



RESEARCH ARTICLE

Factorial evaluation of ethephon dose × application stage for improving sex ratio and seed yield in bitter gourd (*Momordia charantia* L.)

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Abstract

The present investigation was conducted to evaluate the effect of ethephon on sex expression, growth and seed yield in bitter gourd. A field experiment was carried out during 2022 and 2023 at the Research Farm, Department of Seed Science and Technology, Dr Y S Parmar University of Horticulture and Forestry, Nauni, Solan, Himachal Pradesh. The experiment comprised six ethephon concentrations (50, 100, 150, 200, 250 and 300 ppm) and three stages of application [S1: 4 true leaf stage; S2: 4 true leaf stage+ 15 days after first spray; S3: 4 true leaf stage + 15 days after first spray + 15 days after second spray], resulting in 18 treatment combinations, along with a control (no ethephon). The treatment E6S3 (300 ppm at three stages) proved most effective by promoting femaleness and improving seed yield attributes, recorded maximum fruit set (%), the highest number of fruits per plant and maximum seed yield per plot and per hectare, along with earlier female flower appearance and delayed male flower appearance. Overall, repeated application of ethephon at 300 ppm at the 4 true leaf stage and at 15-day intervals was found most suitable for enhancing female flower production, fruit efficiency and seed yield in bitter gourd under mid-hill conditions of Himachal Pradesh.

Keywords: bitter gourd; ethephon; seed yield; sex expression; stages

Introduction

Bitter gourd (*Momordica charantia* L.), 2n=2x=22 of the Cucurbitaceae family, is a popular tropical cucurbit vegetable. The crop is of Asian origin and it is most likely from China or India. It is generally grown in Malaysia, China, the Philippines, tropical Africa and North and South America. Immature fruit is high in vitamin C, vitamin A, phosphate and iron. The juice of the leaves is used to treat coughs, as a purgative and anti-helminthic to expel intestinal parasites and to heal wounds (1). Bitter gourd has potent medicinal properties due to the presence of beneficial phytochemicals with antibacterial, antimutagenic, antioxidant, antiviral, antidiabetic and immune-boosting properties (2).

Due to the monoecious flowering behaviour of cucurbits, staminate and pistillate flowers are produced on distinct nodes of the same plant (3). Male flowers emerge first and bloom at lower nodes, while female flowers emerge a week later and never blossom before male flowers. Bitter gourd faces several crop difficulties, including low seed germination, low yield, a low male-to-female ratio and non-synchronous flowering (4).

Flowering behaviour, on the other hand, varies according to cultivar, climatic conditions and cultural practices (5). The typical ratio of staminate to pistillate flowers in monoecious lines is 50:1 during the flowering period; this ratio can vary significantly (i.e., 9:1 to 48:1) (6, 7). Seed production in bitter gourd largely depends upon the number of pistillate flowers as well as the synchronisation of flowering. The ratio of staminate to pistillate flowers is generally high in bitter gourd, which leads to less fruit set, number of fruits and ultimately low seed production.

Plant growth regulators are naturally occurring or synthesised chemicals that influence developmental or metabolic processes in higher plants (8). They should be used at the best concentrations, stages of application, species specificity and seasons. 2-chloroethylphosphonic acid (ethephon), an ethylene-releasing chemical, has recently been demonstrated to increase femaleness in cucurbits, implying that ethylene has a comparable effect to auxin (9). The use of ethephon resulted in a considerable increase in the ratio of female to male flowers and femaleness percentage in cucurbit plants, which are valued and

critical traits for overall fruit yield (10). Foliar application of ethephon has been shown to alter vegetative development, flowering, sex expression, fruit and seed yield in cucurbitaceous crops; the stage and concentration of administration must be optimised for maximum results. The correlation between controlled sex expression, flower synchronisation, female to male ratio directly leads to increased seed production in bittergourd. The present study advances existing knowledge by identifying optimal doses and stages of ethephon application, specifically targeting constraints related to seed production. Although ethephon has significant potential for sex regulation, enhancing growth, seed output and quality in bitter gourd, research on the optimal dose and stage of application is lacking.

