International Journal of Research in Agronomy

E-ISSN: 2618-0618
P-ISSN: 2618-060X

NAAS Rating (2025): 5.20
www.agronomyjournals.com
2025; SP-8(8): 207-223
Received: 17-06-2025
Accepted: 21-07-2025

Enhancing phenological development and yield of bitter gourd through PGRS and 3G cutting in Chhattisgarh plains

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DOI: https://www.doi.org/10.33545/2618060X.2025.v8.i8Sc.3535

Abstract
Bitter gourd (*Momordica charantia* L.) is one of the most pharmaceutical vegetable crops in India, valued for its high yield potential and profitability for farmers. However, its cultivation is often constrained by challenges related to flowering behavior, which affects phenology and overall yield. To address this, a field experiment was conducted during the *Rabi* seasons of 2023-24 and 2024-25 to evaluate the combined effects of PGRs and 3G cutting on the phenological and yield-related traits of bitter gourd. The study included foliar applications of two concentrations each of GA_3 (100 and 150 ppm), NAA (60 and 120 ppm), Ethephon (100 and 200 ppm), and CCC (50 and 100 ppm), along with two levels of cutting treatments (with and without 3G cutting), and an untreated control (A0). The results revealed that the phenological parameters *viz.*, number of leaves per plant (99.07), number of secondary branches per plant (7.27) under E2P0 treatment, and node number for first male (6.85) and female flower appearance (11.89), days to first male (37.77) and female flower (47.32), number of male (178.92) and female flowers per plant (32.66), and sex ratio (5.48) were significantly found superior in Ethephon @ 200 ppm with 3G cutting (E2P1). In contrast, the control treatment (A0 water spray) recorded delayed flowering, with the first male and female flowers appearing at nodes 9.94 and 15.84, and requiring 46.85 and 61.87 days to emerge and highest number of male flowers (281.25), and a high sex ratio (14.62). Furthermore, E2P1 treatment significantly outperformed others in yield attributes, including earliest fruit harvest (72.68 days), longest fruit length (20.33 cm), fruit diameter (54.06 mm), average fruit weight (208.04 g), number of fruits per plant (33.25), and maximum fruit yield (182.82 q/ha). Conversely, the control treatment (A0) consistently recorded the lowest performance in average fruit weight (107.97 g), number of fruits per plant (9.58), and fruit yield (146.25 q/ha). The findings suggest that the integrated use of ethephon @ 200 ppm and 3G cutting is a promising agronomic strategy for enhancing phenological development and fruit yield in bitter gourd cultivation under Chhattisgarh plains condition.

Keywords: Bitter gourd, plant growth regulators (PGRS), 3 g cutting, phenological traits, fruit yield

Introduction
Bitter gourd (*Momordica charantia* L.) is a most important vegetable crop having pharma-nutraceutical properties and grown for its tender fruits in tropical and subtropical regions. It is one of the most popular and prized fruit vegetable among the cucurbitaceous family and is cultivated round the year in most of the country. In India, it is one of the leading vegetable crops and the crop is preferred by the farmers because of its higher yield and returns (Kumar *et al.*, 2012) [23]. It is also known as balsam pear or bitter cucumber or bitter melon. This plant is true diploid in nature (2n=2x=22). The centre of origin is Indo-Burma region (Singh *et al.*, 2013) [34]. It is also considered native of Tropical Asia, particularly Eastern India and Southern China. It is widely distributed and extensively grown in China, India, Indonesia, Malaysia, Singapore, Thailand, Japan, South-East Asia, Tropical Africa and South America. Among the cucurbitaceous family, bitter gourd has prominent export potential particularly to the Gulf countries.

India being the second largest producer of bitter gourd in the world next only to China. In India,

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bitter gourd is cultivated in an area of 1,10,000 hectares with total production of 13,76,000 tones and productivity of 12.50 ton/ha which shares Madhya Pradesh (20.49%) followed by Chhattisgarh (12.57%), Tamil Nadu (10.61%), Uttar Pradesh (8.74%), Odisha (8.50%), Bihar (6.61%), Punjab (5.08%), Jammu & Kashmir (4.06%) and Assam (3.99%) (Dept. of Agriculture and Farmer Welfare, GoI 2021-22).

In Chhattisgarh bitter gourd occupied an area of 13,026 ha with production of 1,75,484 tones with productivity of 13.47 ton/ha. In Chhattisgarh, Rajnandgaon district is leading in terms of production followed by Bemetara, Durg, Mahasamud district and highest area is occupied by Durg district followed by Raipur, Mahasamud and Bemetara district of Chhattisgarh plains. (Directorate of Horticulture, Chhattisgarh, 2022-23).

Bitter gourd is an important cucurbitaceous vegetable crop extensively grown for immature, tender & tuberculate fruits in different part of the country which have a unique bitter taste. Fruits are used after cooking and delicious preparations are made after stuffing and frying. Bitter gourd is highly cross pollinated in nature due to monoecious sex form.

Fruits are rich source of carbohydrates (4.91 g), protein (0.82 g), fat (2.71 g), dietary fibre (1.9g), mineral like phosphorous (35mg), magnesium (16mg), zinc (0.75mg), iron (0.27mg) and Vitamin C (31.9 mg), Vitamin A (17 µg) per 100 g. (USDA, 2022) [40]**.** Bitter gourd is an anti-diabetic, anti-ulcergonic, anti-leukemic, antioxidant, anti-HIV, antibacterial, anti-tumor, immune-modulatory properties *etc*. Drinking fresh fruit juice is recommended by naturopaths. The fruit contains anti-diabetic properties, including charantin which has been confirmed to have a blood glucose-lowering effect.

Bitter gourd is annual monoecious vine. Bitter gourd is highly cross pollinated in nature due to monoecious sex form. The crop induces greater proportion of staminate flower as compared to pistillate flowers which is not economical and significantly reduces fruit set, crop and seed yield. (Ghani *et al.*, 2013; Patel *et al.*, 2017) [16]. In monoecious lines, the typical ratio of male to female blooms ranges from 15-30:1 (Dey *et al.*, 2005) [13]. High sex ratios and synchronized flowering are desirable for achieving greater yields (Mia *et al.*, 2014). The idea of cucurbit sex modification is to change the flowering order and ratio of sexes. GA_3, NAA, Ethephon and CCC play crucial role to the morphology, growth, and development of plants.

Plant growth regulators (PGRs) are new generation of agrochemicals after pesticides and fertilizers. They improve the interaction between the source and sink relationship and hasten the translocation of photo-assimilates, which leads to improved fruiting. PGRs often work by altering a plants normal homeostasis, specifically the regulation of hormones, which in turn affects the plants growth and development (Rafeekher *et al.*, 2002) [29]. These processes can be regulated by application of PGRs, chemical activators or some external stimuli. The growth regulators include both growth promoters and retardants which have been shown to modify the canopy structure and other yield attributes.

Gibberellic acid (GA_3) is a key PGR that promotes vegetative growth and enhances yield by increasing gynoecy and delaying male flower development in bitter gourd (Zhang *et al.*, 2017) [43]. NAA supports cell division and elongation, contributing to improved plant growth (Nagamani *et al.*, 2015) [27]. Ethephon, a source of ethylene, induces early female flower emergence at lower nodes while suppressing male flowers (Hirpara *et al.*, 2014) [19]. CCC inhibits gibberellin synthesis, enhances branching and leaf area, and influences the female-to-male flower ratio depending on its concentration (Singh, 2011) [35].

3G cutting is revolutionary technique of plant that rising fruit yield per plant in cucurbits such as cucumber, bitter gourd, bottle gourd etc. The main objective of 3G cutting is to maintain proper ratio of male and female flower in plant from which the optimum production can be harvested and increasing the crop production exponentially. Generally, the ratio of male and female flowers is unequal in most of the cucurbitaceous crops and number of staminate flowers is higher in comparison to female flowers. It has been observed that after 3G cutting, the number of female flowers increases and becomes more or equal to male flowers in a crop. This will ultimately increase crop production in a great way (Chaurasiya *et al.*, 2020, Singh *et al.*, 2021) [9, 36].

PGRs are said to affect cucurbitaceous crops vegetative development, blooming, sex expression, and fruit yield; however, for optimal effects, their application stage and concentration must be optimized (Shantappa (2004), Birader and Navalagatti (2008) [32, 7].

In India, fruit production of bitter gourd is feasible in both the rainy (July-October) and spring-summer (February-May) seasons. To meet the growing consumer demand, it is essential to enhance the area under commercial cultivation and adopt improved agronomic practices. This necessitates the development and standardization of fruit production technologies to ensure higher yield, better fruit quality, and profitability for farmers.

Methodology

During the *Rabi* season of 2023-24 and 2024-25, a field experiment entitled "Effect of plant growth regulators (PGRs) and 3G cutting on phenology and yield of Bitter gourd under Chhattisgarh Plains" at Krishi Vigyan Kendra Farm, IGKV, Raipur (C.G.) was conducted. The soil of the experimental area was clayey loam. The experiment comprised 17 treatment combinations, including eight concentrations of four PGRs-GA_3 (100 ppm, 150 ppm), NAA (60 ppm, 120 ppm), Ethephon (100 ppm, 200 ppm), and CCC (50 ppm, 100 ppm) each combined with two levels of cutting (with and without 3G cutting), along with an untreated control (A0). The required quantities of each PGR were initially dissolved in a small amount of 95% absolute alcohol and then diluted with distilled water to prepare stock solutions. Working solutions of the desired concentrations were obtained by further dilution with distilled water. Foliar applications of PGRs were carried out as per the treatment schedule at the 2-4 leaf stage, and at flower and fruit initiation stages. Spraying was done uniformly in each plot using a compressed air hand sprayer during the morning hours. The control plots were treated with distilled water only. 3G cutting is done as routinely observation of selected five plants of each treatment in initial growth of crop. This cutting was completed with help of sharp stainless blade by manually. In the 3G cutting method, the tip of the main vine (1st generation) is pruned at 5-6 ft height, and side branches from the 1st to 12th node are removed, allowing 3-4 strong branches to develop between the 5th and 12th nodes. This encourages the growth of secondary branches (2nd generation), which are also pruned at 2-3 ft height to promote tertiary branches (3rd generation). The 3rd generation branches are then allowed to grow with proper nutrient management and care.

Bitter gourd seeds were sown at a spacing of 1.0 m × 1.0 m. The recommended dose of fertilizers (NPK) was applied at 100:60:60 kg/ha. The full dose of phosphorus and potash, along with one-third of the nitrogen, was applied as a basal dose, while the remaining two-thirds of nitrogen was top-dressed at 25 and 50 days after transplanting. All recommended agronomic practices and plant protection measures were followed to ensure a healthy crop. The experimental data were recorded from various observations and analyzed using a Factorial Randomized Complete Block Design (FRCBD) with three replications. The collected data were subjected to statistical analysis using ANOVA (Analysis of Variance).

Research Findings and Discussion

1. Phenological parameter

1.1 The number of leaves per plant

The number of leaves was significantly influenced by plant growth regulators (PGRs), 3G cutting, and their interactions at both 35 and 70 days after transplanting (DAT) during 2023-24, 2024-25, and in the pooled mean is presented in Table 1 and illustrated in Fig.1.

At 35 DAT, the maximum number of leaves per plant was recorded under NAA @ 120 ppm (N2) with 56.39 (2023-24), 54.22 (2024-25), and a pooled mean of 55.31. In interaction, the highest leaf count was observed in N2P0 (NAA @ 120 ppm + No 3G cutting), with 65.44, 60.11, and 62.77, respectively. Conversely, the minimum number of leaves was recorded in CCC @ 50 ppm (C1) with 40.35, 38.70, and 39.52, while the lowest interaction effect was in C1P1 (CCC @ 50 ppm + 3G cutting) with 38.77, 34.77, and 36.77, respectively.

