square root transformed value *NS – Non significant

Plate 9. Pollen viability



PCPA (30 mgL^{-1})



Control

Plate 10. Flowers with exserted stigma $cluster^{-1}$

PCPA(20 mgL^{-1})+GA_3(20 mgL^{-1})

Control

Plate 11. Fruits $cluster^{-1}$

Vibratory pollination

Control

4.3. Fruit charaters and yield

Effect of artificial pollination methods, growth regulators and their interactions on fruit characters and yield are depicted in tables 8, 9 and 10 respectively.

4.3.1. Fruits cluster^{-1}

The highest number of fruits cluster^{-1} (6.60) was produced by vibratory pollination. Shaking the plants or blowing air to trusses could not alter the number of fruits per cluster. Application of growth regulators did not influence the total number of fruits per cluster as shown in Table 9. The interaction effect was also found to be non-significant (Table 10 and Plate 11).

4.3.2. Fruits plant^{-1}

Vibratory pollination method produced the maximum number of fruits per plant (45.69) which was on par with air blowing (41.50) as depicted in Table 8. Shaking the plants failed to produce any significant impact compared to control.

Significant variation was recorded for growth regulator applications on fruits per plant with maximum number of fruits being recorded for PCPA 30 mgL^{-1} + GA_3 20 mgL^{-1} (45.45) which was on par with GA_3 20 mgL^{-1} (41.12), PCPA 20 mgL^{-1} +GA_3 20 mgL^{-1} (41.07) , PCPA 30 mgL^{-1} (41.00) and PCPA 10 mgL^{-1} + GA_3 20 mgL^{-1} (39.32). Application of PCPA 10 mgL^{-1} or PCPA 20 mgL^{-1} did not produce more fruits than control (Table 9). Interaction effect also failed to increase the number of fruits per plant(Table 10 and Plate 12).

4.3.3. Fruit length

Fruit length was maximum (6.63 cm) for vibratory pollination. Shaking did not alter the length of fruit compared to control. Application of PCPA 30 mgL^{-1} +

GA_3 20 mgL^{-1} produced maximum fruit length (6.90 cm) which was on par with PCPA at 10 mgL^{-1} (6.74 cm), PCPA 20 mgL^{-1} + GA_3 20 mgL^{-1} (6.66 cm) and PCPA 10 mgL^{-1} + GA_3 20 mgL^{-1}(6.58 cm). Application of PCPA 20 mgL^{-1}, PCPA 30 mgL^{-1} and GA_3 20 mgL^{-1} failed to produce any significant improvement in fruit length than control. Interaction effects were non significant (Plate 13).

4.3.4. Fruit girth

The vibratory pollination method recorded maximum fruit girth (15.02 cm). Shaking and air blowing did not significantly alter the girth of fruits.

The maximum fruit girth was observed for PCPA 30 mgL^{-1} + GA_3 20 mgL^{-1} (15.65 cm) which was on par with PCPA 20 mgL^{-1} + GA_3 20 mgL^{-1} (14.79 cm) , PCPA 30 mgL^{-1} (14.64 cm) and PCPA 20 mgL^{-1} (14.57 cm). Application of PCPA 10 mgL^{-1}, GA_3 20 mgL^{-1}, PCPA 10 mgL^{-1} + GA_3 20 mgL^{-1} did not improve fruit girth in comparison to control. Interaction effect between pollination methods and growth regulators was non significant (Plate 14).

4.3.5. Fruit weight

Fruit weight did not significantly vary due to artificial pollination methods. Fruit weight was maximum for PCPA 20 mgL^{-1} (40.97 g) which was on par with PCPA 30 mgL^{-1} (39.46 g), PCPA 20 mgL^{-1} + GA_3 20 mgL^{-1} (38.86 g), PCPA 10 mgL^{-1}(38.76 g), PCPA 30 mgL^{-1} + GA_3 20 mgL^{-1} (37.24 g) and GA_3 20 mgL^{-1} (36.17 g). Application of PCPA 10 mgL^{-1} + GA_3 20 mgL^{-1} failed to improve fruit weight than control (33.23 g) as depicted in Table 9. Interaction between artificial pollination and growth regulator application did not significantly influence the weight of fruits (Plate 15).

4.3.6. Yield plant^{-1} (g)

The highest yield per plant (1311.75 g) among artificial pollination methods was recorded where vibratory pollination method was adopted. Shaking and air blowing could not improve the yield compared to control. Among growth regulators, application of PCPA 30 mgL^{-1} + GA_3 20 mgL^{-1} recorded highest yield (1487.50 g) which was on par with PCPA 20 mgL^{-1} + GA_3 20 mgL^{-1} (1283.00 g). Other growth regulator treatments did not improve yield plant^{-1} in comparison to control and lowest yield was recorded by GA_3 at 20 mgL^{-1} (927.25 g). Interaction between artificial pollination and growth regulators did not influence yield per plant (Table 10).

4.3.7. Yield plot^{-1}(kg m^{-2})

As depicted in Table 8, the highest yield per plot (2.90 kg m^{-2}) was recorded when pollinated using vibrator compared to other methods of pollination. Shaking and air blowing could not improve yield per plot.

It was observed that PCPA 30 mgL^{-1} + GA_3 20 mgL^{-1} produced maximum yield per plot (3.47 kg m^{-2}) which was statistically similar to PCPA 20 mgL^{-1} + GA_3 20 mgL^{-1} (2.94 kg m^{-2}). Application of other growth regulator treatments either individually or in combinations did not significantly improve yield per plot. Interaction between artificial pollination methods and growth regulator application could not influence yield per plot.

4.3.8. Number of seeds fruit^{-1}

Vibratory pollination produced maximum number of seeds per fruit (131.94) . Shaking (102.66) and air blowing (111.76) could not significantly change the number of seeds in the fruit than obtained from control (102.30) (Plate 16).

Application of growth regulator treatments except GA_3 20 mgL^{-1}(121.95) significantly reduced number of seeds in fruit in comparison to control (137.40). The

Table 8. Effect of artificial pollination on fruit characters and yield

Pollination Methods	Fruits $Cluster^{-1}$	Fruits $plant^{-1}$	Fruit length (cm)	Fruit girth (cm)	Fruit weight (g)	Yield $plant^{-1}$ (g)	Yield $plot^{-1}$ (kg/m^2)	Number of seeds $fruit^{-1}$	Thousand seed weight (g)
Shaking (A_1)	5.11	33.96	6.472	13.78	34.53	1023.06	2.23	102.66	3.19
Air blowing (A_2)	5.19	41.50	6.41	14.26	34.56	1081.56	2.44	111.76	3.21
Vibratory pollination (A_3)	6.60	45.69	6.63	15.02	42.05	1311.75	2.90	131.94	3.21
Control (A_0)	5.22	34.75	6.25	14.23	33.86	1071.76	2.24	102.30	3.20
Mean	5.53	38.98	6.44	14.32	36.25	1122.03	2.45	112.16	3.20
SE(m)	0.16	1.93	0.09	0.27	2.30	72.34	0.17	4.90	0.01
C D(0.05)	0.47	5.59	0.28	0.80	NS	209.63	0.50	14.22	NS

*NS – Non significant

Table 9. Effect of growth regulator on fruit characters and yield

Growth Regulators	Fruits Cluster^{-1}	Fruits plant^{-1}	Fruit length (cm)	Fruit girth (cm)	Fruit weight (g)	Yield plant^{-1} (g)	Yield plot^{-1} (kg/m^2)	Number of seeds fruit^{-1}	Thousad seed weight (g)
PCPA (10 mgL^{-1}) (G_1)	5.57	37.07	6.74	14.15	38.76	1030.75	2.31	106.20	3.20
PCPA (20 mgL^{-1}) (G_2)	5.30	36.75	6.49	14.57	40.97	1012.25	2.22	111.15	3.19
PCPA (30 mgL^{-1})(G_3)	5.57	41.00	6.38	14.64	39.46	1161.62	2.24	109.85	3.19
GA_3 (20 mgL^{-1}) (G_4)	5.27	41.12	6.35	13.85	36.17	927.25	2.12	121.95	3.18
PCPA(10 mgL^{-1}) + GA_3 (20mgL^{-1}) (G_5)	5.77	39.32	6.58	13.81	33.23	1129.52	2.28	98.50	3.21
PCPA(20 mgL^{-1}) + GA_3 (20 mgL^{-1}) (G_6)	5.40	41.07	6.66	14.79	38.86	1283.00	2.94	105.98	3.20
PCPA(30 mgL^{-1}) + GA_3 (20 mgL^{-1}) (G_7)	6.17	45.45	6.90	15.65	37.24	1487.50	3.47	106.30	3.22
Control (G_0)	5.17	30.00	6.15	13.13	25.32	944.37	2.04	137.40	3.21
Mean	5.52	38.98	6.53	14.32	36.25	1122.03	2.45	99.66	3.20
SE(m)	0.23	2.72	0.13	0.39	3.24	102.30	0.24	6.94	0.02
C D(0.05)	NS	7.91	0.4	1.13	9.40	296.46	0.71	20.11	NS

*NS–Nonsignificant

Table 10. Interaction effect of artificial pollination and growth regulators on fruit characters and yield

Interaction treatments	Fruits Cluster^{-1}	Fruits plant^{-1}	Fruit length (cm)	Fruit girth (cm)	Fruit weight (g)	Yield Plant^{-1} (g)	Yield Plot^{-1} (kg/m^2)	Number of Seeds fruit^{-1}	Thousand Seed Weight (g)
A_1G_1	5.30	30.50	6.77	13.60	35.44	1112.00	2.57	103.90	3.26
A_1G_2	5.00	30.10	6.27	14.37	44.10	913.50	1.95	117.60	3.16
A_1G_3	5.50	35.10	6.36	13.43	34.79	1157.50	2.23	93.60	3.15
A_1G_4	5.50	35.60	5.90	13.37	32.73	673.00	1.67	103.90	3.13
A_1G_5	4.70	34.90	6.40	12.27	24.47	1090.00	2.23	71.60	3.17
A_1G_6	4.90	39.90	6.44	13.60	33.42	1164.50	2.75	97.30	3.21
A_1G_7	5.10	41.60	7.34	16.55	46.00	1163.50	2.58	110.30	3.17
A_1G_0	4.90	24.00	6.10	13.08	25.3	910.50	1.89	123.10	3.23
A_2G_1	5.20	36.10	6.24	13.25	29.09	833.00	1.89	93.10	3.18
A_2G_2	4.70	39.30	6.50	15.13	42.90	905.00	2.07	117.10	3.21
A_2G_3	4.70	38.20	6.51	14.66	40.15	1071.50	2.05	114.60	3.21
A_2G_4	5.10	46.80	6.62	14.26	37.36	880.50	2.18	132.50	3.19
A_2G5	5.70	43.00	6.43	13.99	32.54	1247.50	2.63	103.60	3.20
A_2G_6	5.50	46.50	6.74	14.97	39.30	1236.50	2.76	92.80	3.20
A_2G_7	5.70	45.00	6.66	13.89	27.12	1547.50	3.87	93.10	3.21
A_2G_0	4.90	37.10	6.28	13.92	28.06	931.00	2.04	147.30	3.22
A_3G_1	6.40	44.30	7.170	15.600	47.47	1239.500	2.76	128.70	3.17
A_3G_2	6.50	48.60	6.96	15.28	43.68	1272.50	2.83	120.90	3.24
A_3G_3	6.80	52.00	6.71	15.98	46.97	1220.00	2.52	130.90	3.17
A_3G_4	6.20	40.40	6.90	15.01	45.17	1423.00	3.18	143.70	3.21
A_3G_5	7.10	47.10	7.04	14.63	38.91	1203.00	2.55	111.00	3.24
A_3G_6	6.00	45.90	6.81	15.11	41.11	1435.00	3.05	118.60	3.22
A_3G_7	7.60	54.80	6.89	14.95	42.74	1735.50	4.11	126.20	3.26
A_3G_0	6.20	32.40	6.36	13.63	30.39	965.50	2.17	175.50	3.13