Materials and Methods

The experiment was carried out at the research farm of the Department of Seed Science and Technology of Dr Yashwant Singh Parmar University of Horticulture and Forestry, Nauni, Solan, during the years 2022 and 2023 on the bitter gourd cultivar Solan Hara. An experiment was laid out in a randomised complete block design (factorial) with additional treatment replicated thrice. The seeds were sown in plots of 2×1.1 m, i.e., 2.2 m². There were 18 treatment combinations with additional treatment, i.e., control (no spray). Among them there were 6 ethephon concentration E_1 : 50 ppm, E_2 : 100 ppm, E_3 : 150 ppm, E_4 : 200 ppm, E_5 : 250 ppm, E_6 : 300ppm and 3 different stages of application of Ethephon S_1 : 4 true leaf stage, S_2 : 4 true leaf stage + 15 days after first application, S_3 : 4 true leaf stage + 15 days after first application + 15 days after second application. The stock solution of 3000 ppm ethephon was prepared by 3 mL ethephon in 1 L of distilled water. For preparation of a 50 ppm ethephon solution of 1 L, take 12.5 mL of the stock solution and add the required quantity of water. Similarly, other doses were worked out. The standard cultural practices and basal application were applied as per the package of practices of vegetable crops, for growing bitter gourd, published by the Directorate of Extension Education, Dr Y S Parmar University of Horticulture and Forestry, Nauni, Solan. Data from two years were pooled and analysed using a mixed-effects factorial model. Treatment (control and PGR), dose (nested within treatment), stage of application and their interactions were considered as fixed effects, while year was treated as a random effect.

Results and Discussion

Effect of ethephon, stages of application and their interaction

On node for first male flower appearance

The pooled data of years 2022 & 2023 regarding node number to

first male flower is depicted in Table 1, which shows that the mean of foliar application of ethephon, stages of application and their interaction resulted in a higher node number for male flower appearance (10.4) and the control shows a lower node number for the appearance of male flower (5.0). Among the ethephon concentrations, E_6 (300 ppm) reported a higher node number to the first male flower and E_1 (50 ppm) recorded a lower node number to the first male flower. In case of stages of application, S_3 (4 true leaf stage + 15 days after first application + 15 days after second application) showed higher node number to first male flower and S_1 (4 true leaf stage) reported lower node number to first male flower. Among the interaction between ethephon concentration and stages of application, E_6S_3 (300 ppm at 4 true leaf stage + 15 days after first application + 15 days after second application) showed higher node for first male flower (14.2) which was significantly higher than other treatment combinations and lower node (5.2) was reported by E_1S_1 (50 ppm at 4 true leaf stage). This is due to the fact that all flowers carry both sex organs at the primordial stage and the application of ethephon inhibits the stamen primordial differentiation while encouraging the pistil primordial differentiation, resulting in the inhibition of male flower production at the lower node. Previous studies have reported that, in cucumber and bottle gourd, a greater node number for the first male flower was observed when ethephon was administered at 300 ppm at three stages (11, 12). Although 300 ppm ethephon consistently produced superior responses, higher doses did not confer a proportional yield advantage, indicating a likely saturation or inhibitory effect of ethylene. Excess ethylene is known to induce phytotoxic responses such as growth suppression, premature senescence and flower abscission in cucurbits, particularly at supra-optimal concentrations. The absence of additional yield gains beyond 300 ppm also raises concerns regarding economic efficiency and potential yield penalties under field conditions. Thus, 300 ppm appears to be an optimal and agronomically safe dose.

On node for first female flower appearance

A cursory glance at the pooled data depicted that the effect of ethephon application at different concentrations at different stages and their interaction shows that the mean of node number to first female flower was at the lowest node (7.69) as compared to additional treatment (11.98), which was at a higher node number (Table 2). In case of different ethephon concentration, E_6 (300 ppm) showed lower node number for first female flower appearance (6.75) and higher node number for first female flower appearance (8.81) was found in E_1 (50ppm). Among stages of application, S_3 (4 true leaf stage + 15 days after first application + 15 days after second application) found lower node (5.52) bearing the first female flower and S_1 (4 true leaf stage) reported higher node (9.77). In interaction, the lower node (3.93) was found in E_6S_3 (300 ppm at 4 true leaf stage + 15 days after first application + 15 days after second application), which was significantly lower than E_1S_1 (50 ppm at 4 true leaf stage), which showed a higher node number for first female flower

Table 1. Effect of foliar application of ethephon, stages of application and their interaction on node bearing the first male flower