At 70 DAT, the main effect of 3G cutting (P1) recorded the highest leaf number with 94.25, 87.99, and 91.14, followed by NAA @ 120 ppm (N2) with 87.73, 81.47, and 83.14, and GA_3 @ 100 ppm (G1) with 87.08, 80.82, and 83.34. Among interactions, N2P1 (NAA @ 120 ppm + 3G cutting) recorded the maximum number of leaves per plant: 104.63 (2023-24), 98.37 (2024-25), and 99.07 (pooled mean). The minimum was observed in C1P0 (CCC @ 50 ppm + No 3G cutting) with 55.10, 48.84, and 52.62, respectively. The significant increase in leaf number under NAA treatments, especially at 120 ppm, may be attributed to its role in enhancing vegetative growth by promoting cell elongation, division, and improved translocation of assimilates. The stimulatory effect of NAA on photosynthetic efficiency and hormonal activity likely contributed to higher leaf production. The 3G cutting system further enhanced leaf number by suppressing apical dominance, encouraging lateral shoot development and branching, thus contributing to more foliage. In contrast, CCC (Cycocel), a known growth retardant, reduced vegetative growth by inhibiting gibberellin biosynthesis, resulting in shorter internodes and fewer leaves. These results are consistent with the findings of Sargent (1965) [31] and Biradar *et al.*, (2010) [18] in NAA application, and Hao *et al.*, (2010) [17] and Shivaraj *et al.*, (2018) [33] in pruned cucurbits, confirming the effectiveness of NAA and pruning techniques in enhancing leaf production and overall plant vigor.

1.2 The number of secondary branches per plant

The number of secondary branches at 35 and 70 DAT was recorded to assess the influence of different plant growth regulators (PGRs), 3G cutting, and their interactions is presented in Table 2 and illustrated in Fig.2.

At 35 DAT among PGRs, the highest number of secondary branches was recorded under Ethephon @ 200 ppm (E2) and Ethephon @ 100 ppm (E1) with pooled mean values of 5.28 and 4.50, respectively. The lowest value was observed in A0 (water spray) with 3.71 secondary branches. In interaction, E2P0 (Ethephon @ 200 ppm + No 3G cutting) recorded the maximum number of branches (5.93), followed by E1P0 (5.20), while A0 (water spray) remained lowest (3.71).

At 70 DAT: At this stage, the highest number of secondary branches was recorded in No 3G cutting (P0) and E2 (Ethephon @ 200 ppm), with pooled mean values of 6.40 and 5.47, respectively. The lowest number of secondary branches was observed under 3G cutting (P1), which recorded 3.52. In interaction, E2P0 produced the highest number of branches (7.27), followed by E1P0 (6.99), while the lowest was recorded in G_1P_1 (GA_3 @ 100 ppm + 3G cutting) with 3.28. Although statistically non-significant, the numerical superiority of ethephon treatments suggests a trend toward increased branching due to ethylene production. Ethylene likely reduced apical dominance by antagonizing auxin activity, thus encouraging lateral shoot development. Similar findings were reported by Mangal *et al.*, (1981) [25] in bitter gourd, El-Kholy and Hafez (1982) [14] in snake cucumber, and Rafeekher *et al.*, (2002) [29] in cucumber.

Moreover, 3G cutting, despite lower pooled means at 70 DAT, is known to enhance branching by physically removing the apical meristem, thus promoting axillary bud outgrowth. The numerical increase in branching observed in E2P0 and E1P0 indicates that ethephon, especially in the absence of pruning, facilitated lateral branch initiation effectively. The mechanism likely involves altered hormone balance and reduced apical dominance, as supported by Arora and Malik (1998) [4], Eve *et al.*, (2016) [15] in *Cucurbita moschata*, and Zafari *et al.*, (2019) [42] in bottle gourd.

1.3 The node numbers at which the first male and female flowers appeared

The node numbers at which the first flowers appeared were significantly influenced by the application of plant growth regulators (PGRs), 3G cutting, and their interactions during both 2023-24 and 2024-25 seasons in presented in Table 3 and illustrated in Fig.3.

First Male Flower Appearance

Among the main effects, the lowest node number for first male flower appearance was recorded under 3G cutting (P1) with values of 7.88 (2023-24), 8.87 (2024-25), and a pooled mean of 8.37, indicating earlier flowering compared to No 3G cutting (P0), which showed the highest node number: 11.42, 11.98, and 11.70, respectively. Among PGRs, Ethephon @ 200 ppm (E2) was the most effective, recording 7.96, 9.07, and 8.51, followed by Ethephon @ 100 ppm (E1). In contrast, CCC @ 50 ppm (C1) combined with P0 resulted in delayed flowering, with node values of 11.63, 12.48, and 12.06, respectively. A significant interaction effect was observed. The earliest male flower initiation occurred in E2P1 (Ethephon @ 200 ppm + 3G cutting) with 6.68, 7.01, and pooled mean 6.85, followed by E1P1 (7.25) and N2P1 (7.80).

First Female Flower Appearance

Similarly, the lowest node number for the first female flower appearance was recorded under 3G cutting (P1) with 14.01, 12.98, and pooled mean 13.57, while the highest was under No 3G cutting (P0): 17.07, 16.03, and 16.49, respectively. Among PGRs, E2 (Ethephon @ 200 ppm) showed the earliest female flowering with 14.33, 13.04, and 13.73, while the maximum delay was seen in CCC @ 50 ppm + P0 (C1P0) with 18.06, 17.29, and 17.90 node numbers, respectively. In interaction, E2P1 again resulted in the earliest female flower appearance: 12.56 (2023-24), 11.05 (2024-25), and pooled mean 11.89, followed by E1P1 (12.80) and N2P1 (12.93). The reduction in the node number for first male and female flower appearance under ethephon and 3G cutting treatments indicates a promotive effect on early flowering. This may be due to the suppression of apical dominance through pruning and the ethylene-releasing property of ethephon, which accelerates floral induction by redistributing assimilates and modifying endogenous hormonal balance, particularly enhancing ethylene levels.

These findings are consistent with Arora and Partap (1988) [5] in bitter gourd and Rafeekher *et al.*, (2002) [29] in cucumber. Ethephon, by releasing ethylene, antagonizes auxin activity at the apex, reducing shoot elongation and promoting flower bud differentiation earlier along the axis. The lowest node numbers in E2P1 (both male and female) suggest that ethephon combined with 3G cutting is highly effective in inducing early flowering. This aligns with the observations of Dalal *et al.*, (2006) [12] and Eve *et al.*, (2016) [15], who reported increased early flowering due to apical suppression. Further, ethrel (ethephon) application likely inhibits cell division and elongation in shoot meristems, producing shorter shoots and reducing node intervals, as noted by Rajala and Peltonen (2001) [30] and Thappa *et al.*, (2011) [39].

1.4 The days required for the appearance of the first male and female flowers

The days required for the appearance of the flowers were significantly influenced by the application of plant growth regulators (PGRs), 3G cutting, and their interactions in presented in Table 4 and illustrated in Fig.4.

Among individual treatments, 3G cutting (P1) consistently promoted earlier flowering. The earliest male flower initiation was observed under P1 with pooled mean of 39.61 days, followed closely by Ethephon @ 200 ppm (E2) with 39.37 days. The longest duration to male flower initiation was recorded under A0 (water spray) with 46.85 days. Interaction effects (AxB) revealed a significant influence, where the treatment E2P1 (Ethephon @ 200 ppm + 3G cutting) recorded the earliest male flower appearance with 37.77 days (pooled mean), followed by E1P1 (Ethephon @ 100 ppm + 3G cutting) with 38.92 days. The maximum delay was again observed in A0 (control).

Similarly, the appearance of the first female flowers was also significantly affected. The earliest female flowering was noted in P1, with a pooled mean of 48.27 days, followed by E2 with 50.82 days, while the maximum number of days (61.87) was taken under A0 (water spray). The interaction E2P1 again recorded the earliest female flower appearance with 47.32 days, followed by E1P1 (49.07 days), while A0 consistently took the longest (61.87 days). The earlier floral initiation under ethephon and 3G cutting treatments may be attributed to ethylene's role in promoting flowering, suppression of apical dominance, and redistribution of assimilates, which collectively enhance hormonal regulation and trigger early reproductive development. These findings are supported by Verma *et al.*, (1984) [41] and Kshirsagar *et al.*, (1995) [22], as well as the hormonal theory proposed by Ito and Saito (1954) [20] regarding the conversion of floral primordia.

1.5 Number of male and female flowers per plant and sex ratio

The application of PGRs and 3G cutting significantly influenced the number of male and female flowers per plant as well as the sex ratio during both years and in the pooled analysis presented in Table 5 and illustrated in Fig.5.

- **Male Flowers:** The minimum number of male flowers per plant was recorded under P1 (3G cutting) with pooled mean of 191.20, followed closely by E_2 (Ethephon @ 200 ppm) and E1 (Ethephon @ 100 ppm) with 205.88 and 208.75, respectively. The combined treatment E2P1 (Ethephon @ 200 ppm + 3G cutting) recorded the lowest male flowers at 178.92, significantly less than the control (A0, 281.25). This reduction in male flowers under 3G cutting and ethephon is likely due to diverted assimilates and hormonal shifts favoring female flower development. Pinching practices increase lateral branches and limit apical dominance, encouraging more pistillate nodes and fewer staminate flowers. These results are supported by Mir (2007) [44], Ciba & Syamala (2017) [45], and Saifuddin *et al.*, (2010) [46].
- **Female Flowers:** Conversely, P1 (3G cutting) showed the maximum number of female flowers with a pooled mean of 30.25, closely followed by E2 (29.94) and E1 (27.76). The combined treatment E2P1 showed the highest female flower count (32.66) and was statistically at par with E1P1 (32.28). The lowest female flower count was observed in the control (A0) with 19.25. These results confirm that both ethephon and 3G cutting are effective in promoting femaleness, likely due to ethylene's role in sex differentiation and pruning's influence on hormonal balance. Similar findings were reported by Chaurasiya *et al.*, (2020) [9], Chapagain *et al.*, (2022) [8], and Bhandary *et al.*, (1974) [6].
- **Sex Ratio (M:F):** The lowest sex ratio (i.e., more favorable towards female flowers) was found in P1 (6.85), followed by E2 (7.02) and E1 (7.16). The E2P1 treatment achieved the lowest sex ratio (5.48), indicating a strong shift towards femaleness, significantly outperforming the control (A0, 14.62). This narrowing of the sex ratio under 3G cutting and ethephon treatments is attributed to the enhancement of female flower production and suppression of male flower formation. Ethylene likely suppresses gibberellin biosynthesis-responsible for male flowers-while promoting female differentiation. Similar effects were documented by Little *et al.*, (2007) [24], Bhandary *et al.*, (1974) [6], and Anand *et al.*, (2014) [1].