A_0G_1	5.40	37.40	6.80	14.17	43.05	938.50	2.02	99.10	3.20
A_0G_2	5.00	29.00	6.23	13.49	33.21	958.00	2.05	89.00	3.14
A_0G_3	5.30	38.70	5.94	14.49	35.93	1197.50	2.16	100.30	3.23
A_0G_4	4.30	41.70	5.97	12.76	29.41	732.50	1.43	107.70	3.19
A_0G_5	5.60	32.30	6. 45	14.34	37.02	977.60	1.73	107.80	3.21
A_0G_6	5.20	32.00	6.64	15.50	41.63	1296.00	3.19	115.20	3.15
A_0G_7	6.30	40.40	6.71	17.23	33.12	1503.50	3.33	95.60	3.24
A_0G_0	4.70	26.50	5.85	11.89	17.50	970.50	2.04	103.70	3.24
Mean	5.52	38.98	6.5	14.32	36.25	1122.03	2.45	103.83	3.20
SE(m)	0.46	5.45	0.27	0.78	6.50	204.60	0.49	13.88	0.05
CD(0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS

*NS – Non significant

Plate 12. Fruits $plant^{-1}$

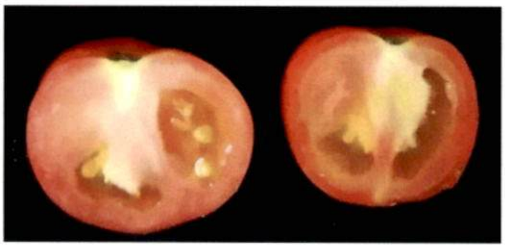
Vibratory pollination
PCPA (30 mgL^{-1}) +GA_3 (20 mgL^{-1})

Vibratory pollination
PCPA (20 mgL^{-1}) +GA_3 (20 mgL^{-1})

Plate 13.Fruit length

PCPA(30 mgL^{-1}) +GA_3 (20 mgL^{-1})

PCPA(20 mgL^{-1}) +GA_3 (20 mgL^{-1})

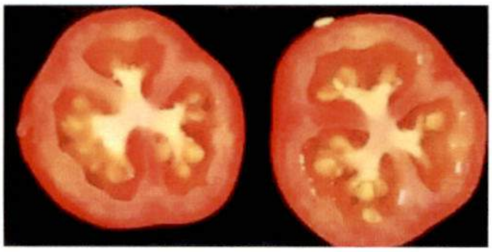


Control

Plate 14. Fruit girth

PCPA(30 mgL^{-1}) +GA_3 (20 mgL^{-1})

PCPA(20 mgL^{-1}) +GA_3 (20 mgL^{-1})



Control

Plate 15. Fruit weight

PCPA (20 mgL^{-1})

PCPA (30 mgL^{-1})

PCPA (10 mgL^{-1})

GA_3 (20 mgL^{-1})

PCPA(20 mgL^{-1}) +GA_3 (20 mgL^{-1})

PCPA(30 mgL^{-1}) +GA_3 (20 mgL^{-1})

Plate 16. Number of seeds $fruit^{-1}$

Vibratory pollination

Control

Control

PCPA(10 mgL^{-1}) +GA_3 (20mgL^{-1})

lowest number of seeds was recorded for PCPA 10 mgL^{-1} +GA_3 20 mgL^{-1} (98.50) which was on par with PCPA 20 mgL^{-1}(111.15), PCPA 30 mgL^{-1} (109.85), PCPA 20 mgL^{-1} + GA_3 20 mgL^{-1} (105.98) and PCPA 30 mgL^{-1}+ GA_3 20 mgL^{-1} (106.30) Interaction effect was non significant as depicted in Table 10.

4.3.9. Thousand seed weight (g)

Artificial pollination methods, growth regulator application as well as their interactions could not influence thousand seed weight. The mean thousand seed weight recorded was 3.20 g as given in Table 10

4.4. Fruit quality

Effect of artificial pollination methods growth regulators and their interactions on fruit quality characters are depicted in tables 11, 12 and 13 respectively.

The number of abnormal fruits per plant was not influenced by any of the artificial pollination methods (Table 11). Application of growth regulator PCPA 30 mgL^{-1} (9.99) and PCPA 30 mgL^{-1} + GA_3 20 mgL^{-1} (9.06) enhanced abnormality. Other growth regulator treatments did not produce significant number of abnormal fruits as depicted in Table 12 and Plate 17. Interaction between pollination methods and growth regulators were non significant in producing abnormal fruits.

Fruit quality attributes like total soluble solids, titrable acidity, vitamin C as well as lycopene did not show any significant variation with artificial pollination methods, growth regulator treatments as well as their interactions as depicted in Table 11, 12 and 13. Mean values of 4.09 °Bx TSS, 0.57 % titrable acidity, 21.67 mg/100g vitamin C and 3641.37 μg/100g lycopene content was recorded.

Table 11. Effect of artificial pollination on fruit quality

Pollination Methods	Abnormal fruits $plant^{-1}$ (%)	Total Soluble Solids (°Bx)	Titrable Acidity (%)	Vitamin C (mg/100g)	Lycopene (μg/100g)
Shaking (A_1)	7.97	3.94	0.57	21.58	3629
Air blowing (A_2)	8.24	4.04	0.57	21.80	3604
Vibratory pollination (A_3)	7.73	4.20	0.57	21.54	3645
Control (A_0)	8.26	4.20	0.57	21.77	3689
Mean	8.05	4.09	0.57	21.67	3641.75
SE(m)	0.24	0.14	0.002	0.15	2.04
C D(0.05)	NS	NS	NS	NS	NS

*NS – Non significant

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Table 12. Effect of growth regulator on fruit quality

Growth Regulators	Abnormal fruits $plant^{-1}$ (%)	Total Soluble Solids (°Bx)	Titrable Acidity (%)	Vitamin C (mg/100g)	Lycopene (µg/100g)
PCPA (10 mgL^{-1}) (G_1)	7.88	4.19	0.57	21.46	3640
PCPA (20 mgL^{-1}) (G_2)	7.79	4.19	0.58	21.88	3625
PCPA (30 mgL^{-1}) (G_3)	9.99	4.18	0.57	21.69	3610
GA_3 (20 mgL^{-1}) (G_4)	7.05	4.08	0.57	21.64	3705
PCPA(10 mgL^{-1}) + GA_3 (20mgL^{-1}) (G_5)	6.66	4.12	0.57	21.95	3752
PCPA(20 mgL^{-1}) + GA_3 (20 mgL^{-1}) (G_6)	8.43	4.17	0.57	21.41	3602
PCPA(30 mgL^{-1}) + GA_3 (20 mgL^{-1}) (G_7)	9.06	4.14	0.57	22.03	3610
Control (G_0)	7.53	3.69	0.57	21.33	3587
Mean	8.04	4.09	0.57	21.67	3641.37
SE(m)	0.35	0.21	0.003	0.22	2.63
CD(0.05)	1.01	NS	NS	NS	NS

*NS – Non significant

Table 13.Interaction effect of artificial pollination and growth regulators on fruit quality

Interaction treatments	Abnormal fruits plant^{-1} (%)	Total Soluble Solids (°Bx)	Titrable Acidity (%)	Vitamin C (mg/100g)	Lycopene (µg/100g)
A_1G_1	7.19	4.12	0.56	21.12	3540
A_1G_2	7.50	4.13	0.57	21.60	3710
A_1G_3	10.66	4.29	0.57	21.66	3490
A_1G_4	6.56	4.10	0.56	21.28	3850
A_1G_5	7.15	4.27	0.56	21.08	3700
A_1G_6	9.23	4.17	0.57	21.44	3690
A_1G_7	8.89	4.29	0.57	21.76	3600
A_1G_0	6.56	2.12	0.57	21.68	3450
A_2G_1	8.01	4.23	0.57	22.00	3600
A_2G_2	7.71	4.25	0.58	20.87	3460
A_2G_3	9.13	3.98	0.56	22.48	3700
A_2G_4	6.87	4.01	0.57	21.84	3750
A_2G5	6.95	3.92	0.57	21.83	3550
A_2G_6	10.24	4.26	0.56	21.60	3630
A_2G_7	9.11	3.79	0.58	21.58	3490
A_2G_0	7.90	4.16	0.57	22.24	3650
A_3G	7.55	4.16	0.57	21.28	3830
A_3G_2	8.35	4.22	0.57	22.56	3650
A_3G_3	9.36	4.28	0.58	21.20	3550
A_3G_4	6.81	3.98	0.57	21.84	3520
A_3G_5	6.16	4.22	0.57	22.76	3820
A_3G_6	6.70	4.33	0.57	20.66	3530
A_3G_7	8.82	4.6	0.56	22.84	3660

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A_3G_0	8.09	4.19	0.57	21.21	3600
A_0G_1	8.76	4.26	0.58	21.43	3590
A_0G_2	7.59	4.17	0.58	22.48	3680
A_0G_3	10.81	4.18	0.57	21.44	3700
A_0G_4	7.96	4.08	0.56	21.60	3700
A_0G_5	6.39	4.12	0.57	22.15	3940
A_0G_6	7.55	4.17	0.58	20.95	3560
A_0G_7	9.42	4.14	0.56	22.96	3690
A_0G_0	7.59	3.69	0.58	21.20	3650
Mean	8.04	4.09	0.57	21.67	3641.5
SE(m)	2.04	0.41	0.005	0.44	2.84
CD(0.05)	NS	NS	NS	NS	NS

*NS – Non significant

Plate 17. Abnormal fruits

DISCUSSION

5. DISCUSSION

The investigation titled "Enhancing fruit set and yield of tomato (*Solanum lycopersicum* L.) in polyhouse using artificial pollination and growth regulators" was carried out at the Department of Vegetable Science, College of Agriculture, Vellayani to enhance the fruit set and yield of tomato in polyhouse through artificial pollination and application of plant growth regulators. The results obtained from the present investigation are discussed in this chapter.

Tomato is one of the most popular and nutritious vegetable crops all over the world. The polyhouse environment may provide a new scope for commercial production of tomato under Kerala conditions. However, poor pollination is regarded as a major cause of low fruit set, undersized fruits and low yield in greenhouse cultivation of tomato. In order to improve the fruit set and yield, different mechanical and chemical methods have been tried in greenhouses. Different methods of artificial pollination and growth regulators influenced growth and yield of tomato variety "Akshaya" in vegetative, flowering and fruiting stages as discussed below.

5.1 Vegetative characters

The vegetative characters like plant height, leaf length and leaf width were significantly influenced by growth regulator application as depicted in Fig.1, Fig.2 and Fig.3 respectively. PCPA 30 mgL^{-1} + GA_3 20 mgL^{-1} and PCPA 20 mgL^{-1} + GA_3 20 mgL^{-1} were at par in producing tallest plants. Application of PCPA 30 mgL^{-1} + GA_3 20 mgL^{-1} resulted in longer and wider leaves. Similar increase in plant height was reported by Choudhury *et al.* (2013) where the tallest plant was recorded from combined application of GA_3 and 4-CPA (PCPA). The beneficial influence of growth regulator especially at higher concentration of 4-CPA on increasing plant height have also been reported by Mahmood and Bahar (2008) and Taiz *et al.* (2010).