Ethephon concentration	Stages of application			Mean	Control	
	S_1	S_2	S_3		5.0	
E_1	5.2	7.7	10	7.6	CD (0.05) F VS NF 0.19 E 0.13 S 0.37 E*S 2.86	
E_2	6.3	8.3	11.53	8.7		
E_3	7.4	11.1	12.16	10.24		
E_4	9	11.8	12.70	11.16		
E_5	10.7	12.3	13.1	12.06		
E_6	12.4	12.6	14.25	13.09		
Mean	8.5	10.6	12.1	10.4		

Table 2. Effect of foliar application of ethephon, stages of application and their interaction on node bearing the first female flower

Ethephon concentration	Stages of application			Mean	Control
	S ₁	S ₂	S ₃		
E ₁	10.86	8.56	7.00	8.81	11.98
E ₂	10.30	8.16	6.63	8.36	CD (0.05)
E ₃	9.88	7.96	5.70	7.85	F VS NF 0.27
E ₄	9.46	7.53	5.03	7.34	E 0.25
E ₅	9.16	7.20	4.83	7.06	S 0.17
E ₆	8.93	7.33	3.93	6.75	E*S 0.43
Mean	9.77	7.79	5.52	7.69	

appearance (10.86). The appearance of first female flower at the lower node may be because ethephon foliar spray advances female flower production by lowering the level of endogenous gibberellic acid and auxins, or by facilitating abscisic acid production (13). Similar findings were reported in cucumber, where ethephon was applied at 300 ppm at three different stages (11, 12).

On inter nodal length (cm)

Significantly, the minimum inter nodal length (7.17) was recorded (Table 3) in the mean of all treatments as compared to the control (8.80). Among the effects of different concentrations, the minimum inter nodal length (6.56) was recorded in E₆ (300 ppm), which is significantly lower than E₁ (7.67). Among stages of application, the minimum inter nodal length (5.84) was recorded in S₃ (4 true leaf stage + 15 days after first application + 15 days after second application) and the maximum (8.26) was recorded in S₁ (4 true leaf stage). While regarding interaction, the minimum inter nodal length was obtained in E₆S₃ (4.88) and the maximum was recorded in E₁S₁ (8.53), which is at par with E₂S₁ and E₃S₁. Here, the minimum inter nodal length was recorded in 300 ppm concentration at 4 true leaf stage + 15 days after first application + 15 days after second application. The internodal length reduces with increasing concentration. This could be because ethephon inhibits sub-apical meristematic activity, which inhibits stem growth and hence decreases internodal length (14). The interaction effect is supported by previous reports that minimum internodal length was recorded with foliar spray of ethephon at 300 ppm applied at three stages, i.e., the 2 true leaf stage, the 4 true leaf stage + and the flower initiation stage (12).

On days to first female flower

The pooled data in Table 4 depict that within the factorial treatment mean and non-factorial mean, the minimum days (48.41) was recorded in the factorial mean for the first female

flower appearance, which was significantly lower than the non-factorial mean (55.30) (i.e., additional treatment). Minimal days to appearance of first female flower (47.22) were observed in E₆ (300 ppm), which is at par with E₅, which was significantly lower (50.25) than E₁ (50 ppm). Minimum days to the onset of the first female flower (45.75) were observed in the S₃ stage of ethephon application and the maximum number of days (50.9) was recorded in S₁ (4 true leaf stage). The interaction between ethephon concentration and stages of application also showed significant differences as E₆S₃ (300 ppm ethephon applied at 4 true leaf stage + 15 days after first application + 15 days after second application) to first female showed less days for first female flower appearance (44.66) which is at par with E₅S₃ and E₁S₁ (50 ppm ethephon sprayed at 4 true leaf stage) showed more days for blooming of first female flower (54.16). The application of ethephon may enhance the content of starch and carbohydrates, resulting in early development of female flowers (15). Although another reason could be that ethephon application slightly slows vegetative growth, accelerates lateral development, reduces respiration and thus results in a more efficient source-sink relationship, which results in accelerated photosynthates accumulation and early appearance of pistillate flowers (16). A previous study reported earlier female flowering in cucumber following the application of 300 ppm ethephon at three different stages (11).