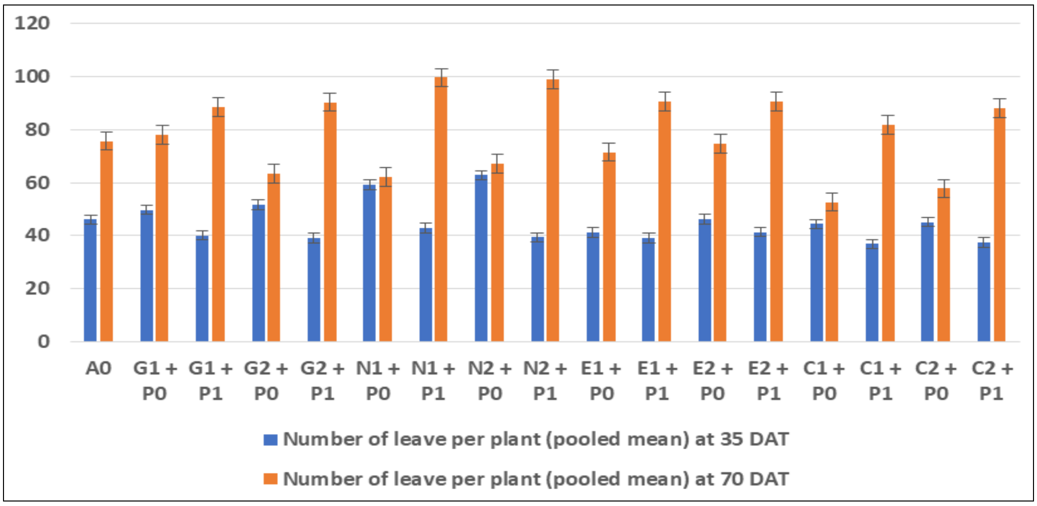


Fig.1 Interaction effect of PGRs and 3G cutting on number of leaves per plant at 35 and 70 DAT

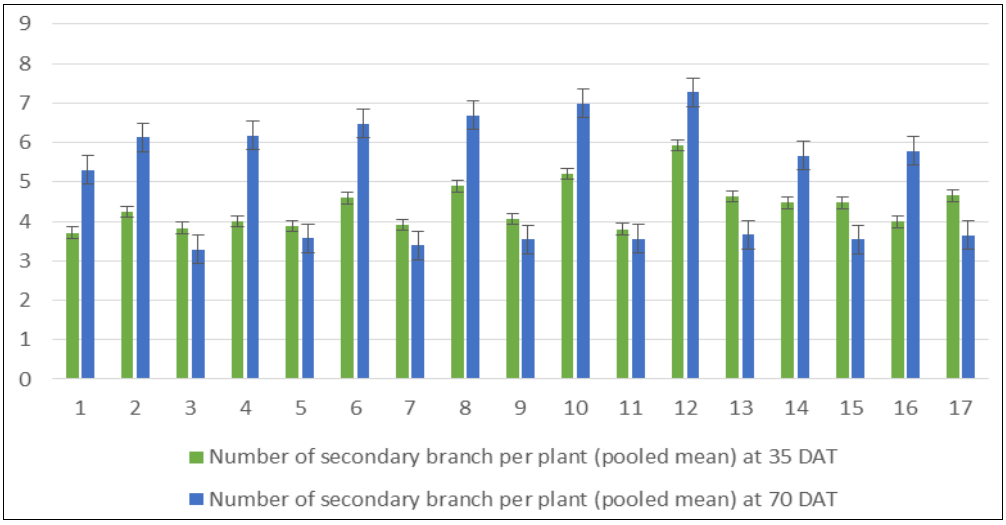


Fig 2 Interaction effect of PGRs and 3G cutting on number of secondary branches plant^{-1} at 35 and 70 DAT

Table 1: Effect of PGRs and 3G cutting on number of leaves per plant at 35 and 70 DAT

Treatments	Number of leaves per plant at 35 DAT			Number of leaves per plant at 70 DAT		
	2023-24	2024-25	Pooled	2023-24	2024-25	Pooled
A_0 (Control: Water Spray)	50.27	41.73	46.00	78.20	71.73	75.68
Factor A (PGR)						
G_1 (GA_3 @ 100 ppm)	46.91	42.77	44.84	87.08	80.82	83.34
G_2 (GA_3 @ 150 ppm)	47.08	43.58	45.33	81.02	74.76	76.80
N_1 (NAA @ 60 ppm)	51.81	52.64	52.22	83.09	76.83	80.87
N_2 (NAA @ 120 ppm)	56.39	54.22	55.31	87.73	81.47	83.14
E_1 (Ethephon @ 100 ppm)	40.61	49.61	40.11	83.86	77.60	81.12
E_2 (Ethephon @ 200 ppm)	44.85	42.50	43.67	85.51	79.25	82.72
C_1 (CCC @ 50 ppm)	40.35	38.70	39.52	70.08	63.82	67.26
C_2 (CCC @ 100 ppm)	42.73	39.63	41.18	75.81	69.55	72.91
SEm (±)	0.60	0.56	0.31	2.03	0.98	0.57
CD (5%)	1.74	1.62	0.91	5.87	2.83	1.65
Factor B (Cutting)						
P_0 (No 3G Cutting)	52.14	50.55	51.34	69.29	63.03	65.90
P_1 (3G Cutting)	41.05	37.86	39.45	94.25	87.99	91.14
SEm (±)	0.60	0.56	0.31	2.03	0.98	0.57
CD (5%)	1.74	1.62	0.91	5.87	2.83	1.65
Int. A X B						
A_0 (Control: Water Spray)	50.27	41.73	46.00	78.20	71.73	75.68
SEm (±)	0.85	0.48	0.32	5.61	1.35	1.07
CD (5%)	1.27	1.13	1.04	7.18	1.88	1.42
G_1P_0 (GA_3@100ppm+No 3G Cutting)	51.33	48.04	49.69	81.98	75.72	78.07
G_1P_1 (GA_3@100ppm+ 3G Cutting)	42.49	37.49	39.99	92.19	85.93	88.61
G_2P_0(GA_3@150ppm+No 3G Cutting)	54.06	59.06	51.56	66.85	60.59	63.23
G_2P_1(GA_3@150ppm+ 3G Cutting)	40.09	38.09	39.09	95.18	88.92	90.37
N_1P_0(NAA@60ppm+No 3G Cutting)	60.16	58.31	59.23	65.21	58.95	62.05
N_1P_1(NAA@60ppm+3G Cutting)	43.45	41.97	42.71	100.97	94.71	99.69
N_2P_0(NAA@120ppm+No3G Cutting)	65.44	60.11	62.77	70.83	64.57	67.20
N_2P_1(NAA@120ppm+3G Cutting)	40.34	38.34	39.34	104.63	98.37	99.07
E_1P_0(ETP@100ppm+No 3G Cutting)	40.10	42.10	41.10	75.21	68.95	71.53
E_1P_1(ETP@100ppm+3G Cutting)	41.12	37.12	39.12	92.51	86.25	90.71
E_2P_0(ETP@200ppm+No 3G Cutting)	46.93	45.22	46.08	77.86	71.60	74.76
E_2P_1(ETP@200ppm+3G Cutting)	42.77	39.77	41.27	93.15	86.89	90.69
C_1P_0(CCC@50ppm+No 3G Cutting)	45.93	42.62	44.28	55.10	48.84	52.62
C_1P_1(CCC@50ppm+3G Cutting)	38.77	34.77	36.77	85.06	78.80	81.91
C_2P_0(CCC@100ppm+No3G Cutting)	46.13	43.93	45.03	61.28	55.02	57.72
C_2P_1(CCC@100ppm+3G Cutting)	39.33	35.33	37.33	90.34	84.08	88.09
SEm (±)	1.20	1.12	0.63	4.06	1.96	1.14
CD (5%)	3.48	3.25	1.82	11.74	5.66	3.30
CV	9.02	8.65	8.01	8.13	7.96	6.34

Table 2: Effect of PGRs and 3G cutting on number of secondary branches plant^{-1} 35 DAT and 70 DAT

Treatments	Number of secondary branches per plant at 35 DAT			Number of secondary branches per plant at 70 DAT		
	2023-24	2024-25	Pooled	2023-24	2024-25	Pooled
A_0 (Control: Water Spray)	4.42	3.01	3.71	5.54	5.07	5.31
Factor A (PGR)						
G_1 (GA_3 @ 100 ppm)	4.24	3.84	4.04	4.98	4.72	4.85
G_2 (GA_3 @ 150 ppm)	4.14	3.74	3.94	4.85	4.59	4.72
N_1 (NAA @ 60 ppm)	4.46	4.06	4.26	5.07	4.81	4.94
N_2 (NAA @ 120 ppm)	4.68	4.28	4.48	5.25	4.99	5.12
E_1 (Ethephon @ 100 ppm)	4.70	4.30	4.50	5.41	5.15	5.28
E_2 (Ethephon @ 200 ppm)	5.48	5.08	5.28	5.60	5.34	5.47
C_1 (CCC @ 50 ppm)	4.67	4.27	4.47	4.74	4.48	4.61
C_2 (CCC @ 100 ppm)	4.52	4.12	4.32	4.85	4.59	4.72
SEm (±)	0.18	0.16	0.17	0.17	0.18	0.19
CD (5%)	NS	NS	NS	NS	NS	NS
Factor B (Cutting)						
P_0 (No 3G Cutting)	4.86	4.46	4.66	6.53	6.27	6.40
P_1 (3G Cutting)	4.35	3.95	4.15	3.65	3.39	3.52
SEm (±)	0.18	0.16	0.17	0.17	0.18	0.19
CD (5%)	NS	NS	NS	NS	NS	NS
Int. A X B						
A_0 (Control: Water Spray)	4.42	3.01	3.71	5.54	5.07	5.31
SEm (±)	0.80	0.69	0.58	0.27	0.24	0.20
CD (5%)	NS	NS	NS	NS	NS	NS
G_1P_0 (GA_3@100ppm+No 3G Cutting)	4.45	4.05	4.25	6.26	6.00	6.13
G_1P_1 (GA_3@100ppm+ 3G Cutting)	4.03	3.63	3.83	3.41	3.15	3.28
G_2P_0(GA_3@150ppm+No 3G Cutting)	4.20	3.80	4.00	6.30	6.04	6.17
G_2P_1(GA_3@150ppm+ 3G Cutting)	4.08	3.68	3.88	3.70	3.44	3.57
N_1P_0(NAA@60ppm+No 3G Cutting)	4.79	4.39	4.59	6.61	6.35	6.48
N_1P_1(NAA@60ppm+3G Cutting)	4.12	3.72	3.92	3.52	3.26	3.39
N_2P_0(NAA@120ppm+No3G Cutting)	5.09	4.69	4.89	6.82	6.56	6.69
N_2P_1(NAA@120ppm+3G Cutting)	4.27	3.87	4.07	3.67	3.41	3.54
E_1P_0(ETP@100ppm+No 3G Cutting)	5.40	5.00	5.20	7.12	6.86	6.99
E_1P_1(ETP@100ppm+3G Cutting)	4.00	3.60	3.80	3.69	3.43	3.56
E_2P_0(ETP@200ppm+No 3G Cutting)	6.13	5.73	5.93	7.40	7.14	7.27
E_2P_1(ETP@200ppm+3G Cutting)	4.83	4.43	4.63	3.80	3.54	3.67
C_1P_0(CCC@50ppm+No 3G Cutting)	4.67	4.27	4.47	5.80	5.54	5.67
C_1P_1(CCC@50ppm+3G Cutting)	4.67	4.27	4.47	3.67	3.41	3.54
C_2P_0(CCC@100ppm+No3G Cutting)	4.19	3.79	3.99	5.91	5.65	5.78
C_2P_1(CCC@100ppm+3G Cutting)	4.85	4.45	4.65	3.78	3.52	3.65
SEm (±)	0.36	0.33	0.33	0.34	0.33	0.35
CD (5%)	NS	NS	NS	NS	NS	NS
CV	6.51	7.14	7.26	6.05	6.00	7.35