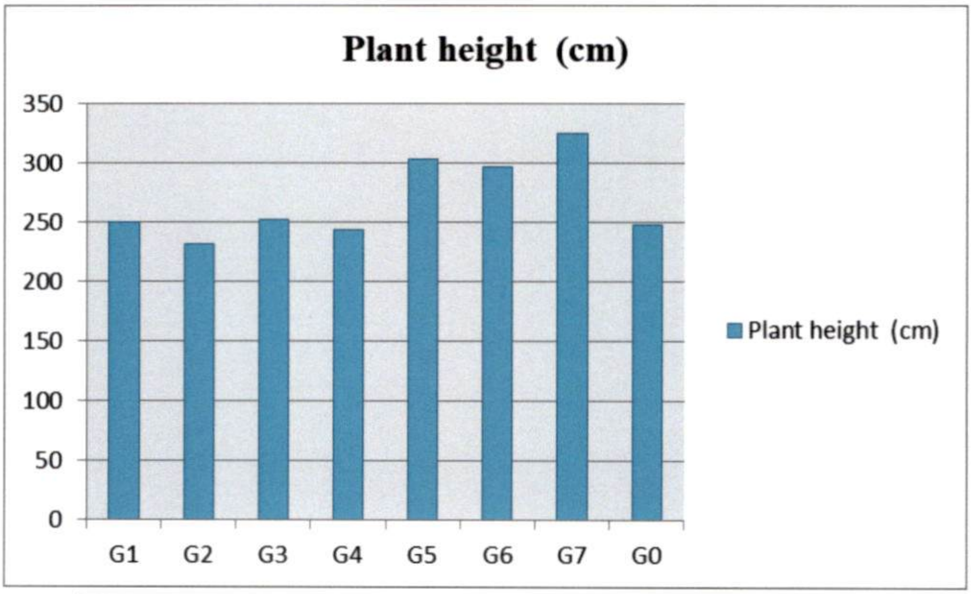

Figure 1. Effect of growth regulators on plant height

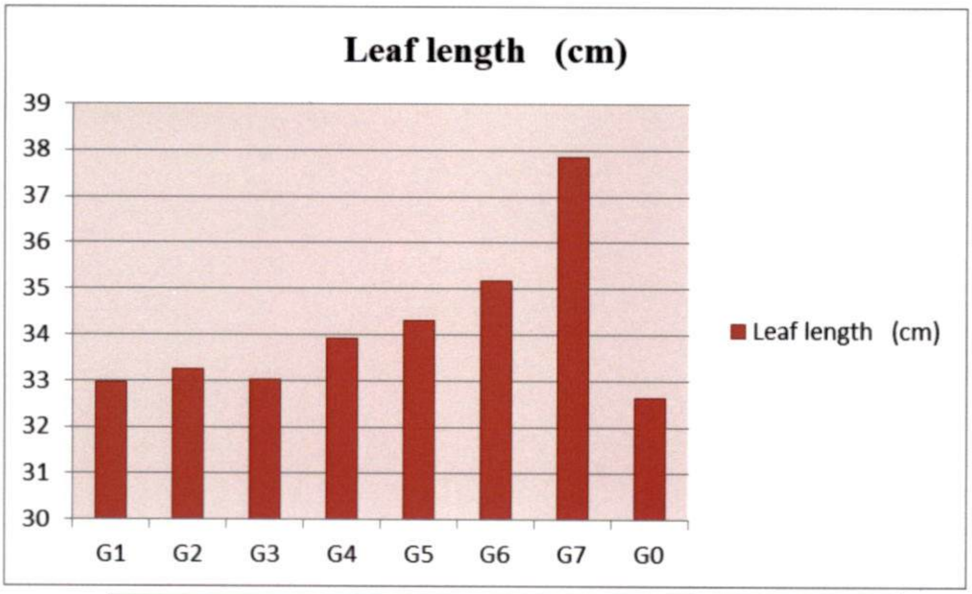

Figure 2. Effect of growth regulators on leaf length

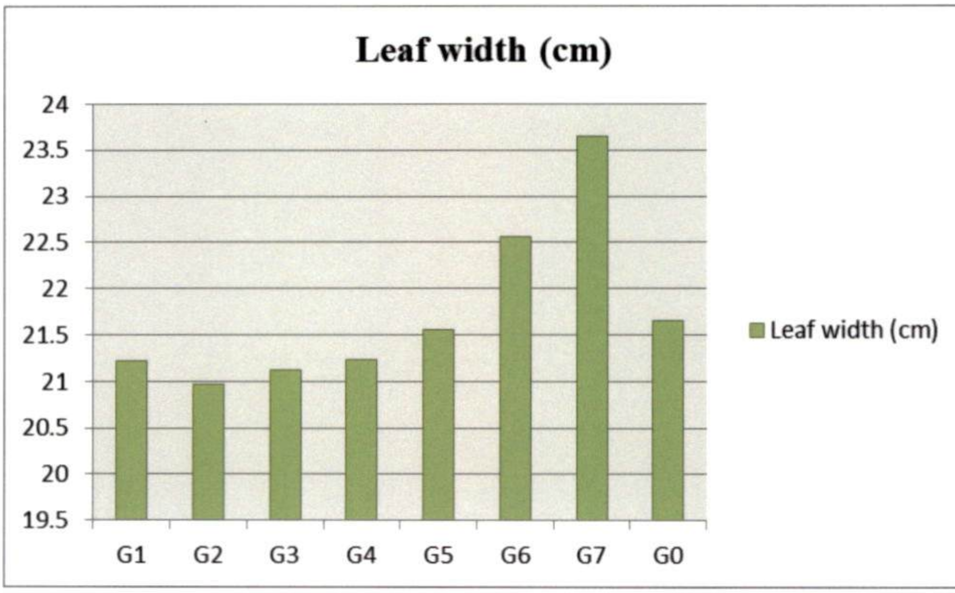

Figure 3. Effect of growth regulators on leaf width

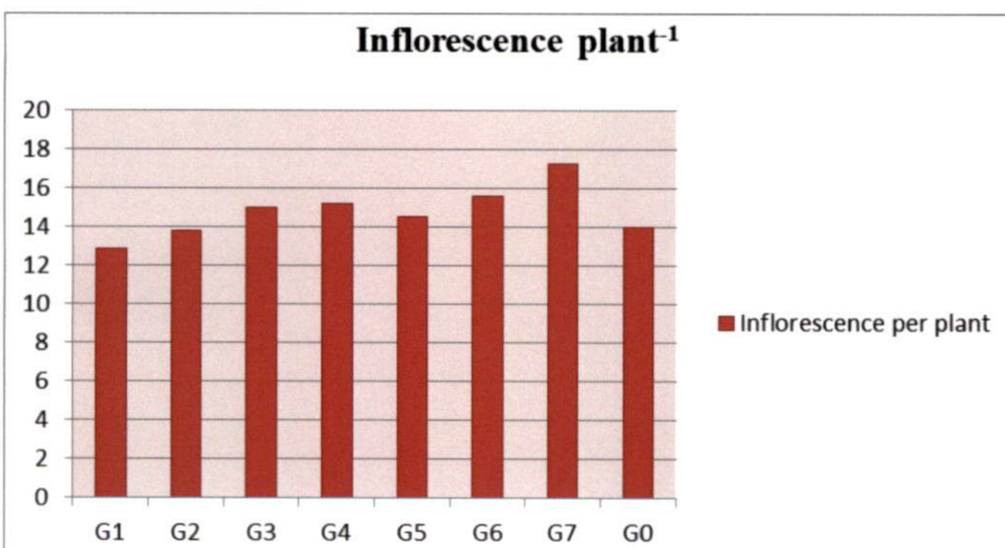

Figure 4. Effect of of growth regulators on inflorescence plant^{-1}

According to Katyan (2017) GA_3 tends to increase the cell division and cell size which results in increase in morphological parameters like size of leaves. Effect of GA_3 and PCPA in improving vegetative growth was supported by Tiwari *et al.*, (2005) who attributed the increased vegetative parameters to enhanced photosynthetic area of plants. Similar findings were reported by Kumar *et al.* (2014) where the highest plant height and number of leaves were exhibited by application of 50 ppm GA_3.

5.2 Flowering Characters

Artificial pollination methods and growth regulators significantly influenced flowering characters as depicted in Fig.4, Fig.5, Fig.6, Fig.7 and Fig.8 .

Vibratory pollination had a positive effect on fruit set compared to other methods of pollination. Pollination using vibrator produced maximum fruit set (67.35 %). Shaking and blowing air on flower trusses could not improve fruit set significantly. However, Palma *et al.* (2008) observed that mechanical vibration resulted in a fruit setting similar to that obtained with insect pollination. Pinillos and Cuevas (2008) also observed that flower vibrators helps to release more pollen from anthers, thus improving fruit set in greenhouse tomato production.

Among growth regulator treatments higher inflorescence plant^{-1} was recorded for PCPA 30 mgL^{-1} + GA_3 20 mgL^{-1} which was on par with PCPA 20 mgL^{-1} + GA_3 20 mgL^{-1} and GA_3 20 mgL^{-1}. Individual application of PCPA irrespective of the concentrations failed to improve inflorescence plant^{-1}. The result indicated that GA_3 alone as well in combination with PCPA increased the number of inflorescence per plant compared to other treatments. Similar results were obtained by Megbo (2010) where tomato plants treated with GA_3 increased the number of inflorescences per plant by 28% as compared to the control.