On days to first male flower

The mean of all the factorial treatments (47.13) was significantly superior to the non-factorial mean, i.e., control (39.80), depicted in Table 5. In different concentrations of ethephon, the number of days to first male flower appearance was reported to be maximum in E₆ (49.83), while the minimum number of days to first male flower appearance was recorded in E₁ (45.61), which is at par with E₂. In case of different stages of application, the maximum

Table 3. Effect of foliar application of ethephon, stages of application and their interaction on inter-nodal length

Ethephon concentration	Stages of application			Mean	Control
	S ₁	S ₂	S ₃		
E ₁	8.53	8.03	7.46	7.67	8.80
E ₂	8.31	7.73	6.26	7.43	CD (0.05)
E ₃	8.25	7.41	6.05	7.23	F VS NF 0.15
E ₄	8.20	7.35	5.86	7.13	E 0.13
E ₅	8.18	7.21	5.51	6.97	S 0.13
E ₆	8.10	6.71	4.88	6.56	E*S 0.23
Mean	8.26	7.41	5.84	7.17	

Table 4. Effect of foliar application of ethephon, stages of application and their interaction on the number of days to first female flower

Ethephon concentration	Stages of application			Mean	Control
	S ₁	S ₂	S ₃		
E ₁	54.16	49.83	46.76	50.25	55.30
E ₂	50.83	48.68	46.70	48.73	CD (0.05)
E ₃	50.50	48.33	46.16	48.33	F VS NF 0.71
E ₄	50.15	48.13	45.76	48.01	E 0.55
E ₅	50.01	48.03	45.28	47.77	S 0.39
E ₆	49.73	47.26	44.66	47.22	E*S 0.95
Mean	50.90	48.38	45.97	48.41	

Table 5. Effect of foliar application of ethephon, stages of application and their interaction on the number of days to first male flower

Ethephon concentration	Stages of application			Mean	Control
	S ₁	S ₂	S ₃		
E ₁	43.63	45.80	47.40	45.61	CD (0.05) F VS NF 0.47 E 0.40 S 0.07 E*S 0.67
E ₂	43.95	46.16	47.93	46.01	
E ₃	43.66	46.60	49.13	46.44	
E ₄	44.53	47.05	50.06	47.21	
E ₅	44.41	46.80	51.90	47.70	
E ₆	45.15	48.46	55.90	49.83	
Mean	44.21	46.81	50.38	47.13	

number of days to the first male flower was recorded in S₃ (50.38), whereas the minimum days were found in S₁ (44.21). Maximum number of days to first male flower (55.90) was observed with treatment combination of E₆S₃ i.e., 300 ppm concentration at 4 true leaf stage + 15 days after first application + 15 days after second application and minimum number of days to first male flower (43.63) which is at par with E₂S₁ and E₃S₁ was observed in E₁S₁ (50 ppm at 4 true leaf stage). These findings are mostly because of the presence of gibberellins which leads to early production of male flowers, but ethephon administration may result in a decrease in level of endogenous gibberellins, delaying the appearance of male flowers (17). The results are consistent with a study that observed that spraying ethephon at 300 ppm at the 2–4 true leaf stage, followed by a second spray 7 days after the first and a third spray 10 days after the second, resulted in the longest period of male flowering (11).

On number of female flowers per plant

The data revealed that factorial mean (24.00) is found superior to non-factorial mean (19.45) regarding the number of female flowers (Table 6). In case of different Ethephon concentrations, E₆ (300 ppm) reported the maximum number of female flowers (26.81) while the minimum number (21.50) was found in E₁ (50 ppm). Among stages of application, the maximum number of female flowers per plant (25.86) was recorded in S₃ (4 true leaf stage + 15 days after first spray + 15 days after second spray) and a lesser number (22.86) in S₁ (4 true leaf stage). In case of interactions, maximum female flower per plant (30.68) was possibly recorded in E₆S₃ which is 300 ppm concentration at 4 true leaf stage + 15 days after first spray + 15 days after second spray, while minimum (20.48) was presented in treatment E₁S₁ (50 ppm at 4 true leaf stage), a previous study proposed that endogenous auxin levels in neighbouring flower primordial control sexual

differentiation, with increased auxin levels in vicinity of differentiating primordial favouring formation of female organs and low auxin levels favouring formation of male organs (18). As a result of the ethephon spray, high auxin levels have been documented, increasing the number of female flowers. The result conforms with another study, which reported that an increased number of female flowers was observed with the application of 300 ppm at three stages (11).

On number of male flowers per plant

An introspection of the pooled data revealed smaller number of male flowers (83.49) as compared to the non-factorial mean (98.71) (Table 7). In the case of ethephon concentration, E₆ (300 ppm) resulted in a smaller number of male flowers per plant (76.67) and a greater number of male flowers (88.55) in E₁ (50 ppm). S₃ (69.35) reported the minimum number of male flowers, while S₁ (95.39) found the maximum number of male flowers in the case of stages of application. Among different treatment combinations, E₆S₃ recorded the minimum number of male flowers (58.60) and the maximum (97.70) was reported in E₁S₁ i.e., 50 ppm at the 4 true leaf stage, which is at par with E₂S₁ ethephon suppresses male flower production by decreasing endogenous gibberellin production throughout the differentiation process, as well as changing the proportion of gibberellins to auxins, which eventually induces male flower suppression (19). Similar findings were observed in cucumber (11).