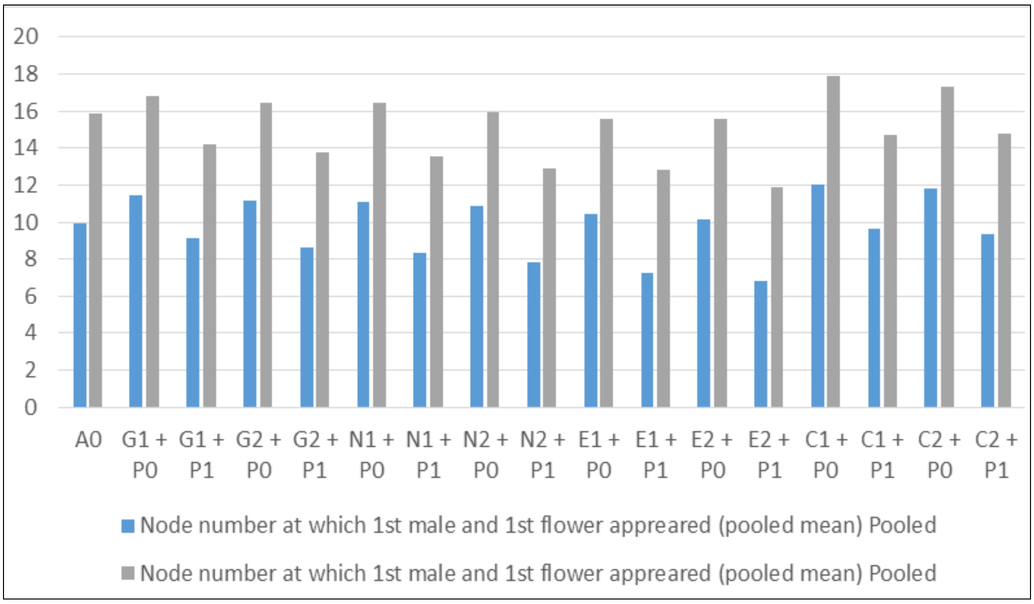


Fig 3: Interaction effect of PGRs and 3G cutting on node numbers at which the first male and female flowers appeared

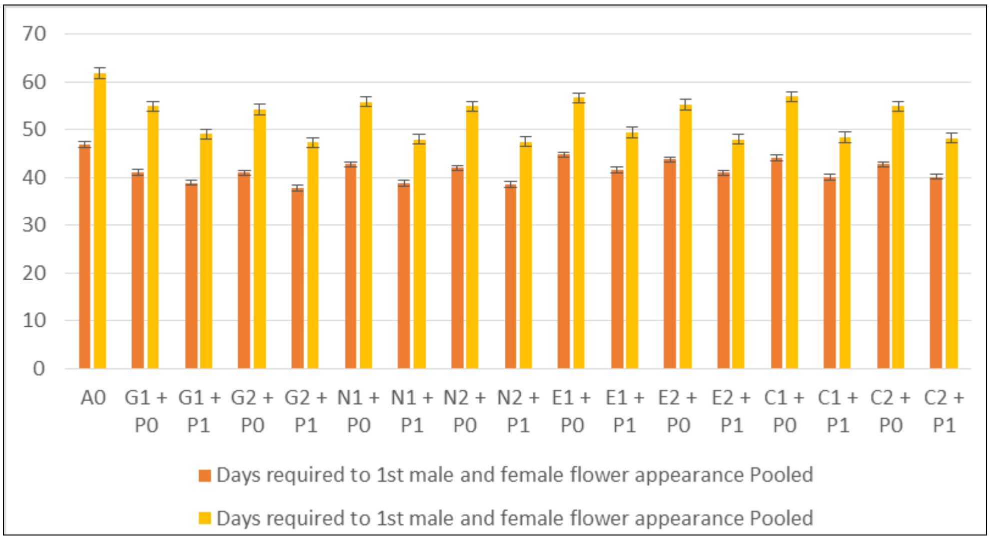


Fig 4: Interaction effect of PGRs and 3G cutting on days required to the first male and female flowers appearance

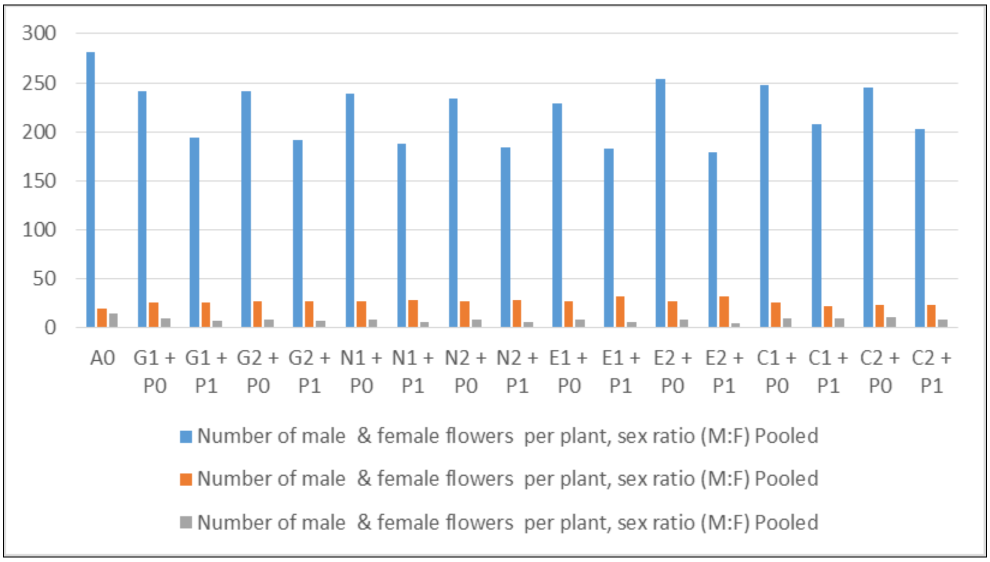


Fig 5: Interaction effect of PGRs and 3G cutting on number of male and female flowers per plant & sex ratio (M:F)

Table 3: Effect of PGRs and 3G cutting on node number at which 1st male and 1st female flower appeared

Treatments	Node number at which 1st male flower appeared			Node number at which 1st female flower appeared		
	2023-24	2024-25	Pooled	2023-24	2024-25	Pooled
A_0 (Control: Water Spray)	9.06	10.81	9.94	16.00	15.66	15.84
Factor A (PGR)						
G_1 (GA_3 @ 100 ppm)	9.53	11.07	10.30	15.90	15.08	15.51
G_2 (GA_3 @ 150 ppm)	9.14	10.64	9.89	15.69	14.67	15.12
N_1 (NAA @ 60 ppm)	8.90	10.52	9.71	15.50	14.47	14.98
N_2 (NAA @ 120 ppm)	8.73	9.92	9.32	15.07	13.90	14.42
E_1 (Ethephon @ 100 ppm)	8.21	9.46	8.83	14.71	13.62	14.20
E_2 (Ethephon @ 200 ppm)	7.96	9.07	8.51	14.33	13.04	13.73
C_1 (CCC @ 50 ppm)	10.28	10.27	10.27	16.63	15.74	16.29
C_2 (CCC @ 100 ppm)	9.87	11.32	10.59	16.50	15.52	16.02
SEm (±)	0.30	0.35	0.35	0.33	0.38	0.36
CD (5%)	0.88	1.02	1.03	0.97	1.11	1.04
Factor B (Cutting)						
P_0 (No 3G Cutting)	11.42	11.98	11.70	17.07	16.03	16.49
P_1 (3G Cutting)	7.88	8.87	8.37	14.01	12.98	13.57
SEm (±)	0.30	0.35	0.35	0.33	0.38	0.36
CD (5%)	0.88	1.02	1.03	0.97	1.11	1.04
Int. A X B						
A_0 (Control: Water Spray)	9.06	10.81	9.94	16.00	15.66	15.84
SEm (±)	0.16	0.25	0.05	0.66	0.88	0.76
CD (5%)	0.97	1.53	0.31	4.03	5.38	4.65
G_1P_0 (GA_3@100ppm+No 3G Cutting)	10.55	12.36	11.46	17.37	16.60	16.81

G_1P_1 (GA_3@100ppm+ 3G Cutting)	8.50	9.77	9.14	14.43	13.55	14.20
G_2P_0(GA_3@150ppm+No 3G Cutting)	10.16	12.16	11.16	17.16	16.05	16.48
G_2P_1(GA_3@150ppm+ 3G Cutting)	8.12	9.12	8.62	14.22	13.29	13.76
N_1P_0(NAA@60ppm+No 3G Cutting)	10.08	12.08	11.08	16.89	15.93	16.41
N_1P_1(NAA@60ppm+3G Cutting)	7.72	8.96	8.34	14.10	13.01	13.55
N_2P_0(NAA@120ppm+No3G Cutting)	9.98	11.71	10.85	16.66	15.40	15.91
N_2P_1(NAA@120ppm+3G Cutting)	7.47	8.13	7.80	13.47	12.40	12.93
E_1P_0(ETP@100ppm+No 3G Cutting)	9.49	11.33	10.41	16.40	15.04	15.60
E_1P_1(ETP@100ppm+3G Cutting)	6.92	7.58	7.25	13.02	12.20	12.80
E_2P_0(ETP@200ppm+No 3G Cutting)	9.23	11.12	10.18	16.09	15.02	15.56
E_2P_1(ETP@200ppm+3G Cutting)	6.68	7.01	6.85	12.56	11.05	11.89
C_1P_0(CCC@50ppm+No 3G Cutting)	11.63	12.48	12.06	18.06	17.29	17.90
C_1P_1(CCC@50ppm+3G Cutting)	8.92	10.36	9.64	15.19	14.19	14.69
C_2P_0(CCC@100ppm+No3G Cutting)	11.02	12.63	11.83	17.95	16.88	17.29
C_2P_1(CCC@100ppm+3G Cutting)	8.71	10.01	9.36	15.05	14.15	14.75
SEm (±)	0.61	0.70	0.71	0.67	0.77	0.72
CD (5%)	1.77	2.04	2.07	1.94	2.23	0.08
CV	11.01	11.04	11.99	9.59	10.94	10.20

Table 4: Effect of PGRs and 3G cutting on Days required to 1st male flower and 1st female flower appearance