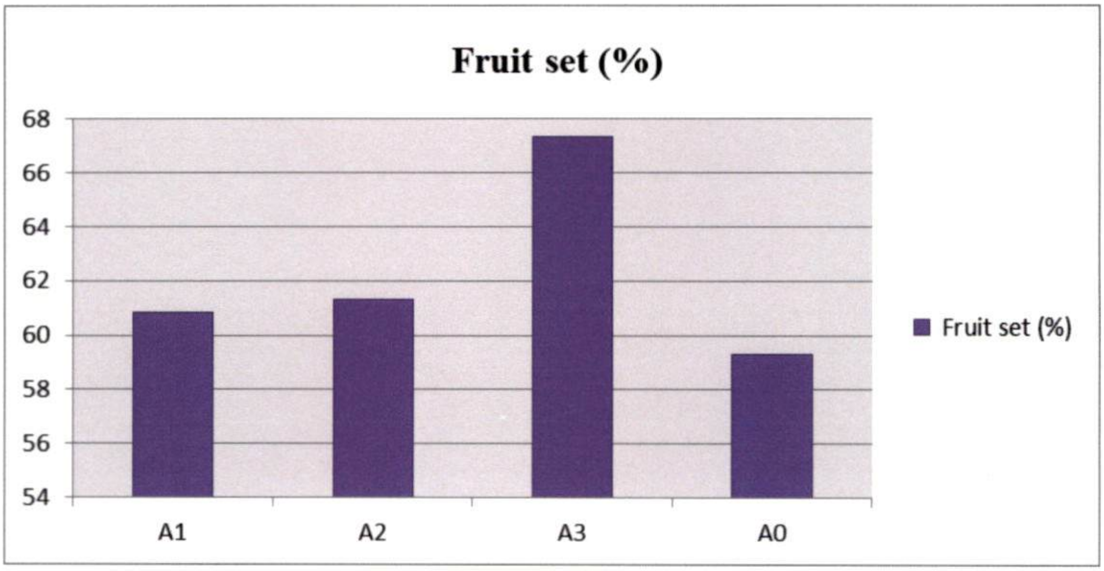

Figure 5. Effect of artificial pollination on fruit set

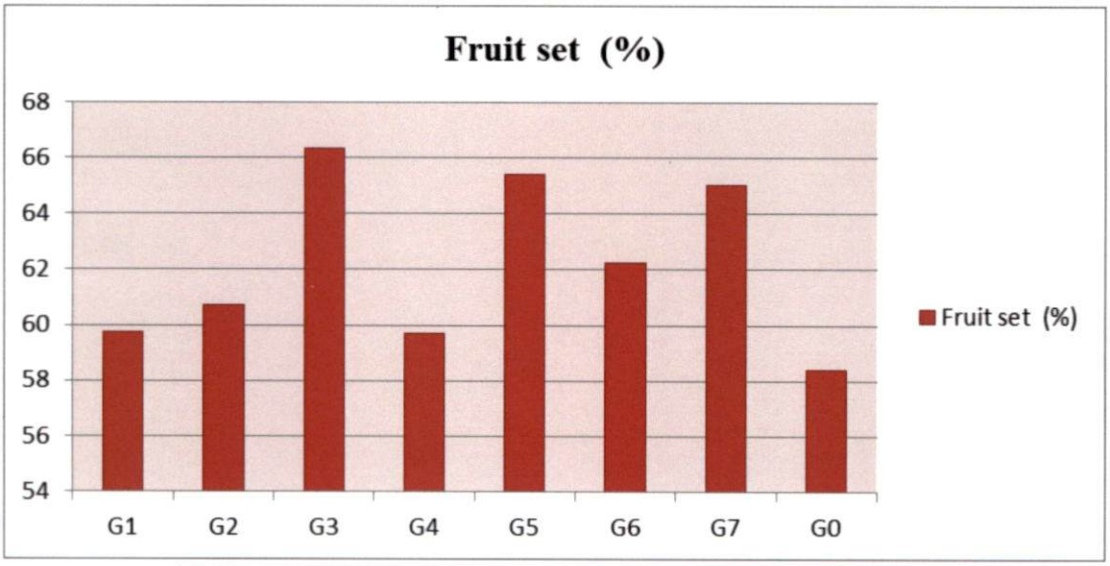

Figure 6. Effect of growth regulators on fruit set

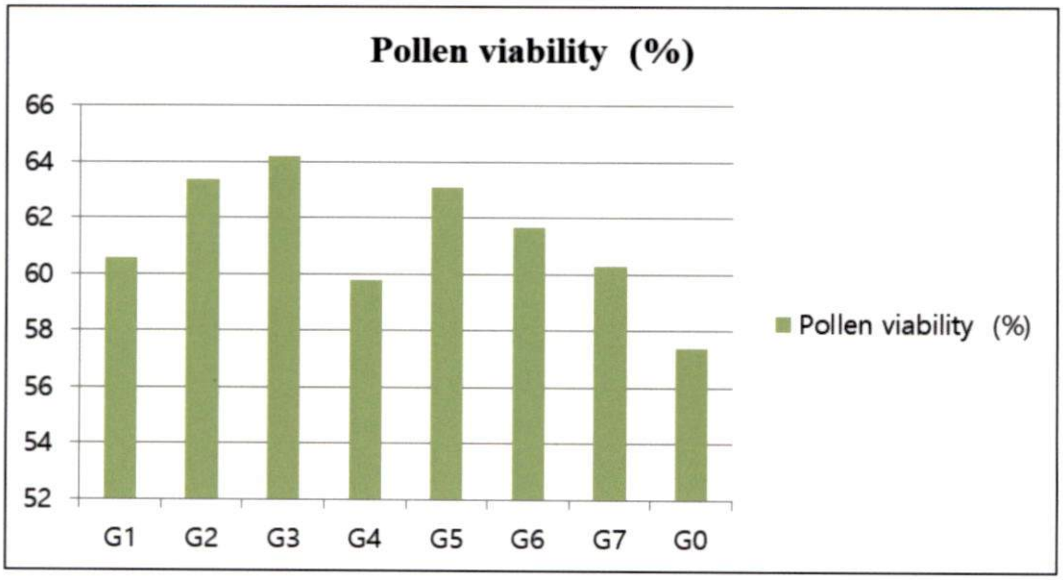

Figure 7. Effect of growth regulators on pollen viability

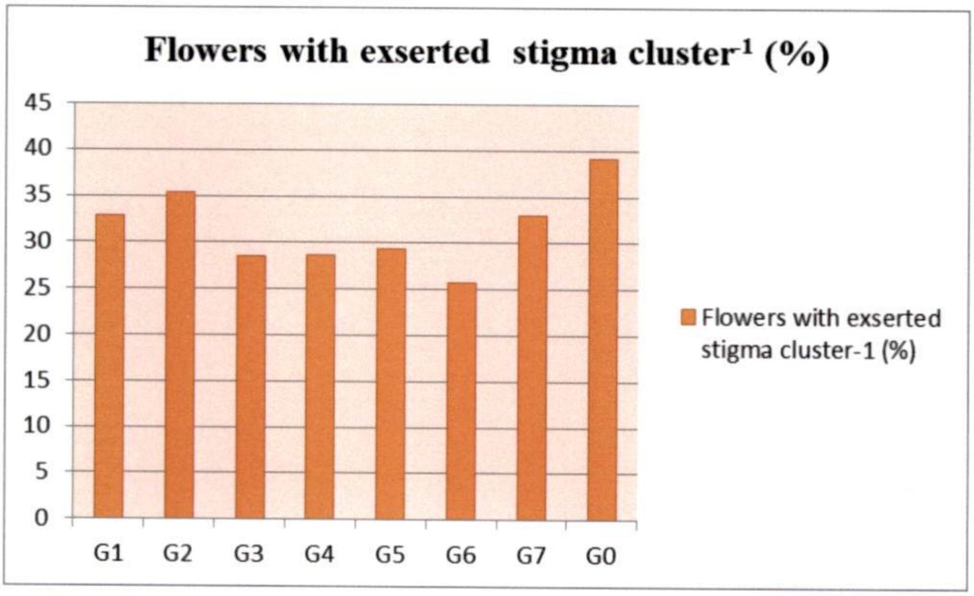

Figure 8. Effect of growth regulators on flowers with exserted stigma cluster $^{-1}$

The effect of growth regulators on fruit set was highly significant in which PCPA 30 mgL^{-1}, PCPA 10 mgL^{-1} + GA_3 20 mgL^{-1} , PCPA 20 mgL^{-1} + GA_3 20 mgL^{-1} and PCPA 30 mgL^{-1} + GA_3 20 mgL^{-1} were at par in improving fruit set. The results obtained were in partial agreement with the results of Baliyan *et al.* (2013), where fruit set increased by 75ppm 4-CPA application. Application of 20ppm GA_3 also increased fruit set (Adlakha and Verma, 1965). However effect of combined application of these growth regulators was reported by Sasaki *et al.* (2005), where tomato plants treated with a mixture of 4-CPA and GA_3 increased fruit set.

Treatment PCPA 30 mgL^{-1}, PCPA 20 mgL^{-1}, PCPA 10 mgL^{-1} + GA_3 20 mgL^{-1} and PCPA 20 mgL^{-1} + GA_3 20 mgL^{-1} was at par for producing more viable pollen. The flower trusses treated with PCPA 10 mgL^{-1}, GA_3 20 mgL^{-1} and PCPA 30 mgL^{-1} + GA_3 20 mgL^{-1} did not exhibit higher pollen viability.

The result indicated that the application of growth hormones reduced number of flowers with exserted stigma $cluster^{-1}$. PCPA 20 mgL^{-1} + GA_3 20 mgL^{-1}, PCPA 30 mgL^{-1}, GA_3 20 mgL^{-1} and PCPA 10 mgL^{-1} + GA_3 20 mgL^{-1} were equally effective in reducing flowers with exserted stigma. However, PCPA 10 mgL^{-1}, PCPA 20 mgL^{-1}, PCPA 30 mgL^{-1} + GA_3 20 mgL^{-1} were not effective in reduction of flowers with exserted stigma. Interaction effect was also non significant. The existence of perfect anther cones in tomato favors the effect of vibration with higher ovule fertilization and seed and fruit formation (Nuez, 2001).

5.3. Fruit Characters and yield

Effect of artificial pollination methods and growth regulators on fruit and yield characters like fruits $cluster^{-1}$, fruits $plant^{-1}$, fruit length, fruit girth, fruit weight, yield $plant^{-1}$ and number of seeds $fruit^{-1}$ are depicted in Fig.9, Fig.10, Fig.11, Fig.12, Fig.13, Fig.14, Fig.15, Fig.16, Fig.17, Fig.18 and Fig.19 respectively.

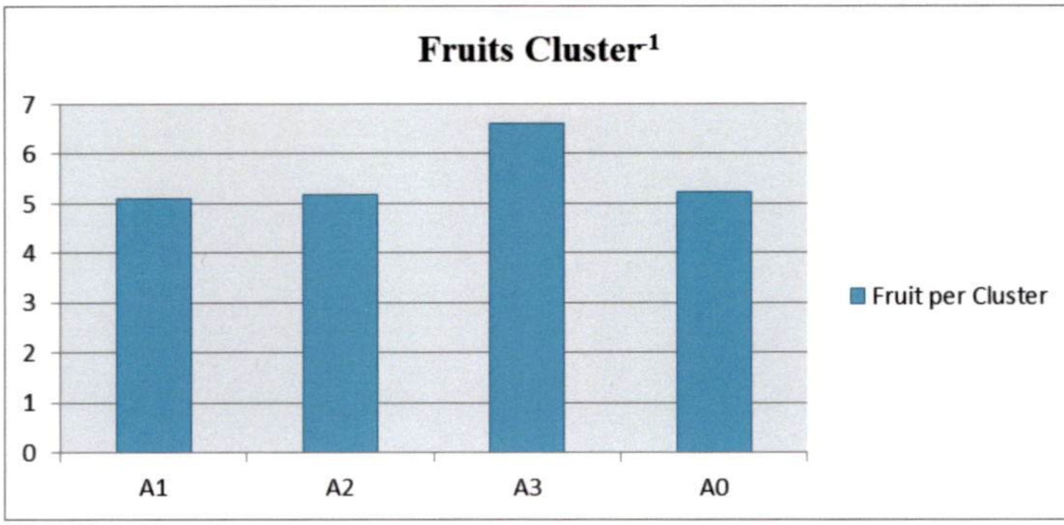

Figure 9. Effect of artificial pollination on fruits cluster^{-1}

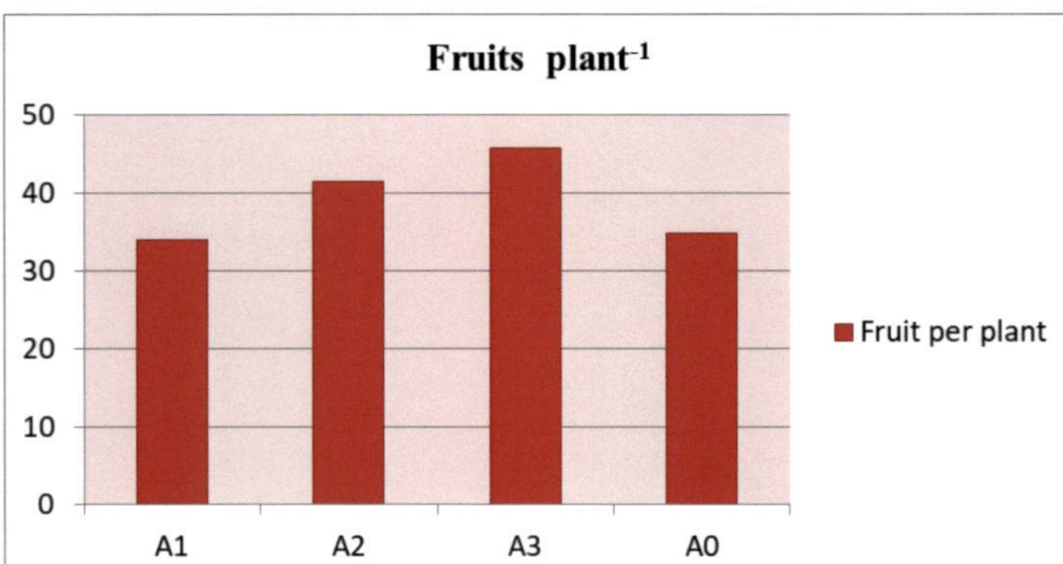

Figure 10. Effect of artificial pollination on fruits plant^{-1}

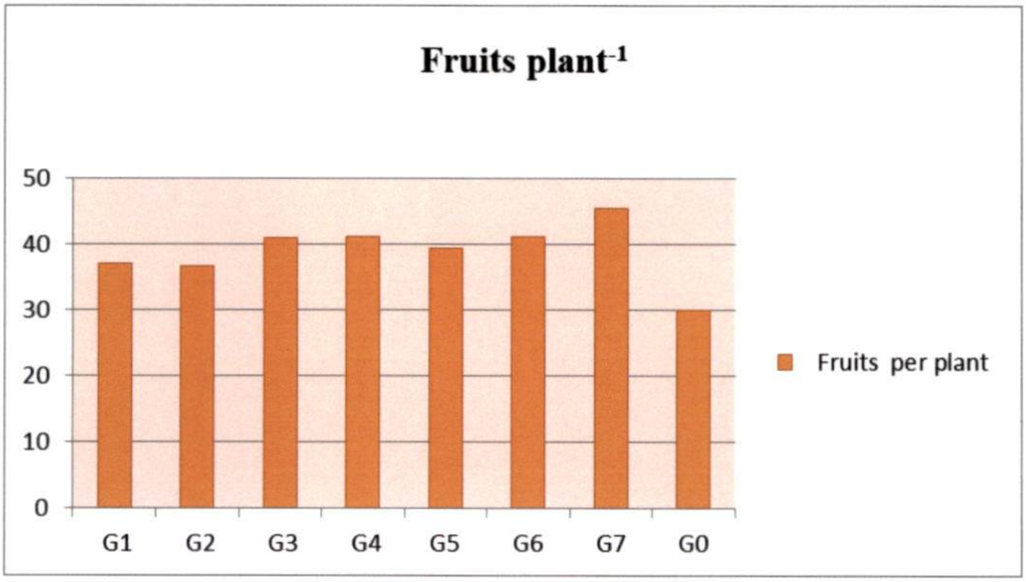

Figure 11. Effect of growth regulators on fruits plant^{-1}

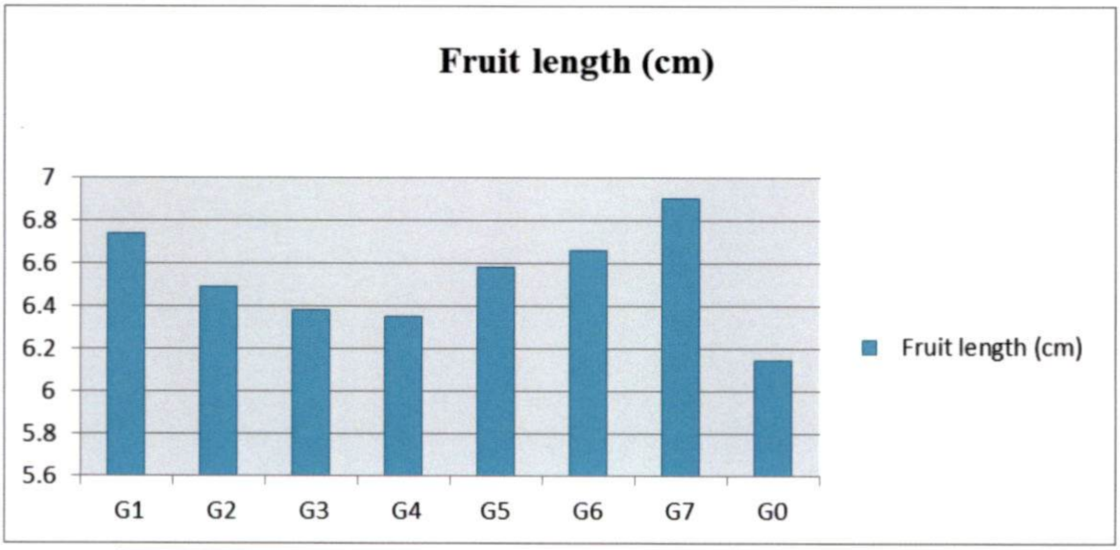

Figure 12. Effect of growth regulators on fruit length

Vibratory pollination improved fruit and yield characters like fruit cluster^{-1},fruit plant^{-1}, fruit length, fruit girth, yield plant^{-1}, yield plot^{-1} and number of seeds fruit^{-1}. Shaking and air blowing could not produce significant changes compared to control. Artificial pollination methods, growth regulator application as well as their interactions did not influence thousand seed weight.