On sex ratio

Table 8 indicates the significant difference between factorial treatment and additional treatment, as the mean of all the factorial treatments (3.54) was significantly lower than the additional treatment mean (5.07). Among the different concentrations of ethephon, the lowest sex ratio (2.93) was recorded in E₆ (300 ppm) and the highest (4.15) was recorded in

Table 6. Effect of foliar application of ethephon, stages of application and their interaction on the number of female flowers per plant

Ethephon concentration	Stages of application			Mean	Control
	S ₁	S ₂	S ₃		
E ₁	20.48	21.30	22.71	21.50	CD (0.05) F VS NF 0.47 E 0.39 S 0.27 E*S 0.67
E ₂	21.38	21.83	23.70	22.30	
E ₃	22.78	23.11	24.60	23.50	
E ₄	23.71	24.06	25.40	24.39	
E ₅	24.31	24.31	28.08	25.51	
E ₆	24.71	25.05	30.68	26.81	
Mean	22.86	23.28	25.86	24.00	

Table 7. Effect of foliar application of ethephon, stages of application and their interaction on the number of male flowers per plant

Ethephon concentration	Stages of application			Mean	Control
	S ₁	S ₂	S ₃		
E ₁	97.70	90.85	77.11	88.55	CD (0.05) F VS NF 0.47 E 0.39 S 0.27 E*S 0.71
E ₂	97.03	89.63	75.10	87.25	
E ₃	96.53	87.41	72.06	85.33	
E ₄	95.18	84.85	71.16	83.73	
E ₅	94.13	82.15	62.06	79.45	
E ₆	91.78	79.65	58.60	76.67	
Mean	95.39	85.75	69.35	83.49	

Table 8. Effect of foliar application of ethephon, stages of application and their interaction on sex ratio

Ethephon concentration	Stages of application			Mean	Control 5.07
	S ₁	S ₂	S ₃		
E ₁	4.78	4.26	3.40	4.15	CD (0.05) F VS NF 0.06 E 0.03 S 0.03 E*S 0.08
E ₂	4.54	4.11	3.17	3.94	
E ₃	4.24	3.78	2.93	3.66	
E ₄	4.01	3.52	2.80	3.45	
E ₅	3.90	3.37	2.20	3.16	
E ₆	3.71	3.17	1.90	2.93	
Mean	4.20	3.70	2.73	3.54	

E₁ (50 ppm). In case of stages of application, a narrower sex ratio (2.73) was reported in S₃ (4 true leaf stage + 15 days after first application + 15 days after second application) and a wider (4.20) was recorded in S₁ (4 true leaf stage). While in treatment combinations, E₆S₃ (300 ppm foliar application of ethephon at 4 true leaf stage + 15 days after first application + 15 days after second application) showed the lowest sex ratio (1.90), which was significantly lower than E₁S₁ (foliar spray of 50 ppm ethephon at 4 true leaf stage), which showed the highest sex ratio (4.78). The ethephon treatment may have influenced sex ratio and flowering sequence in bitter melon by increasing female flower production and decreasing male flowers. This may be because ethephon inhibits starch digestion, transpiration and respiration in plant tissues (19).

On number of fruits per plant

The pooled analysis reported the maximum number of fruits per plant in factorial mean (18.46) as compared to non-factorial mean (12.50) (Table 9). E₆ (300 ppm) showed a greater number of fruits per plant (21.90) and E₁ (50 ppm) recorded the minimum number of fruits per plant (15.47). Among the stages of application, a larger number of fruits (21.03) was obtained in S₃ (4 true leaf stage + 15 days after first application + 15 days after second application), while S₁ (4 true leaf stage) contributed to a smaller number of fruits (16.34). Maximum fruits per plant (27.08) were recorded in treatment combinations with E₆S₃ and E₁S₁ showed the minimum number of fruits per plant (13.71). The increase in the number of fruits per plant could be attributed to the fact that as ethephon concentration increases, male flower production decreases while female flower production increases, resulting in an increase in the number of fruits per plant (3). Another study reported the maximum number of fruits per plant with the application of 300 ppm ethephon at three stages (11, 12).