Treatments	Days required to 1st male flower appearance			Days required to 1st female flower appearance		
	2023-24	2024-25	Pooled	2023-24	2024-25	Pooled
A_0 (Control: Water Spray)	45.14	48.44	46.85	60.14	63.44	61.87
Factor A (PGR)						
G_1 (GA_3 @ 100 ppm)	38.27	41.57	39.99	50.27	53.57	52.00
G_2 (GA_3 @ 150 ppm)	37.88	41.18	39.37	49.38	52.68	50.82
N_1 (NAA @ 60 ppm)	39.11	42.41	40.77	50.29	53.59	51.95
N_2 (NAA @ 120 ppm)	38.77	42.07	40.26	49.77	53.07	51.21
E_1 (Ethephon @ 100 ppm)	41.40	44.70	43.19	51.27	54.57	53.08
E_2 (Ethephon @ 200 ppm)	40.58	43.88	42.38	49.83	53.13	51.65
C_1 (CCC @ 50 ppm)	40.16	43.46	42.08	50.71	54.01	52.71
C_2 (CCC @ 100 ppm)	39.79	43.09	41.47	49.91	53.21	51.59
SEm (±)	1.38	1.47	1.33	1.83	1.99	1.82
CD (5%)	4.00	4.26	3.85	5.30	5.75	5.26
Factor B (Cutting)						
P_0 (No 3G Cutting)	40.43	44.57	42.77	54.03	57.33	55.49
P_1 (3G Cutting)	37.72	41.02	39.61	46.33	49.63	48.27
SEm (±)	1.38	1.47	1.33	1.83	1.99	1.82
CD (5%)	4.00	4.26	3.85	5.30	5.75	5.26
Int. A X B						
A_0 (Control: Water Spray)	45.14	48.44	46.85	60.14	63.44	61.87
SEm (±)	0.22	0.58	0.32	0.33	0.58	0.33
CD (5%)	1.35	3.54	1.94	2.08	3.54	2.08
G_1P_0 (GA_3@100ppm+No 3G Cutting)	39.84	43.14	41.07	53.84	57.14	54.93
G_1P_1 (GA_3@100ppm+ 3G Cutting)	36.70	40.00	38.92	46.70	50.00	49.07
G_2P_0(GA_3@150ppm+No 3G Cutting)	39.62	42.92	40.96	53.07	56.37	54.31
G_2P_1(GA_3@150ppm+ 3G Cutting)	36.13	39.43	37.77	45.68	48.98	47.32
N_1P_0(NAA@60ppm+No 3G Cutting)	41.09	44.39	42.76	54.24	57.54	55.91
N_1P_1(NAA@60ppm+3G Cutting)	37.13	40.43	38.79	46.33	49.63	47.99
N_2P_0(NAA@120ppm+No3G Cutting)	40.68	43.98	42.01	53.68	56.98	54.91
N_2P_1(NAA@120ppm+3G Cutting)	36.85	40.15	38.51	45.85	49.15	47.51
E_1P_0(ETP@100ppm+No 3G Cutting)	43.47	46.77	44.78	55.47	58.77	56.69
E_1P_1(ETP@100ppm+3G Cutting)	39.33	42.63	41.60	47.08	50.38	49.47
E_2P_0(ETP@200ppm+No 3G Cutting)	42.13	45.43	43.77	53.63	56.93	55.27
E_2P_1(ETP@200ppm+3G Cutting)	39.03	42.33	40.99	46.03	49.33	48.04
C_1P_0(CCC@50ppm+No 3G Cutting)	41.86	45.16	44.05	54.61	57.91	56.96
C_1P_1(CCC@50ppm+3G Cutting)	38.46	41.76	40.12	46.81	50.11	48.47
C_2P_0(CCC@100ppm+No3G Cutting)	41.44	44.74	42.76	53.69	56.99	54.92
C_2P_1(CCC@100ppm+3G Cutting)	38.13	41.43	40.17	46.13	49.43	48.25
SEm (±)	2.77	2.95	2.66	3.67	3.98	3.64
CD (5%)	8.01	8.52	7.70	10.60	11.56	10.52
CV	11.36	11.16	10.47	11.79	12.01	11.32

Table 5. Effect of PGRs and 3G cutting on number of male & female flowers per plant and sex ratio (M:F)

Treatments	Number of male flowers per plant				Number of female flowers per plant			Sex ratio (M:F)	
	2023-24	2024-25	Pooled	2023-24	2024-25	Pooled	2023-24	2024-25	Pooled
A_0 (Control: Water Spray)	305.00	257.50	281.25	20.00	18.50	19.25	15.25	13.91	14.62
Factor A (PGR)									
G_1 (GA_3 @ 100 ppm)	224.33	211.83	218.08	27.07	24.57	25.05	8.29	8.62	8.71
G_2 (GA_3 @ 150 ppm)	223.16	210.66	216.91	27.73	25.23	26.18	7.91	8.19	8.07
N_1 (NAA @ 60 ppm)	219.39	206.89	213.14	28.23	25.73	26.88	7.50	7.73	7.61
N_2 (NAA @ 120 ppm)	215.00	202.50	208.75	29.25	26.75	27.99	7.38	7.61	7.52
E_1 (Ethephon @ 100 ppm)	212.13	199.63	205.88	29.12	26.62	27.76	7.05	6.99	7.02
E_2 (Ethephon @ 200 ppm)	222.92	210.42	216.67	31.05	28.55	29.94	7.11	7.29	7.16
C_1 (CCC @ 50 ppm)	234.00	221.50	227.75	25.00	22.50	23.91	9.36	9.84	9.53
C_2 (CCC @ 100 ppm)	229.92	217.42	223.67	24.75	22.25	23.54	9.29	9.77	9.50
SEm (±)	7.16	6.91	7.48	0.89	0.83	0.98	0.27	0.26	0.26
CD (5%)	20.68	19.96	21.60	2.58	2.41	2.84	0.79	0.76	0.77
Factor B (Cutting)									
P_0 (No 3G Cutting)	247.76	235.26	241.51	28.73	26.23	27.64	8.93	9.32	9.22
P_1 (3G Cutting)	197.45	184.95	191.20	31.37	28.87	30.25	6.87	6.83	6.85
SEm (±)	7.16	6.91	7.48	0.89	0.83	0.98	0.27	0.26	0.26
CD (5%)	20.68	19.96	21.60	2.58	2.41	2.84	0.79	0.76	0.77
Int. A X B									
A_0 (Control: Water Spray)	305.00	257.50	281.25	20.00	18.50	19.25	15.25	13.91	14.62
SEm (±)	7.04	5.95	6.50	0.41	0.35	0.40	0.36	0.27	0.36
CD (5%)	42.80	36.20	39.50	2.53	2.18	2.45	2.24	1.65	2.21
G_1P_0 (GA_3@100ppm+No 3G Cutting)	248.00	235.50	241.75	27.33	24.83	26.08	9.07	9.48	9.27
G_1P_1 (GA_3@100ppm+ 3G Cutting)	200.67	188.17	194.42	26.80	24.30	25.55	7.49	7.74	7.61
G_2P_0(GA_3@150ppm+No 3G Cutting)	247.99	235.49	241.74	28.33	25.83	27.08	8.75	9.12	8.93
G_2P_1(GA_3@150ppm+ 3G Cutting)	198.33	185.83	192.08	28.13	25.63	26.88	7.05	7.25	7.15
N_1P_0(NAA@60ppm+No 3G Cutting)	245.00	232.50	238.75	29.00	26.50	27.75	8.45	8.77	8.60
N_1P_1(NAA@60ppm+3G Cutting)	193.78	181.28	187.53	29.50	27.00	28.25	6.57	6.71	6.64
N_2P_0(NAA@120ppm+No3G Cutting)	239.99	227.49	233.74	28.40	25.90	27.15	8.45	8.78	8.61
N_2P_1(NAA@120ppm+3G Cutting)	190.00	177.50	183.75	29.83	27.33	28.58	6.37	6.49	6.43
E_1P_0(ETP@100ppm+No 3G Cutting)	235.60	223.10	229.35	28.47	25.97	27.22	8.28	8.59	8.43
E_1P_1(ETP@100ppm+3G Cutting)	188.66	176.16	182.41	33.63	31.13	32.38	5.61	5.66	5.63
E_2P_0(ETP@200ppm+No 3G Cutting)	260.66	248.16	254.41	28.83	26.33	27.58	9.04	9.42	9.22
E_2P_1(ETP@200ppm+3G Cutting)	185.17	172.67	178.92	33.91	31.41	32.66	5.46	5.50	5.48
C_1P_0(CCC@50ppm+No 3G Cutting)	253.66	241.16	247.41	27.00	24.50	25.75	9.39	9.84	9.61
C_1P_1(CCC@50ppm+3G Cutting)	214.33	201.83	208.08	23.00	20.50	21.75	9.32	9.85	9.57
C_2P_0(CCC@100ppm+No3G Cutting)	251.17	238.67	244.92	24.50	22.00	23.25	10.25	10.85	10.53
C_2P_1(CCC@100ppm+3G Cutting)	208.66	196.16	202.41	25.00	22.50	23.75	8.35	8.72	8.52
SEm (±)	14.32	13.82	11.07	1.78	1.67	1.96	0.55	0.53	0.53
CD (5%)	41.36	39.93	19.89	5.16	4.82	5.68	1.59	1.53	1.54
CV	10.26	10.58	7.62	10.55	10.83	12.18	10.61	9.93	10.13

2. Fruit metrics

2.1 Days taken to 1st fruit picking and last fruit picking

The results revealed that both PGRs and 3G cutting had non-significant (NS) effects on the number of days taken to first and last fruit picking in presented in Table 6 and illustrated in Fig.6. However, numerical trends showed that the earliest first fruit picking was recorded under E2P1 (Ethephon @ 200 ppm + 3G cutting) with 72.68 days, followed by E1P1 (73.73 days), while the maximum day require for first picking was under A0 (water spray) with 89.79 days. Similarly, for last fruit picking, the earliest was also noted in E2P1 (132.68 days), followed by E1P1 (133.73 days), and the maximum was again observed under A0 (149.85 days). Though statistically non-significant, the consistent trend of earlier harvesting in ethephon-treated and 3G-cut plants suggests that these treatments may promote faster reproductive growth and early crop maturity. This is likely due to ethylene's role in inducing early female flowering and fruit development, as also supported by the findings of Ghani *et al.*, (2013) [16], Kadi *et al.*, (2018) [21], and Soni *et al.*, (2016) [38].

2.1 Fruit length (cm), Fruit diameter (mm) and Average fruit weight (g)

The application of PGRs and 3G cutting significantly influenced fruit length, diameter, and average fruit weight across both years and pooled mean presented in Table 7 and illustrated in Fig.7. Among main effects, Ethephon @ 200 ppm (E2) consistently recorded the highest fruit length (15.94 cm), followed closely by 3G cutting (P1) with 15.57 cm. The shortest fruits were found in control (A0) with 10.13 cm. In interaction effects, E2P1 (Ethephon 200 ppm + 3G cutting) exhibited the maximum fruit length (20.33 cm), statistically at par with E1P1 (17.27 cm) and N2P1 (17.07 cm).

For fruit diameter, P1 treatment showed the thickest fruits (50.18 mm), closely followed by E2 (48.75 mm), while A0 recorded the thinnest fruits (33.10 mm). The interaction effect E2P1 resulted in the highest diameter (54.06 mm), statistically at par with N2P1 (52.69 mm) and E1P1 (51.34 mm). Similarly, average fruit weight was highest under P1 (161.91 g) and E2 (160.42 g), and lowest in A0 (107.97 g). The E2P1 combination produced the heaviest fruits (208.04 g), followed by E1P1 (194.42 g) and N2P1 (181.78 g).

This enhanced fruit size and weight under Ethephon and 3G pruning may be attributed to improved hormonal balance and resource partitioning. Ethylene likely promoted early flowering and fruit set, while pruning enhanced assimilate distribution to fewer, well-developed fruits. These findings align with Singh & Singh (1984) [37], Nagamani *et al.*, (2015) [27], and Carine Cocco (2021) [11], highlighting the synergistic effect of pruning and growth regulators in enhancing fruit morphology and yield traits.