In the present study, vibratory pollination was found to be more effective than other artificial pollination methods in improving fruit size. The results in present study are in conformity with Charles and Harris (1972), where vibratory pollination enhanced the number of seeds per fruit resulting in bigger fruit. Pollinating tomato plants by vibrating the plants with an electric vibrator have forced the anthers to release more pollen, resulting in more efficient pollination and fertilization of the ovules inside the ovary. Pollination using vibrator produced highest yield plant^{-1} (1311.75 g) and yield plot^{-1} (2.90 kgm^{-2}) which can be attributed to higher fruit set by vibratory pollination .Vibratory pollination produced maximum number of seeds fruit^{-1} than shaking and air blowing. Higuti *et al.* (2010) observed an increase in the number of seeds per fruit with plant vibration in five tomato hybrids and also reported that seed formation is directly proportional to the number of pollen deposited in stigma. Vibratory pollination were effective in releasing higher number of pollens and Verkerk (1957) also reported similar result as more the number of pollen used for pollination, more the seed set (Fig 19). However, Hanna (1995) observed a contradictory result where the use of a wind blower was more efficient in increasing fruit size, yield and the percentage of marketable fruit. Vidyadhar *et al.* (2015) also reported that air blowing method recorded highest number of fruits per plant (67.46), 100 seed weight (0.129 g) and seeds berry^{-1}(68.05) compared to stick method and vibratory pollination method.

Application of PCPA 30 mgL^{-1} + GA_3 20 mgL^{-1} improved fruit plant^{-1}, fruit length ,fruit girth, yield plant^{-1} and yield plot^{-1}. PCPA 20 mgL^{-1} + GA_3 20 mgL^{-1} was also equally effective in all these characters. Both treatments were on par with PCPA 30 mgL^{-1}, PCPA 20 mgL^{-1} and PCPA 10 mgL^{-1} + GA_3 20 mgL^{-1} in improving fruits

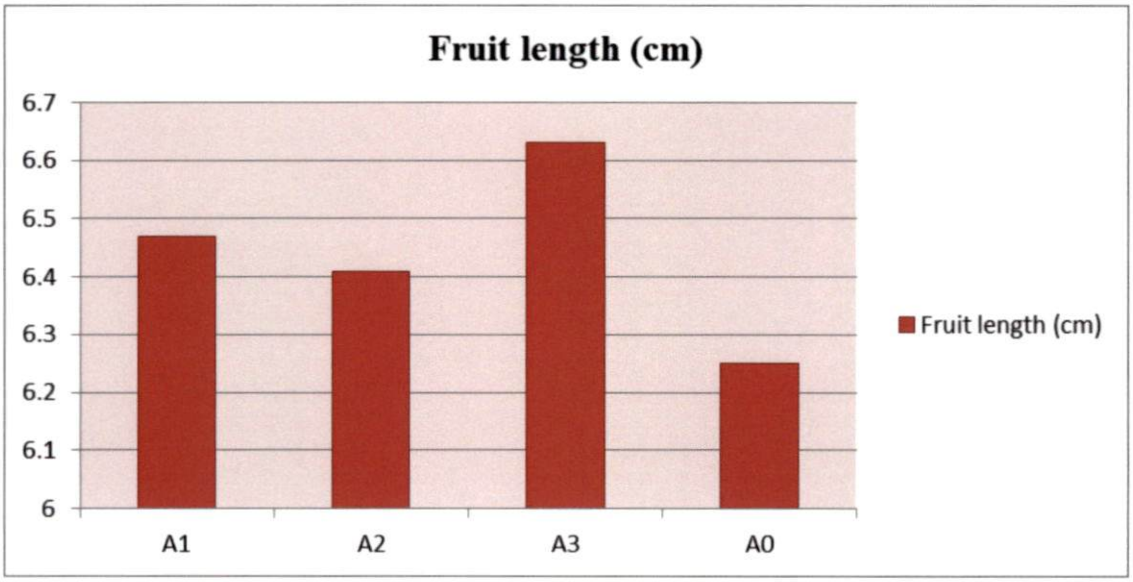

Figure 13. Effect of artificial pollination on fruit length

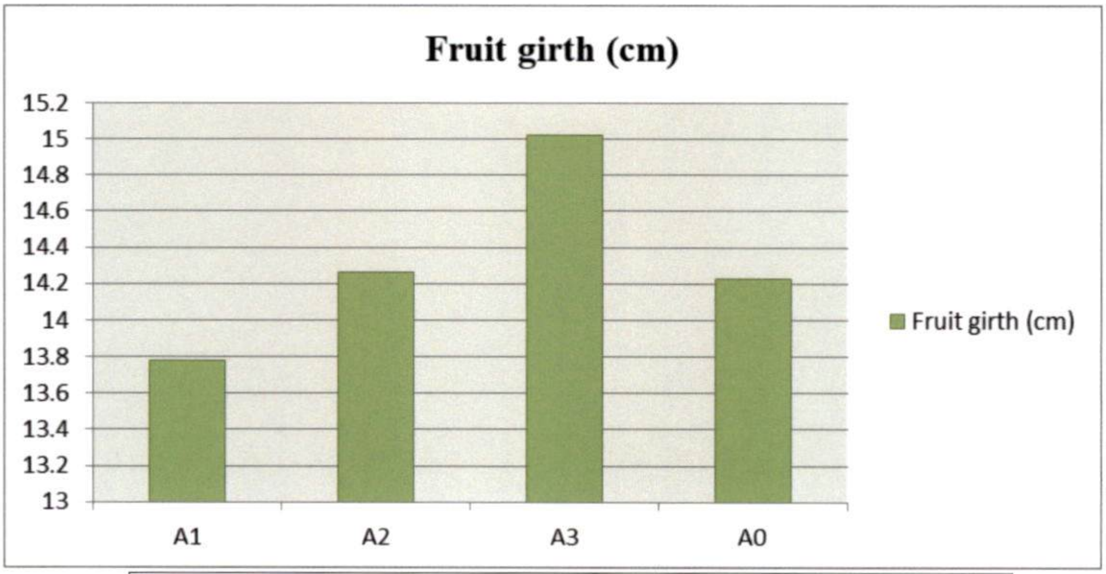

Figure 14. Effect of artificial pollination on fruit length

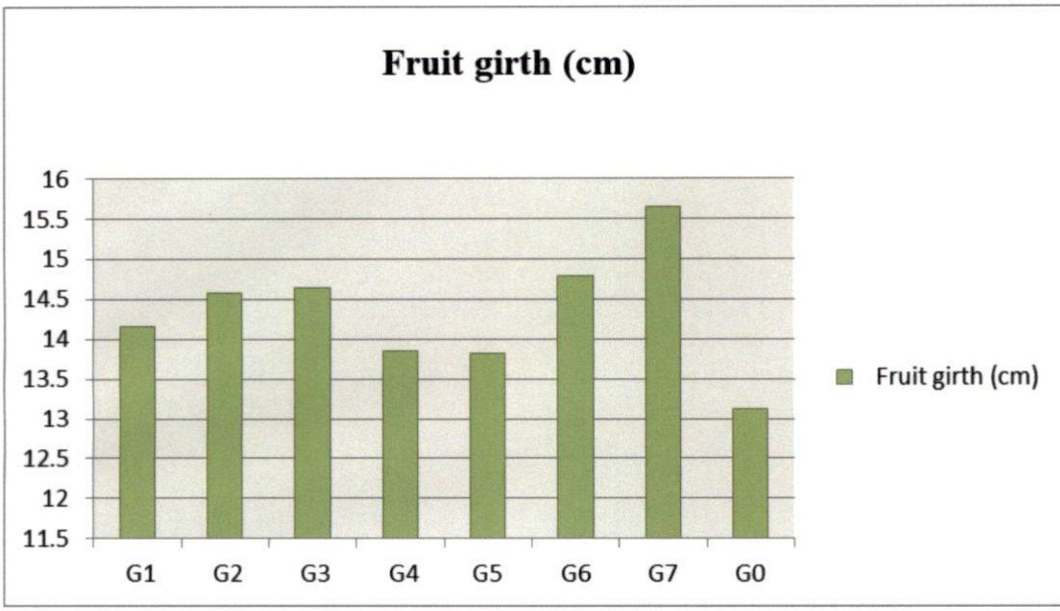

Figure 15. Effect of growth regulators on fruit girth

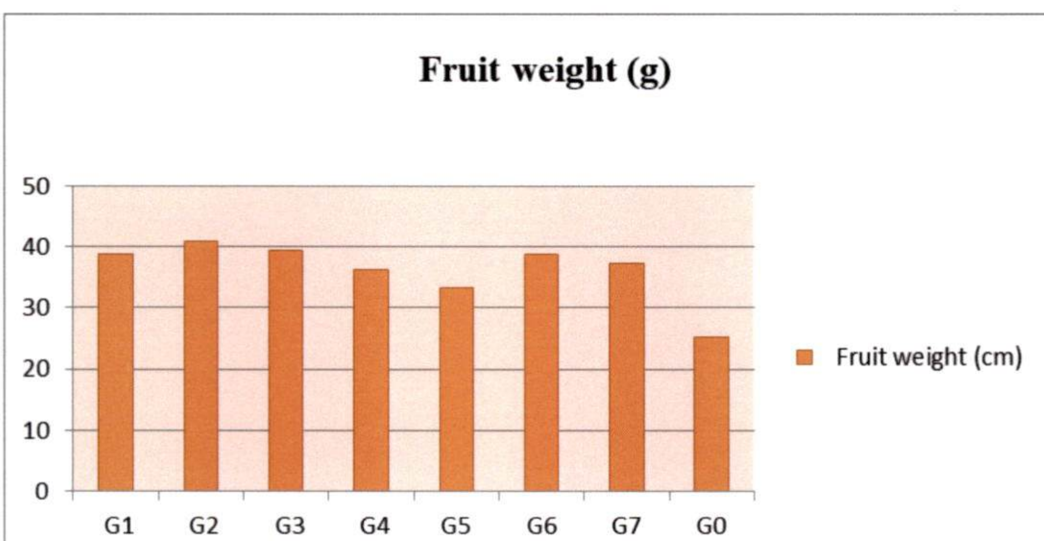

Figure 16. Effect of growth regulators on fruit weight

plant^{-1}, with PCPA 10 mgL^{-1}, PCPA 10 mgL^{-1} + GA_3 20 mgL^{-1} on fruit length and with PCPA 20 mgL^{-1} and PCPA 30 mgL^{-1} on fruit girth.

According to Tomar *et al.* (2017), application of GA_3 significantly increased the number of fruits per plant. The increase in number of fruits per plant by GA_3 treatment might be due to rapid and better nutrient translocation from roots to apical parts of the plant. The Gibberellic acid increased the number of flower clusters and fruit set per plant resulting in more number of fruits per plant. Mehrotra *et al.* (1970) and Pandita *et al.* (1979) reported maximum number of fruits per plant by PCPA spray compared to control.The application of 4-CPA under high temperature improved fruit set of tomato resulting in more number of fruits plant^{-1}(Karim *et al.*, 2015).

These results were also confirmed by Choudhury *et al.* (2013) where 20 ppm PCPA + 20 ppm GA_3 produced more number of fruits plant^{-1} compared to their individual spray application. In addition, combined application of 4-CPA and GA_3 increased the length of fruit than when each of them were applied independently. Similar findings were reported by Sasaki *et al.* (2005) where tomato plants treated with a mixture of 4-CPA and GA_3 increased proportion of normal fruits. The results were also in accordance with the findings of Luitel *et al.* (2015).

Application of PCPA 30 mgL^{-1} + GA_3 20 mgL^{-1} produced fruits with maximum girth which was on par with PCPA 20 mgL^{-1} + GA_3 20 mgL^{-1}, PCPA 30 mgL^{-1} and PCPA 20 mgL^{-1} . The fruit weight also showed positive influence by growth regulator spray. All growth regulator combination except PCPA 10 mgL^{-1} + GA_3 20 mgL^{-1} showed improvement in average fruit weight. According to Kaushik *et al.* (1974), application of GA_3 at vegetative stage increased fruit size which in turn improved individual fruit weight. Higher concentrations of 4-CPA also produced significant differences in the average fruit weight and fruit diameter as compared to control (Gemici *et al.*, 2006).

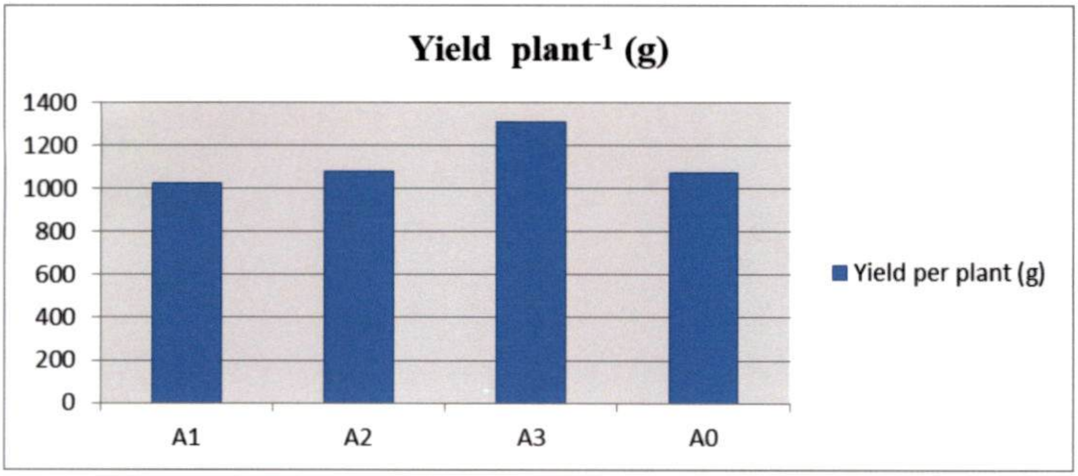

Figure 17. Effect of artificial pollination on yield plant^{-1}

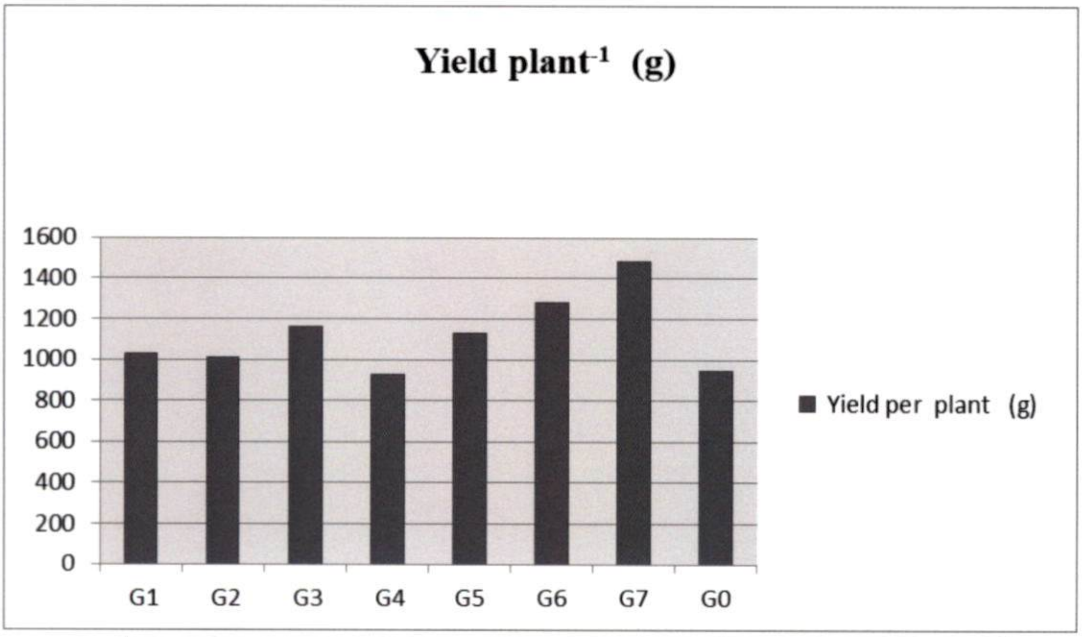

Figure 18. Effect of growth regulators on yield plant^{-1}

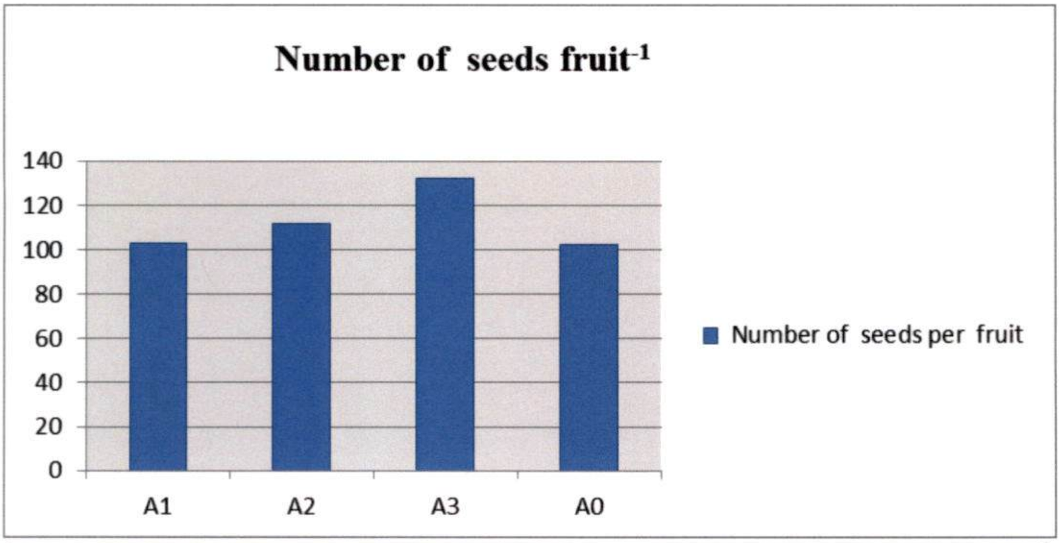

Figure 19. Effect of artificial pollination on number of seeds fruit^{-1}

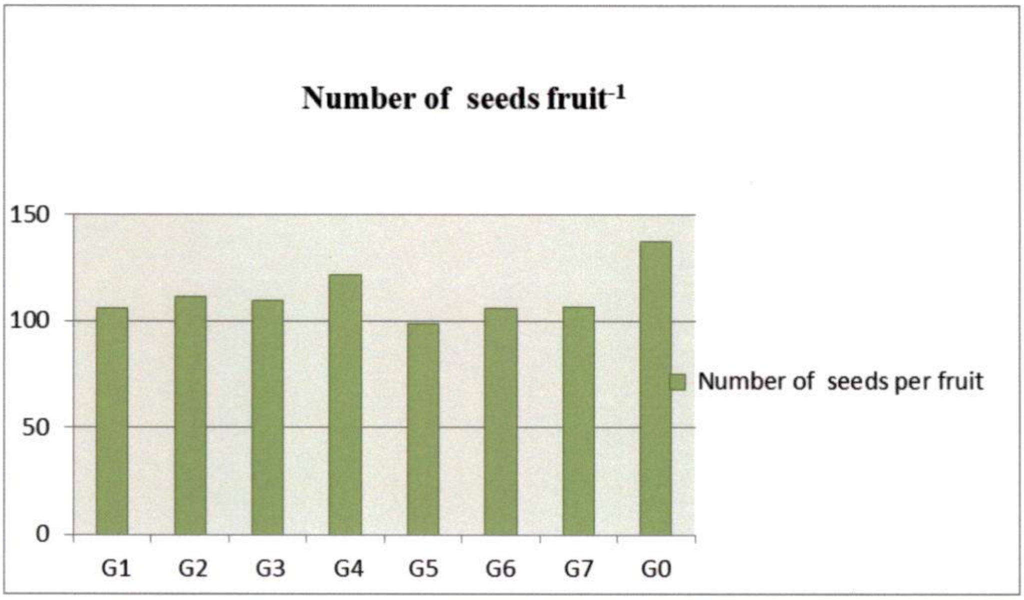

Figure 20. Effect of growth regulators on number of seeds fruit^{-1}

Maximum yield plant^{-1} was recorded by PCPA 30 mgL^{-1}+ GA_3 20 mgL^{-1} which was on par with PCPA 20 mgL^{-1} + GA_3 at 20 mgL^{-1}. Application of PCPA and GA_3 were found to influence the yield per plot significantly. It was observed that PCPA 30 mgL^{-1}+ GA_3 20 mgL^{-1} produced maximum yield per plot which was on par with PCPA 20 mgL^{-1} + GA_3 20 mgL^{-1}. The increase in yield with GA_3 and PCPA may be due to the cumulative effect of increase in several fruit and yield parameters such as flowers cluster^{-1}, fruits cluster^{-1}, fruits plant^{-1} and fruit set. Saleh and Abdul (1980) reported increased yield per plant by foliar application of GA_3 in tomato. The increase in yield due to application of PCPA was supported by Pandita *et al.* (1979), that it may be due to auxin directed mobilization of nutrients into flowers and fruits by external application of auxins in tomato. Lipari and Paratore (1989) reported that treatment with 4 CPA at 130 ppm produced higher yield in tomato. Arora *et al.* (1992) and Li *et al.* (1992) concluded that PCPA application on flower trusses at 30- 50 ppm contributed to higher yield per plant. GA_3 recorded earlier fruit setting, maturity as well as yield plant^{-1} as reported by Mehta and Mathi (1975). PCPA is effective in fruit retention of horticultural crops and thus increased the yield substantially (Paidi, 2014).

Surendra *et al.* (2006) revealed that there is a significant increase in fruit length, number of seeds and seed weight in okra which in turn increased the fruit yield due to application of GA_3 (25 and 50 ppm). Application of GA_3 (75ppm) to cherry tomato resulted in better yield (Bhosle *et al.*, 2002). Increase in yield per plant was also obtained with GA_3 by Hossain (1974). Similar findings were reported by Baliyan *et al.* (2013) and Patidar (2015) wherein highest fruit yield plot^{-1} was for 20 ppm GA_3 followed by 15 ppm GA_3 and 10 ppm GA_3. Other growth regulators treatments did not improve the yield per plot.