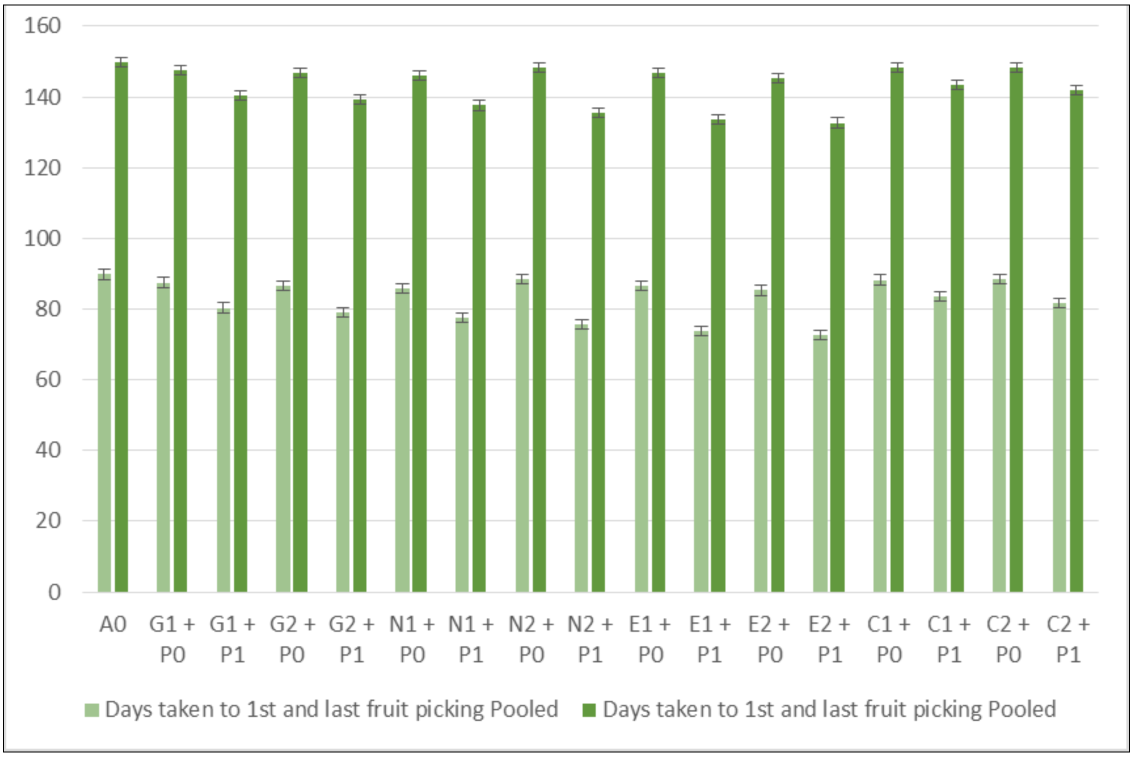


Fig 6: Interaction effect of PGRs and 3G cutting on Days taken to 1st and last fruit picking

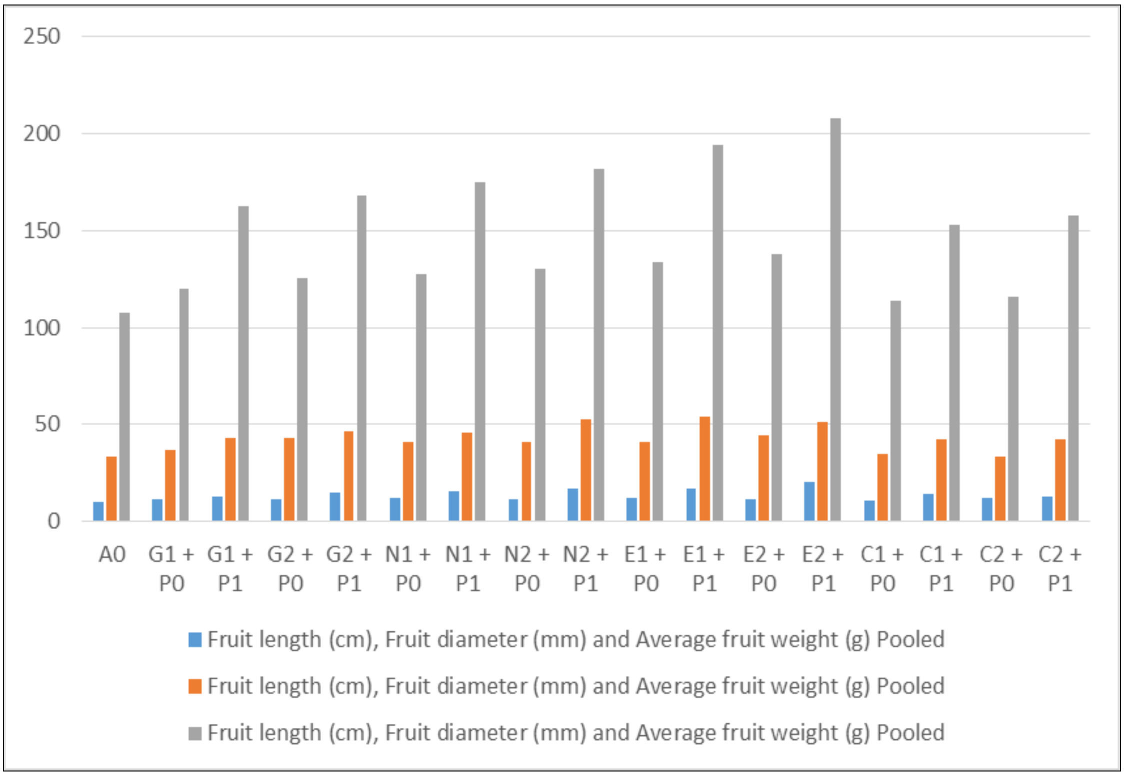


Fig 7: Interaction effect of PGRs and 3G cutting on Fruit length (cm), Fruit diameter (mm) & Average fruit weight (g)

Table 6: Effect of PGRs and 3G cutting on Days taken to 1st and last fruit picking

Treatments	Days taken to 1st fruit picking			Days taken to last fruit picking		
	2023-24	2024-25	Pooled	2023-24	2024-25	Pooled
A_0 (Control: Water Spray)	88.14	91.44	89.79	148.14	151.55	149.85
Factor A (PGR)						
G_1 (GA_3 @ 100 ppm)	82.27	85.57	83.92	142.27	145.57	143.92
G_2 (GA_3 @ 150 ppm)	81.28	84.58	82.93	141.28	144.58	142.93
N_1 (NAA @ 60 ppm)	80.09	83.39	81.74	140.09	143.39	141.74
N_2 (NAA @ 120 ppm)	80.27	83.57	81.92	140.27	143.57	141.92
E_1 (Ethephon @ 100 ppm)	78.57	81.87	80.22	138.57	141.87	140.22
E_2 (Ethephon @ 200 ppm)	77.33	80.63	78.98	137.33	140.63	138.98
C_1 (CCC @ 50 ppm)	84.21	87.51	85.86	144.21	147.51	145.86
C_2 (CCC @ 100 ppm)	83.41	86.71	85.06	143.41	146.71	145.06
SEm (±)	2.53	2.94	2.93	5.10	4.44	4.43
CD (5%)	NS	NS	NS	NS	NS	NS
Factor B (Cutting)						
P_0 (No 3G Cutting)	85.48	88.78	87.13	145.48	148.78	147.13
P_1 (3G Cutting)	76.38	79.68	78.03	136.38	139.68	138.03
SEm (±)	2.53	2.94	2.93	5.10	4.44	4.43
CD (5%)	NS	NS	NS	NS	NS	NS
Int. A X B						
A_0 (Control: Water Spray)	88.14	91.44	89.79	148.14	151.55	149.85
SEm (±)	1.78	1.80	0.89	3.33	2.52	3.34
CD (5%)	NS	NS	NS	NS	NS	NS
G_1P_0 (GA_3@100ppm+No 3G Cutting)	85.84	89.14	87.49	145.84	149.14	147.49
G_1P_1 (GA_3@100ppm+ 3G Cutting)	78.70	82.00	80.35	138.70	142.00	140.35
G_2P_0(GA_3@150ppm+No 3G Cutting)	85.07	88.37	86.72	145.07	148.37	146.72
G_2P_1(GA_3@150ppm+ 3G Cutting)	77.48	80.78	79.13	137.48	140.78	139.13
N_1P_0(NAA@60ppm+No 3G Cutting)	84.24	87.54	85.89	144.24	147.54	145.89
N_1P_1(NAA@60ppm+3G Cutting)	75.93	79.23	77.58	135.93	139.23	137.58
N_2P_0(NAA@120ppm+No 3G Cutting)	86.68	89.98	88.33	146.68	149.98	148.33
N_2P_1(NAA@120ppm+3G Cutting)	73.85	77.15	75.50	133.85	137.15	135.50
E_1P_0(ETP@100ppm+No 3G Cutting)	85.07	88.37	86.72	145.07	148.37	146.72
E_1P_1(ETP@100ppm+3G Cutting)	72.08	75.38	73.73	132.08	135.38	133.73
E_2P_0(ETP@200ppm+No 3G Cutting)	83.63	86.93	85.28	143.63	146.93	145.28
E_2P_1(ETP@200ppm+3G Cutting)	71.03	74.33	72.68	131.03	134.33	132.68
C_1P_0(CCC@50ppm+No 3G Cutting)	86.61	89.91	88.26	146.61	149.91	148.26
C_1P_1(CCC@50ppm+3G Cutting)	81.81	85.11	83.46	141.81	145.11	143.46
C_2P_0(CCC@100ppm+No 3G Cutting)	86.69	89.99	88.34	146.69	149.99	148.34
C_2P_1(CCC@100ppm+3G Cutting)	80.13	83.43	81.78	140.13	143.43	141.78
SEm (±)	5.07	5.89	5.86	10.20	8.88	8.87
CD (5%)	NS	NS	NS	NS	NS	NS
CV	10.16	11.35	11.51	11.76	10.10	10.11

Table 7: Effect of PGRs and 3G cutting on Fruit length (cm), Fruit diameter (mm) and Average fruit weight (g)

Treatments	Fruit length (cm)			Fruit diameter (mm)			Average fruit weight (g)		
	2023-24	2024-25	Pooled	2023-24	2024-25	Pooled	2023-24	2024-25	Pooled
A_0 (Control: Water Spray)	11.60	8.67	10.13	33.93	32.27	33.10	110.12	105.83	107.97
Factor A (PGR)									
G_1 (GA_3 @ 100 ppm)	12.08	11.53	11.80	40.11	40.07	40.09	110.70	105.45	108.08
G_2 (GA_3 @ 150 ppm)	14.30	11.95	13.12	46.00	43.48	44.74	124.00	118.34	121.17
N_1 (NAA @ 60 ppm)	14.60	12.90	13.75	43.61	43.00	43.31	134.50	128.87	131.68
N_2 (NAA @ 120 ppm)	14.55	13.67	14.11	50.79	42.65	46.72	139.20	133.51	136.35
E_1 (Ethephon @ 100 ppm)	14.15	14.94	14.54	51.37	43.50	47.44	154.10	148.88	151.49
E_2 (Ethephon @ 200 ppm)	15.97	15.91	15.94	50.34	47.16	48.75	163.07	157.77	160.42
C_1 (CCC @ 50 ppm)	13.95	11.00	12.47	39.48	37.34	38.41	99.25	93.85	96.55
C_2 (CCC @ 100 ppm)	13.30	11.75	12.53	37.43	38.37	37.90	92.80	87.43	90.11
SEm (±)	0.48	0.42	0.38	1.56	1.47	1.33	4.01	4.16	2.81
CD (5%)	1.40	1.22	1.11	4.50	4.24	3.84	11.58	12.03	8.11
Factor B (Cutting)									
P_0 (No 3G Cutting)	12.58	10.42	11.50	39.97	38.70	39.33	89.73	84.38	87.05
P_1 (3G Cutting)	15.65	15.49	15.57	49.85	50.52	50.18	164.67	159.15	161.91
SEm (±)	0.48	0.42	0.38	1.56	1.47	1.33	4.01	4.16	2.81
CD (5%)	1.40	1.22	1.11	4.50	4.24	3.84	11.58	12.03	8.11
Int. A X B									
A_0 (Control: Water Spray)	11.60	8.67	10.13	33.93	32.27	33.10	110.12	105.83	107.97
SEm (±)	0.40	0.20	0.54	1.18	0.98	1.09	1.39	1.26	1.33

CD (5%)	2.45	1.23	3.31	7.20	5.99	6.66	8.50	7.71	8.18
G_1P_0 (GA_3@100ppm+No 3G Cutting)	12.80	9.39	11.10	36.28	37.28	36.78	122.20	117.30	119.75
G_1P_1 (GA_3@100ppm+ 3G Cutting)	11.35	13.66	12.51	43.93	42.85	43.39	167.20	157.60	162.40
G_2P_0(GA_3@150ppm+No 3G Cutting)	12.80	9.77	11.29	42.47	43.47	42.97	127.60	123.75	125.68
G_2P_1(GA_3@150ppm+ 3G Cutting)	15.80	14.12	14.96	49.52	43.48	46.50	170.40	165.94	168.17
N_1P_0(NAA@60ppm+No 3G Cutting)	13.30	10.40	11.85	40.83	40.70	40.77	130.20	125.64	127.92
N_1P_1(NAA@60ppm+3G Cutting)	15.90	15.40	15.65	46.39	45.30	45.85	177.80	172.10	174.95
N_2P_0(NAA@120ppm+No3G Cutting)	11.50	10.82	11.16	41.95	39.55	40.75	132.80	128.06	130.43
N_2P_1(NAA@120ppm+3G Cutting)	17.60	16.53	17.07	59.62	45.75	52.69	184.60	178.96	181.78
E_1P_0(ETP@100ppm+No 3G Cutting)	12.50	11.14	11.82	43.12	38.50	40.81	136.20	130.93	133.57
E_1P_1(ETP@100ppm+3G Cutting)	15.80	18.73	17.27	59.62	48.50	54.06	197.00	191.83	194.42
E_2P_0(ETP@200ppm+No 3G Cutting)	11.60	11.50	11.55	48.35	40.32	44.34	140.33	135.28	137.81
E_2P_1(ETP@200ppm+3G Cutting)	20.34	20.31	20.33	52.68	50.00	51.34	210.80	205.27	208.04
C_1P_0(CCC@50ppm+No 3G Cutting)	12.00	9.66	10.83	35.02	34.02	34.52	115.30	113.04	114.17
C_1P_1(CCC@50ppm+3G Cutting)	15.90	12.33	14.12	43.93	40.65	42.29	155.20	150.67	152.94
C_2P_0(CCC@100ppm+No3G Cutting)	14.10	10.70	12.40	31.74	35.74	33.74	117.20	115.00	116.10
C_2P_1(CCC@100ppm+3G Cutting)	12.50	12.80	12.65	43.12	41.00	42.06	160.39	155.86	158.13
SEm (±)	0.97	0.84	0.77	3.12	2.94	2.66	8.02	8.33	5.62
CD (5%)	2.80	2.44	2.23	9.01	8.49	7.68	23.16	24.07	16.23
CV	11.33	10.88	9.45	11.49	11.66	10.16	10.61	11.53	7.60

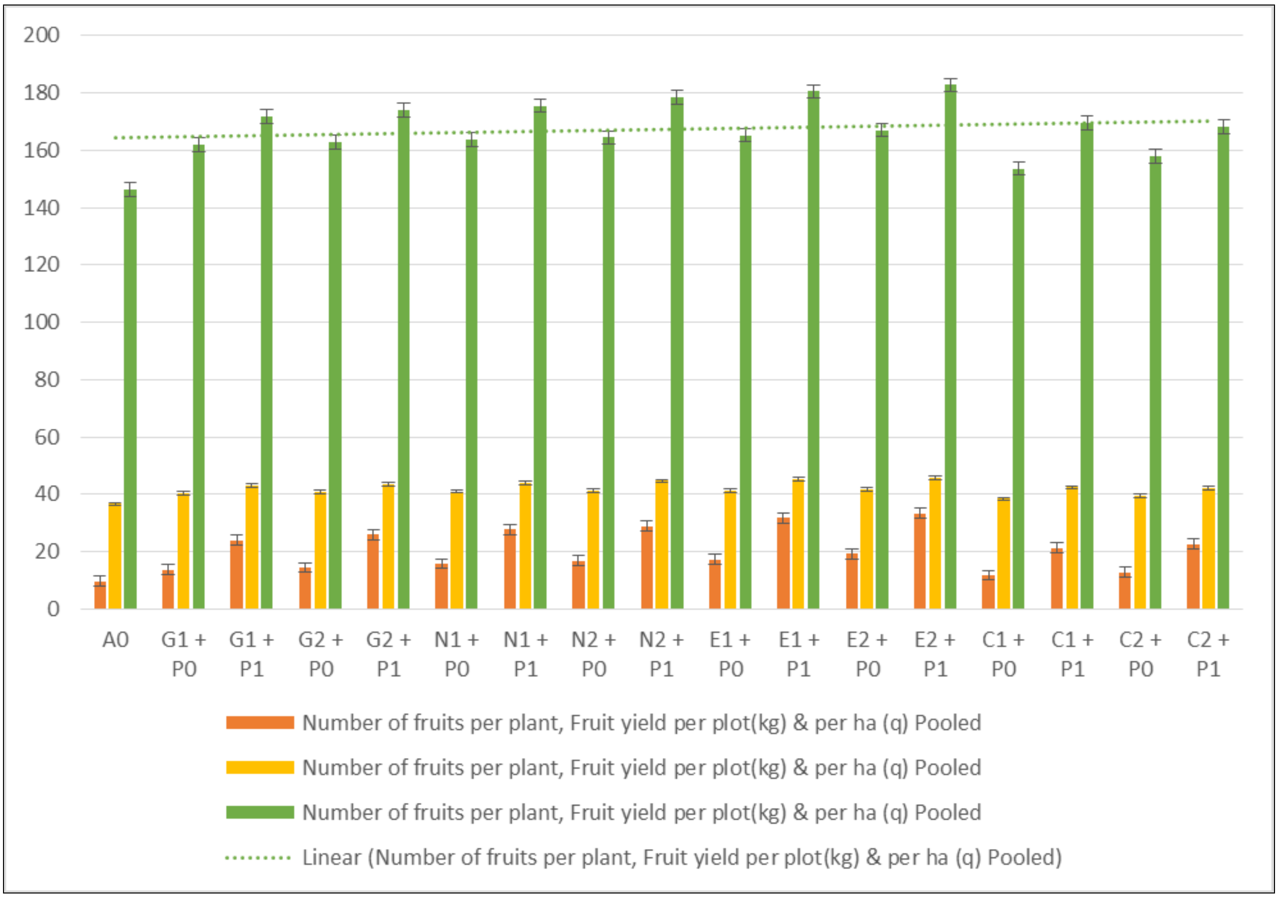


Fig 8: Interaction effect of PGRs and 3G cutting on Number of fruits per plant, fruit yield per plot (kg) and per ha (q)

Table 8: Effect of PGRs and 3G cutting on Number of fruits per plant, Fruit yield per plot (kg) and Fruit yield per ha (q)

Treatments	Number of fruits per plant			Fruit yield per plot (kg)			Fruit yield per ha (q)		
	2023-24	2024-25	Pooled	2023-24	2024-25	Pooled	2023-24	2024-25	Pooled
A_0 (Control: Water Spray)	10.83	8.33	9.58	37.50	35.62	36.56	150.00	142.50	146.25
Factor A (PGR)									
G_1 (GA_3 @ 100 ppm)	19.99	17.52	18.75	42.79	40.65	41.72	171.15	162.59	166.87
G_2 (GA_3 @ 150 ppm)	21.37	18.87	20.12	43.20	41.04	42.12	172.79	164.15	168.47
N_1 (NAA @ 60 ppm)	23.01	20.51	21.76	43.50	41.33	42.41	174.00	165.30	169.65
N_2 (NAA @ 120 ppm)	24.10	21.60	22.85	43.97	41.77	42.87	175.88	167.08	171.48
E_1 (Ethephon @ 100 ppm)	25.75	23.25	24.50	44.34	42.13	43.24	177.38	168.51	172.94
E_2 (Ethephon @ 200 ppm)	27.52	25.02	26.27	44.85	42.61	43.73	179.40	170.43	174.92

C_1 (CCC @ 50 ppm)	17.75	15.25	16.50	41.44	39.37	40.40	165.75	157.46	161.61
C_2 (CCC @ 100 ppm)	18.91	16.41	17.66	41.81	39.72	40.77	167.25	158.89	163.07
SEm (±)	0.69	0.74	0.96	2.17	2.02	2.02	7.23	7.86	7.89
CD (5%)	2.00	2.15	2.01	6.28	5.84	5.83	20.89	22.72	22.80
Factor B (Cutting)									
P_0 (No 3G Cutting)	16.44	13.95	15.19	41.57	39.49	40.53	166.28	157.96	162.12
P_1 (3G Cutting)	28.16	25.66	26.91	44.90	42.66	43.78	179.61	170.63	175.12
SEm (±)	0.69	0.74	0.96	2.17	2.02	2.02	7.23	7.86	7.89
CD (5%)	2.00	2.15	2.01	6.28	5.84	5.83	20.89	22.72	22.80
Int. A X B									
A_0 (Control: Water Spray)	10.83	8.33	9.58	37.50	35.62	36.56	150.00	142.50	146.25
SEm (±)	0.19	0.14	0.22	0.87	0.82	0.42	3.46	3.29	3.38
CD (5%)	1.14	0.87	1.37	5.25	5.00	5.57	21.05	20.01	20.57
G_1P_0 (GA_3@100ppm+No 3G Cutting)	14.79	12.33	13.56	41.51	39.44	40.48	166.05	157.75	161.90
G_1P_1 (GA_3@100ppm+ 3G Cutting)	25.20	22.70	23.95	44.06	41.86	42.96	176.25	167.44	171.85
G_2P_0(GA_3@150ppm+No 3G Cutting)	15.67	13.17	14.42	41.78	39.69	40.73	167.10	158.75	162.93
G_2P_1(GA_3@150ppm+ 3G Cutting)	27.08	24.58	25.83	44.62	42.39	43.51	178.49	169.56	174.03
N_1P_0(NAA@60ppm+No 3G Cutting)	17.01	14.51	15.76	42.00	39.90	40.95	168.00	159.60	163.80
N_1P_1(NAA@60ppm+3G Cutting)	29.01	26.51	27.76	45.00	42.75	43.88	180.00	171.00	175.50
N_2P_0(NAA@120ppm+No3G Cutting)	18.03	15.53	16.78	42.19	40.08	41.13	168.75	160.31	164.53
N_2P_1(NAA@120ppm+3G Cutting)	30.17	27.67	28.92	45.75	43.46	44.61	183.00	173.85	178.43
E_1P_0(ETP@100ppm+No 3G Cutting)	18.50	16.00	17.25	42.38	40.26	41.32	169.50	161.03	165.27
E_1P_1(ETP@100ppm+3G Cutting)	33.00	30.50	31.75	46.31	44.00	45.16	185.25	175.99	180.62
E_2P_0(ETP@200ppm+No 3G Cutting)	20.54	18.04	19.29	42.83	40.69	41.76	171.30	162.74	167.02
E_2P_1(ETP@200ppm+3G Cutting)	34.50	32.00	33.25	46.88	44.53	45.70	187.50	178.13	182.82
C_1P_0(CCC@50ppm+No 3G Cutting)	13.00	10.50	11.75	39.38	37.41	38.39	157.50	149.63	153.57
C_1P_1(CCC@50ppm+3G Cutting)	22.50	20.00	21.25	43.50	41.33	42.41	174.00	165.30	169.65
C_2P_0(CCC@100ppm+No3G Cutting)	14.00	11.50	12.75	40.50	38.48	39.49	162.00	153.90	157.95
C_2P_1(CCC@100ppm+3G Cutting)	23.83	21.33	22.58	43.13	40.97	42.05	172.50	163.88	168.19
SEm (±)	1.38	1.49	1.39	4.35	4.04	4.04	14.47	15.73	15.78
CD (5%)	4.00	4.31	4.02	12.56	11.64	11.67	41.79	45.55	45.60
CV	10.45	12.72	11.13	15.28	14.96	14.56	12.71	14.55	14.22

2.2 Number of fruits per plant, Fruit yield per plot (kg) and per ha (q)

The application of PGRs and 3G cutting significantly influenced the number of fruits per plant, fruit yield per plot, and per hectare across both years and pooled means in presented in Table 8 and illustrated in Fig 8. The highest number of fruits per plant was recorded in the E2P1 (Ethephon @ 200 ppm + 3G cutting) treatment, with a pooled mean of 33.25 fruits, statistically at par with E1P1 (31.75), N2P1 (28.92), and N1P1 (27.76). The individual effects also revealed that P1 (3G cutting) and E2 treatments independently produced higher fruit numbers compared to control (A0), which recorded the lowest values (9.58 fruits per plant).