It was observed that maximum number of seeds per fruit was for control which was on par with application of GA_3 at 20 mgL^{-1}. Other growth regulator treatments reduced the number of seeds per fruit. Koornneef *et al.* (1990) noted that high GA_3

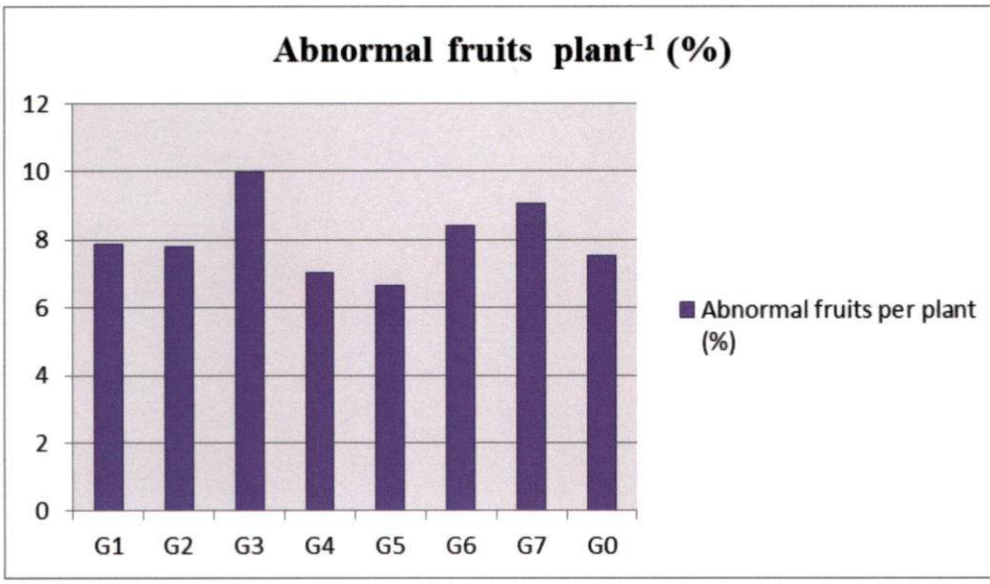

Figure 21. Effect of growth regulators on abnormal fruits plant^{-1}

levels in young tomato fruits tends to stimulate fruit and seed development. Whereas Tonder *et al.* (2003) reported that the number of seeds per fruit decreased as the number of applications of PCPA increased.

5.4. Fruit quality

The effect of growth regulators on abnormal fruits plant^{-1} is shown in Fig.20. The application of plant growth regulators, though improved growth and yield, caused abnormalities in fruit shape. Application of PCPA 30 mgL^{-1}, PCPA 30 mgL^{-1} + GA_3 20 mgL^{-1} enhanced abnormality. However, lower concentrations of PCPA or its combination with GA_3 did not produue more number of abnormal fruits than control. Picken and Grimmet (1986) reported that the use of synthetic auxins, particularly 4-CPA, in greenhouses has a detrimental effect on fruit shape. Gibberellin treated plants showed more degree of malformation than fruits in other treatments including control (Asahira *et al.*, 1982).

Different growth regulators and their combinations could not produce significant differences among quality parameters like total soluble solids, titrable acidity, vitamin C as well as lycopene.

SUMMARY

6. SUMMARY

The study entitled "Enhancing fruit set and yield of tomato (*Solanum lycopersicum* L.) in polyhouse using artificial pollination and growth regulators" was carried out in the Department of Vegetable science ,College of Agriculture, Vellayani during October 2017 to March 2018. The main objective was to enhance the fruit set and yield of tomato under poly house through artificial pollination and application of plant growth regulators.

The experiment was carried out on semi determinate tomato variety Akshaya with three artificial pollination methods (Shaking, Air Blowing and Vibratory Pollination) seven growth regulator treatments (PCPA 10 mgL^{-1}, PCPA 20 mgL^{-1}, PCPA 30 mgL^{-1}, GA_3 20 mgL^{-1}, PCPA 10 mgL^{-1} + GA_3 20 mgL^{-1}, PCPA 20 mgL^{-1} + GA_3 20 mgL^{-1}, PCPA 30 mgL^{-1} +GA_3 20 mgL^{-1}) and their combinations along with control. Artificial pollination methods were executed in morning hours daily throughout the flowering period by shaking the plant with hand or blowing air with the help of a blower to the flower trusses or pollination through vibrating the flower truss with the help of an electrical vibrator and plant growth regulators at specific concentrations were sprayed on to the flower trusses at fortnightly intervals during the entire flowering period.

Observations were recorded on vegetative, flowering, fruiting and fruit quality parameters. The artificial pollination methods and its interaction with growth regulators did not significantly influence vegetative characters like plant height, height at flowering, primary branches $plant^{-1}$, leaf length and leaf width. Combination of Gibberellic acid (GA_3) and Parachlorophenoxy acetic acid (PCPA) was more effective in improving vegetative growth of plant by increasing plant height, leaf length and leaf width against control and application of individual growth regulators. PCPA 30 mgL^{-1} + GA_3 20 mgL^{-1} and PCPA 20 mgL^{-1} + GA_3 20 mgL^{-1} was at par for production of taller plants. Application of PCPA 30 mgL^{-1} + GA_3 20 mgL^{-1} resulted in longer and wider leaves.

Vibratory pollination had a positive effect on fruit set compared to other methods of pollination. Pollination using vibrator produced maximum fruit set (67.35 %) . Shaking and air blowing did not influence fruit set.

Application of growth regulators did not influence days to first flowering, days to fruit set and flowers $cluster^{-1}$ but significantly improved inflorescence $plant^{-1}$, fruit set and pollen viability and reduced number of flowers with exserted stigma. The result indicated that GA_3 alone as well as in combination with PCPA increased the number of inflorescence per plant compared to other treatments. Maximum inflorescence $plant^{-1}$ (17.27) was obtained for PCPA 30 mgL^{-1} + GA_3 20 mgL^{-1} which was on par with PCPA 20 mgL^{-1} + GA_3 20 mgL^{-1} (15.57) and GA_3 20 mgL^{-1} (15.17). Highest fruit set (66.34 %) and pollen viability (64.19 %) was obtained by application of PCPA 30 mgL^{-1} which was on par with PCPA 10 mgL^{-1} and PCPA 20 mgL^{-1} in combination with GA_3 20 mgL^{-1}. PCPA 20 mgL^{-1} + GA_3 20 mgL^{-1} significantly reduced flowers with exserted stigma (25.72 %).

Pollination with vibrator significantly improved fruits $cluster^{-1}$ (6.60), fruits $plant^{-1}$ (45.69), fruit length (6.63 cm), fruit girth (15.02 cm), yield $plant^{-1}$ (1311.75 g) and yield $plot^{-1}$ (2.90 kgm^{-2}) and number of seeds $fruit^{-1}$ (131.94) compared to other methods and control. Shaking and air blowing did not significantly influence any of the fruit characters. Application of PCPA 30 mgL^{-1} + GA_3 20 mgL^{-1} improved fruit $plant^{-1}$ (45.45), fruit length (6.90), fruit girth (15.65), yield $plant^{-1}$ (1487.50 g), yield $plot^{-1}$ (3.47 kgm^{-2}). PCPA 20 mgL^{-1} + GA_3 20 mgL^{-1} was equally effective in all these characters. All growth regulator treatments except PCPA 10 mgL^{-1} + GA_3 20 mgL^{-1} were equally effective in improving fruit weight. However, all growth regulator treatments except GA_3 20 mgL^{-1} lowered the number of seeds $fruit^{-1}$. Growth regulator application did not influence fruits $cluster^{-1}$ and thousand seed weight.

Fruit quality parameters like total soluble solids, titrable acidity, vitamin C and lycopene were not significantly influenced by any of the treatments and their interactions. Application of PCPA 30 mgL^{-1}, PCPA 30 mgL^{-1} + GA_3 20 mgL^{-1} enhanced abnormality in fruits. However, lower concentration of PCPA or its combination with GA_3 did not cause more number of abnormal fruits than control.

CONCLUSION

Vibratory pollination improved fruit set, fruits $cluster^{-1}$, fruits $plant^{-1}$, fruit length, fruit girth, yield $plant^{-1}$, yield $plot^{-1}$ and number of seeds $fruit^{-1}$ whereas shaking and air blowing did not influence any of these characters. Among growth regulators PCPA 30 mgL^{-1} + GA_3 20 mgL^{-1} and PCPA 20 mgL^{-1}+GA_3 20 mgL^{-1} were at par to improve plant height, inflorescence $plant^{-1}$, fruit set, fruits $plant^{-1}$, fruit length, fruit girth, fruit weight, yield $plant^{-1}$, yield $plot^{-1}$ and to reduce number of seeds $fruit^{-1}$. In addition, PCPA 20 mgL^{-1}+ GA_3 20 mgL^{-1} improved pollen viability and reduced the number of flowers with exserted stigma without altering proportion of normal fruits. Interaction effect of pollination methods and growth regulators were non significant in all parameters. It is inferred that vibratory pollination can be successfully used to enhance fruit set, fruit yield and seed yield of tomato. While growth regulator treatment PCPA 20 mgL^{-1} + GA_3 20 mgL^{-1} can be employed for higher fruit set, fruit yield with less number of seeds in polyhouse condition.

FUTURE LINE OF WORK.

The following relevant suggestions are being made on the basis of the findings of the present study.

- Efficacy of growth regulator combination need to be ascertained in various locations in Kerala.

- Variations in varietal response to application of growth regulators need to be ascertained.

- Need to develop a low cost locally fabricated vibratory pollinators for further spread of technology

- Vibratory pollination is a skill requiring operation. Hence need to be included in extension programs for skill development.

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ENHANCING FRUIT SET AND YIELD OF TOMATO (*Solanum lycopersicum* L.) IN POLYHOUSE USING ARTIFICIAL POLLINATION AND GROWTH REGULATORS.

by

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ABSTRACT

The present investigation entitled "Enhancing fruit set and yield of tomato (*Solanum lycopersicum* L.) in poly house using artificial pollination and growth regulators" was conducted at the Department of Vegetable Science, College of Agriculture, Vellayani during 2017-2018. The objective of the study was to enhance the fruit set and yield of tomato under poly house through artificial pollination and application of plant growth regulators.

The tomato variety "Akshaya" was raised in polyhouse and subjected to three artificial pollination methods, seven growth regulator treatments and their combinations along with control. The artificial pollination methods were A_0 (Control), A_1 (Shaking), A_2 (Air Blowing), A_3 (Vibratory Pollination) and growth regulator treatments were G_0 (control), G_1 (PCPA 10 mgL^{-1}), G_2 (PCPA 20 mgL^{-1}), G_3 (PCPA 30 mgL^{-1}), G_4 (GA_3 20 mgL^{-1}), G_5 (PCPA 10 mgL^{-1} + GA_3 20 mgL^{-1}), G_6 (PCPA 20 mgL^{-1} + GA_3 20 mgL^{-1}) and G_7 (PCPA 30 mgL^{-1} +GA_3 20 mgL^{-1}). Artificial pollination methods were executed daily during morning hours and plant growth regulators were sprayed on to the flower trusses at fortnightly intervals during the entire flowering period.

The artificial pollination methods and its interaction with growth regulators did not significantly influence vegetative characters like plant height, height at flowering, primary branches $plant^{-1}$, leaf length and leaf width. Combination of Gibberellic acid (GA_3) and Parachlorophenoxy acetic acid (PCPA) improved vegetative growth of plant by increasing plant height, leaf length and leaf width against control and application of individual growth regulators. Application of PCPA 30 mgL^{-1} + GA_3 20 mgL^{-1} resulted in maximum plant height (324.90 cm) which was on par with combination of PCPA 20 mgL^{-1} + GA_3 20 mgL^{-1}. Application of PCPA 30 mgL^{-1} + GA_3 20 mgL^{-1} produced longer (37.85 cm) and wider (23.65 cm) leaves.

Vibratory pollination significantly improved fruit set (67.35 %) compared to other methods and control. Shaking or blowing air on flower trusses could not improve fruit set significantly. Application of growth regulators did not influence days to first flowering, days to fruit set and flowers $cluster^{-1}$ but significantly improved inflorescence $plant^{-1}$, fruit set and

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pollen viability and reduced number of flowers with exserted stigma. Highest fruit set (66.34 %) and pollen viability (64.20 %) was obtained by application of PCPA 30 mgL^{-1} which was on par with PCPA (10 mgL^{-1} and 20 mgL^{-1}) in combination with GA_3 20 mgL^{-1}. Maximum inflorescence $plant^{-1}$(17.27) was obtained for PCPA 30 mgL^{-1} + GA_3 20 mgL^{-1} which was on par with PCPA 20 mgL^{-1} + GA_3 20 mgL^{-1} (15.57) and GA_3 20 mgL^{-1} (15.17). PCPA 20 mgL^{-1}+ GA_3 20 mgL^{-1} significantly reduced flowers with exserted stigma (25.72 %). PCPA 30 mgL^{-1}, GA_3 20 mgL^{-1} and PCPA 10 mgL^{-1} + GA_3 20 mgL^{-1} also were on par.