Similarly, maximum fruit yield per plot was obtained from E2P1 (45.70 kg), followed by E1P1 (45.16 kg) and N2P1 (44.61 kg), while control recorded the lowest (36.56 kg). On a per hectare basis, E2P1 yielded the highest production (182.82 q/ha), followed closely by E1P1 (180.62 q/ha) and N2P1 (178.43 q/ha), with control (A0) showing the least (146.25 q/ha).

These enhancements in yield-related traits are attributed to ethrel's ability to promote female flowering, improved fruit set, and pruning's role in increasing photosynthetic efficiency through better light interception and sink-source balance. The results are consistent with previous findings by Hilli *et al.*, (2010) [18], Kadi *et al.*, (2018) [21], and Chapagain *et al.*, (2022) [8], who reported improved fruit number and yield due to similar PGR and pruning treatments in cucurbits. Thus, the integration of PGRs especially Ethephon and 3G cutting proves effective in enhancing both yield quantity and quality in bitter gourd cultivation.

Plate 1: 3G Cutting of bitter gourd tagged plants

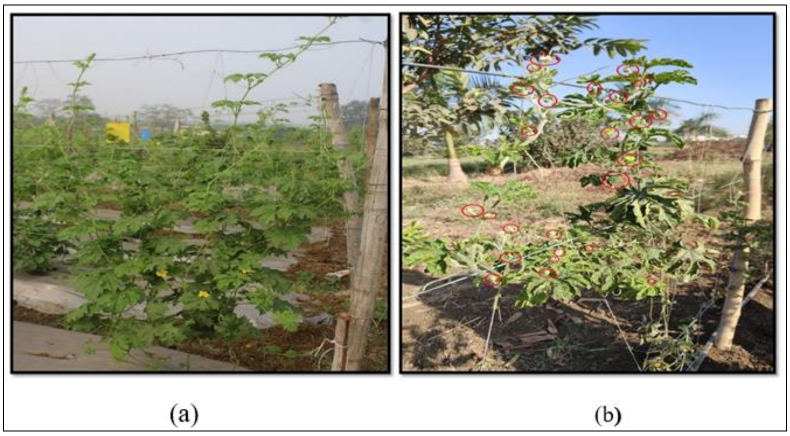


Plate 2: (a) Without 3G Cutting, (b) With 3G Cutting

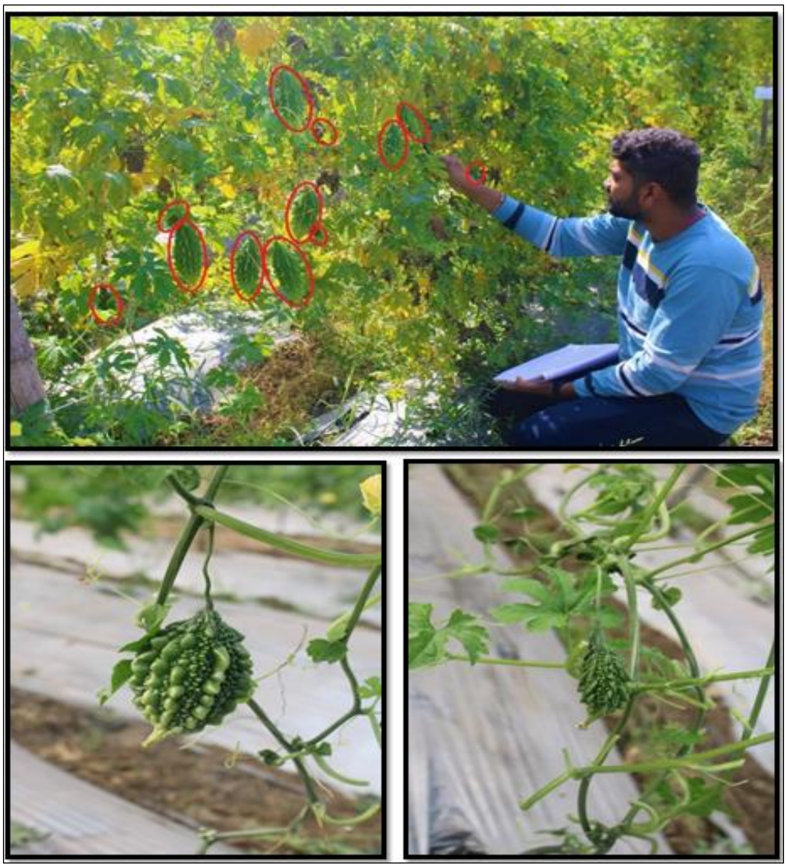
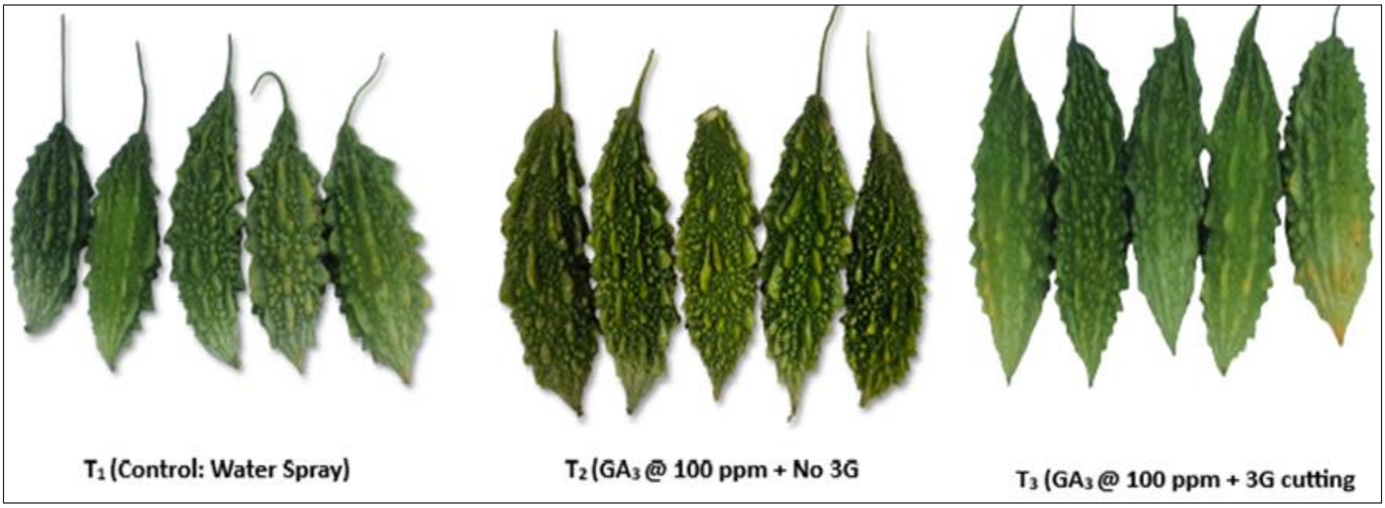


Plate 3: Boost in improving fruit numbers and fruit yield by 3G Cutting

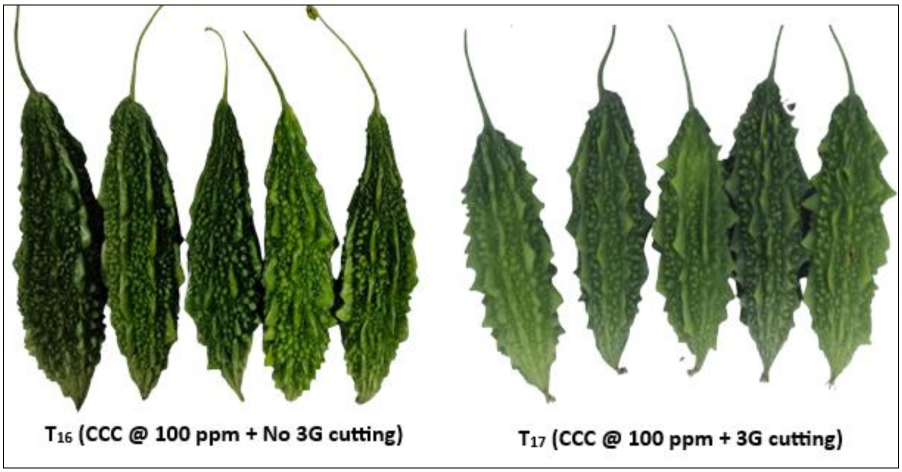


T_4 (GA_3 @ 150 ppm + No 3G cutting) T_5 (GA_3 @ 150 ppm + 3G cutting) T_6 (NAA @ 60 ppm + No 3G cutting)

T_7 (NAA @ 60 ppm + 3G cutting) T_8 (NAA @ 120 ppm + No 3G cutting) T_9 (NAA @ 120 ppm + 3G cutting)

T_{10} (Ethephon @ 100 ppm + No 3G cutting) T_{11} (Ethephon @ 100 ppm + 3G cutting) T_{12} (Ethephon @ 200 ppm + No 3G cutting)

T_{13} (Ethephon @ 200 ppm + 3G cutting) T_{14} (CCC @ 50 ppm + No 3G cutting) T_{15} (CCC @ 50 ppm + 3G cutting)



Conclusion

The treatment combination of Ethephon @ 200 ppm with 3G cutting (E_2P_1) consistently proved to be the most effective. This combination recorded superior performance across a wide range of agronomic traits, including a higher number of branches and leaves, enhanced flowering behavior with an increased number of female flowers, a reduced sex ratio, and improved fruit attributes such as fruit length, diameter, weight, and number of fruits per plant and overall fruit yield and significantly enhanced seed yield per fruit, per plant, and per hectare. Notably, the E_2P_1 treatment achieved the highest pooled fruit yield, clearly establishing its agronomic superiority over other treatment combinations. On the contrary, the absence of PGRs and without 3G cutting water spray treatment (A_0) resulted in the lowest performance across nearly all parameters. These findings highlight the synergistic benefits of combining proper PGRs and 3G cutting techniques, particularly the application of Ethephon with 3G cutting system, for enhancing bitter gourd overall yield, productivity, and fruit quality under the agro-climatic conditions of Chhattisgarh Plains. Therefore, this integrated approach is recommended for adoption by farmers and horticultural practitioners to maximize bitter gourd crop efficiency and profitability

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