Pollination with vibrator significantly improved fruits $cluster^{-1}$ (6.60), fruits $plant^{-1}$ (45.69) , fruit length (6.63 cm), fruit girth (15.02 cm), yield $plant^{-1}$(1311.75 g) and yield $plot^{-1}$ (2.90 kg m^{-2}) and number of seeds $fruit^{-1}$ (131.94) compared to other methods and control. Shaking and air blowing did not significantly influence any of the fruit characters. PCPA 30 mgL^{-1} + GA_3 20 mgL^{-1} produced maximum fruits $plant^{-1}$ (45.45) , fruit length (6.90 cm), fruit girth (15.65 cm), yield $plant^{-1}$ (1487.50 g) and yield $plot^{-1}$ (3.47 kg m^{-2}). PCPA 20 mgL^{-1} + GA_3 20 mgL^{-1} was also equally effective for all these characters. All growth regulator treatments except PCPA 10 mgL^{-1} + GA_3 20 mgL^{-1} were equally effective in improving fruit weight. However, all growth regulator treatments except GA_3 20 mgL^{-1} lowered the number of seeds $fruit^{-1}$. Growth regulator application did not influence fruits $cluster^{-1}$ and thousand seed weight.

Fruit quality parameters like total soluble solids, titrable acidity, vitamin C and lycopene were not significantly influenced by any of the treatments and their interactions. Application of growth regulators PCPA 30 mgL^{-1} + GA_3 20 mgL^{-1} and PCPA 30 mgL^{-1} induced more abnormalities in fruits.

The results indicated that application of PCPA 20 mgL^{-1} + GA_3 20 mgL^{-1} on flower clusters at fortnightly intervals during the flowering period not only enhanced inflorescence $plant^{-1}$, pollen viability, fruit set, fruit size and yield of tomato but also reduced the number of flowers with exserted stigma and number of seeds $fruit^{-1}$ while vibratory pollination improved fruit set, fruit size, yield and number of seeds $fruit^{-1}$, which can be used selectively for improving fruit production and seed production of tomato under poly houses in Kerala.

APPENDICES

APPENDIX -I

FERTIGATION SCHEDULE FOR PRECISION FARMING IN TOMATO

50 Split – 150Days

SL NO	Days of Fertigation	Fertiliser to be applied (Water Soluble)	Quantity (kg/ha) 200 sq m	
		Basal Dose P (kg/ha)	65.00	1.300
1	3^{rd} Day after planting	19:19:19	8.60	0.170
		13:0:45	4.50	0.010
		Urea	8.60	0.175
		12:61:0	0.00	0.00
2	6^{th} Day after planting	19:19:19	8.60	0.170
		13:0:45	4.50	0.010
		Urea	8.60	0.175
		12:61:0	0.00	0.00
3	9^{th} Day after planting	19:19:19	8.60	0.170
		13:0:45	4.50	0.010
		Urea	8.60	0.175
		12:61:0	0.00	0.00
4	12^{th} Day after planting	19:19:19	8.60	0.170
		13:0:45	4.50	0.010
		Urea	8.60	0.175
		12:61:0	0.00	0.00
5	15^{th} Day after planting	19:19:19	8.60	0.170
		13:0:45	4.50	0.010
		Urea	8.60	0.175
		12:61:0	0.00	0.00
6	18^{th} Day after planting	19:19:19	8.60	0.170
		13:0:45	4.50	0.010
		Urea	8.60	0.175
		12:61:0	0.00	0.00
7	21^{st} Day after planting	19:19:19	4.30	0.090
		13:0:45	15.10	0.300
		Urea	4.40	0.090
		12:61:0	1.30	0.030
8	24^{th} Day after planting	19:19:19	4.30	0.090
		13:0:45	15.10	0.300
		Urea	4.40	0.090
		12:61:0	1.30	0.030
9	27^{th} Day after planting	19:19:19	4.30	0.090

		13:0:45	15.10	0.300
		Urea	4.40	0.090
		12:61:0	1.30	0.030
10	30st Day after planting	19:19:19	4.30	0.090
		13:0:45	15.10	0.300
		Urea	4.40	0.090
		12:61:0	1.30	0.030
11	33rd Day after planting	19:19:19	4.30	0.090
		13:0:45	15.10	0.300
		Urea	4.40	0.090
		12:61:0	1.30	0.030
12	36th Day after planting	19:19:19	4.30	0.090
		13:0:45	15.10	0.300
		Urea	4.40	0.090
		12:61:0	1.30	0.030
13	39th Day after planting	19:19:19	4.30	0.090
		13:0:45	15.10	0.300
		Urea	4.40	0.090
		12:61:0	1.30	0.030
14	42nd Day after planting	19:19:19	4.30	0.090
		13:0:45	15.10	0.300
		Urea	4.40	0.090
		12:61:0	1.30	0.030
15	45th Day after planting	19:19:19	4.30	0.090
		13:0:45	15.10	0.300
		Urea	4.40	0.090
		12:61:0	1.30	0.030
16	48th Day after planting	19:19:19	4.30	0.090
		13:0:45	15.10	0.300
		Urea	4.40	0.090
		12:61:0	1.30	0.030
17	51st Day after planting	19:19:19	4.30	0.090
		13:0:45	15.10	0.300
		Urea	4.40	0.090
		12:61:0	1.30	0.030
18	54th Day after planting	19:19:19	4.30	0.090
		13:0:45	15.10	0.300
		Urea	4.40	0.090
		12:61:0	1.30	0.030
19	57th Day after planting	19:19:19	4.30	0.090
		13:0:45	15.10	0.300
		Urea	10.30	0.210
		12:61:0	1.30	0.020
20	60th Day after planting	19:19:19	4.30	0.090
		13:0:45	15.10	0.300
		Urea	10.30	0.210
		12:61:0	1.30	0.020
21	63th Day after planting	19:19:19	4.30	0.090

		13:0:45	15.10	0.300
		Urea	10.30	0.210
		12:61:0	1.30	0.020
22	66st Day after planting	19:19:19	4.30	0.090
		13:0:45	15.10	0.300
		Urea	10.30	0.210
		12:61:0	1.30	0.020
23	69th Day after planting	19:19:19	4.30	0.090
		13:0:45	15.10	0.300
		Urea	10.30	0.210
		12:61:0	1.30	0.020
24	72th Day after planting	19:19:19	4.30	0.090
		13:0:45	15.10	0.300
		Urea	10.30	0.210
		12:61:0	1.30	0.020
25	75th Day after planting	19:19:19	4.30	0.090
		13:0:45	15.10	0.300
		Urea	10.30	0.210
		12:61:0	1.30	0.020
26	78th Day after planting	19:19:19	4.30	0.090
		13:0:45	15.10	0.300
		Urea	10.30	0.210
		12:61:0	1.30	0.020
27	81st Day after planting	19:19:19	4.30	0.090
		13:0:45	15.10	0.300
		Urea	10.30	0.210
		12:61:0	1.30	0.020
28	84th Day after planting	19:19:19	4.30	0.090
		13:0:45	15.10	0.300
		Urea	10.30	0.210
		12:61:0	1.30	0.020
29	87th Day after planting	19:19:19	4.30	0.090
		13:0:45	15.10	0.300
		Urea	10.30	0.210
		12:61:0	1.30	0.020
30	90th Day after planting	19:19:19	4.30	0.090
		13:0:45	15.10	0.300
		Urea	10.30	0.210
		12:61:0	1.30	0.020
31	93rd Day after planting	19:19:19	4.30	0.090
		13:0:45	15.10	0.300
		Urea	10.30	0.210
		12:61:0	1.30	0.020
32	96th Day after planting	19:19:19	4.30	0.090
		13:0:45	15.10	0.300
		Urea	10.30	0.210
		12:61:0	1.30	0.020
33	99th Day after planting	19:19:19	4.30	0.090

		13:0:45	15.10	0.300
		Urea	10.30	0.210
		12:61:0	1.30	0.020
34	102rd Day after planting	19:19:19	4.30	0.090
		13:0:45	15.10	0.300
		Urea	10.30	0.210
		12:61:0	1.30	0.020
35	105th Day after planting	19:19:19	4.30	0.090
		13:0:45	15.10	0.300
		Urea	10.30	0.210
		12:61:0	1.30	0.020
36	108rd Day after planting	19:19:19	4.30	0.090
		13:0:45	15.10	0.300
		Urea	10.30	0.210
		12:61:0	1.30	0.020
37	111th Day after planting	19:19:19	4.30	0.090
		13:0:45	15.10	0.300
		Urea	10.30	0.210
		12:61:0	1.30	0.020
38	114th Day after planting	19:19:19	4.30	0.090
		13:0:45	15.10	0.300
		Urea	10.30	0.210
		12:61:0	1.30	0.020
39	117th Day after planting	19:19:19	4.30	0.090
		13:0:45	15.10	0.300
		Urea	10.30	0.210
		12:61:0	1.30	0.020
40	120th Day after planting	19:19:19	4.30	0.090
		13:0:45	15.10	0.300
		Urea	10.30	0.210
		12:61:0	1.30	0.020
41	123rd Day after planting	19:19:19	0.00	0.00
		13:0:45	16.90	0.340
		Urea	4.35	0.090
		12:61:0	0.00	0.00
42	126th Day after planting	19:19:19	0.00	0.00
		13:0:45	16.90	0.340
		Urea	4.35	0.090
		12:61:0	0.00	0.00
43	129th Day after planting	19:19:19	0.00	0.00
		13:0:45	16.90	0.340
		Urea	4.35	0.090
		12:61:0	0.00	0.00
44	132th Day after planting	19:19:19	0.00	0.00
		13:0:45	16.90	0.340
		Urea	4.35	0.090
		12:61:0	0.00	0.00
45	135th Day after planting	19:19:19	0.00	0.00
		13:0:45	16.90	0.340
		Urea	4.35	0.090

		12:61:0	0.00	0.00
46	138rd Day after planting	19:19:19	0.00	0.00
		13:0:45	16.90	0.340
		Urea	4.35	0.090
		12:61:0	0.00	0.00
47	141th Day after planting	19:19:19	0.00	0.00
		13:0:45	16.90	0.340
		Urea	4.35	0.090
		12:61:0	0.00	0.00
48	144th Day after planting	19:19:19	0.00	0.00
		13:0:45	16.90	0.340
		Urea	4.35	0.090
		12:61:0	0.00	0.00
49	147th Day after planting	19:19:19	0.00	0.00
		13:0:45	16.90	0.340
		Urea	4.35	0.090
		12:61:0	0.00	0.00
50	150th Day after planting	19:19:19	0.00	0.00
		13:0:45	16.90	0.340
		Urea	4.35	0.090
		12:61:0	0.00	0.00

APPENDIX II

ECONOMICS OF TOMATO CULTIVATION USING ARTIFICIALPOLLINATION AND APPLICATION OF GROWTH REGULATORS (for 500 m^2)

1. Labour charge for land preparation = Rs 1555
2. Labour charge for soil sterilization and basal application of manures and fertilizers = Rs 2333
3. Plastic mulch = Rs 1116
4. Labour charge for mulching with plastic sheet = Rs 3111
5. Cost of seeds = Rs 223
6. Labour charge for raising pro tray seedlings = Rs 2333
7. Labour charge for transplanting of seedlings = Rs 3111
8. Cost of Manures = Rs 948
9. Cost of fertilizers and fertigation = Rs 1116
10. Materials for trailing (G I wire, Jute thread, clips etc) = Rs 1116
11. Labour charge for trailing of plants = Rs 2223
12. Plant protection chemicals = Rs 558
13. Labour charge for applying plant protection chemicals = Rs 741
14. Weeding = Rs 1555
15. Cost of electric vibrator(S): Rs 6000

    Life span of the unit (n): 15 years

    Interest rate (i): 11% per annum

$$\text{Fixed cost of vibrator} = \frac{i(i+1)^n}{(i+1)^n} \times S$$

$$= \frac{0.11(0.11+1)^{15}}{\quad} \text{X } 6000 = \text{Rs } 833$$

$(0.11+1)^{15}$ -1

Maintenance cost of vibrator : 2% of initial cost	=	Rs 120
19. Labour cost for pollination	=	Rs. 5928
20. Cost of growth regulators and chemicals	=	Rs 2000
21. Labour cost for growth regulator application	=	Rs 1000
22. Polyhouse maintenance (cleaning roof, fogger nozzles, drippers etc)	=	Rs 2333
23. Harvesting	=	Rs 2333
Total cost	=	Rs 36586
Yield (500 m^2)	=	1525 kg
Price of tomato per kg	=	Rs 40
Net returns	=	Rs 61000
Benefit Cost ratio	=	1.6