Table 9. Effect of foliar application of ethephon, stages of application and their interaction on the number of fruits per plant

Ethephon concentration	Stages of application			Mean	Control 12.50
	S ₁	S ₂	S ₃		
E ₁	13.71	15.93	16.76	15.47	CD (0.05) F VS NF 0.61 E 0.49 S 0.33 E*S 0.85
E ₂	14.83	16.41	18.11	16.45	
E ₃	15.80	17.75	19.78	17.77	
E ₄	16.81	18.91	21.31	19.01	
E ₅	18.11	19.20	23.16	20.16	
E ₆	18.80	19.83	27.08	21.90	
Mean	16.34	18.00	21.03	18.46	

Table 10. Effect of foliar application of ethephon, stages of application and their interaction on fruit set percentage

Ethephon concentration	Stages of application			Mean	Control 64.3
	S ₁	S ₂	S ₃		
E ₁	67.20	76.53	74.16	72.63	CD (0.05) F VS NF 3.12 E 2.48 S 1.75 E*S 4.3
E ₂	70.43	74.15	75.95	73.51	
E ₃	70.63	75.48	81.45	75.85	
E ₄	71.10	78.53	78.76	76.13	
E ₅	74.65	79.83	84.36	79.61	
E ₆	79.41	79.50	89.00	82.63	
Mean	72.23	77.33	80.61	76.73	

On fruit set percentage

Table 10 showed a significant difference between the mean of factorial treatment and non-factorial treatment, as a higher fruit set per cent was recorded in factorial treatment (76.74) than in non-factorial treatment (64.30). E₆ (300 ppm) effectively increases the fruit set percentage (84.46) and E₁ (50 ppm) resulted in less fruit set percentage (72.58), which is at par with E₂. In case of stages of application, maximum fruit set percentage (79.48) was recorded in S₃ and minimum (72.59) was recorded in S₁. Maximum fruit set percentage (88.35) was recorded in E₆S₃ and minimum (67.20) was found in E₁S₁ in the case of interaction. This is most likely due to the fact that treated plants can store appropriate carbohydrate reserves, resulting in early flowering, an increased number of female flowers and eventually maximum fruit set (20). The interaction results conform with those in cucumber and in bottle gourd (11,12). They observed maximum fruit length with foliar application of ethephon at 300 ppm at three different stages.

On fruit length at the time of seed maturity

The pooled data for mean fruit length at the time of seed maturity showed that all the treatments were superior (24.26) to the control (19.02) (Table 11). Among different concentrations, maximum fruit length (26.96) was found in E₆ (300 ppm) and minimum (21.96) was recorded in E₁ (50 ppm). In the case of stages of application, S₃ was found superior for maximum fruit length (25.66) at the time of seed maturity and S₁ resulted in minimum fruit length (23.27). E₆S₃ results in maximum fruit length at the time of maturity (28.98) and E₁S₁ found the minimum length of fruit at the time of seed maturity (20.45). The increase in length with ethephon administration could be linked to cell division and cell elongation when metabolic activity increases (3), since with an increase in concentration, metabolic activity increases, ultimately leading to an increase in fruit length. With an increase in the concentration of

Table 11. Effect of foliar application of ethephon, stages of application and their interaction on fruit length at the time of seed maturity

Ethephon concentration	Stages of application			Mean	Control
	S ₁	S ₂	S ₃		
					19.02
E ₁	20.45	21.48	23.95	21.96	CD (0.05) F VS NF 0.55 E 0.43 S 0.29 E*S 0.75
E ₂	22.60	23.46	24.60	23.55	
E ₃	23.48	23.53	25.08	24.03	
E ₄	23.56	23.83	25.48	24.29	
E ₅	24.08	24.35	25.91	24.78	
E ₆	25.46	26.44	28.98	26.96	
Mean	23.27	23.85	25.66	24.26	

ethephon, fruit length increased. These findings are in line with another study conducted on bottle gourd (12).

On days to fruit ripening

Minimum days to fruit ripening (65.80) were recorded by the mean of the factorial treatments and maximum days to ripening of fruit (78.53) were reported by the mean of the non-factorial treatments. Minimum days to fruit ripening (60.13) was recorded with an increase in concentration; therefore, E₆ (300 ppm) reported fewer days to fruit ripening as compared to the lowest dose E₁ (50 ppm), which required more days to fruit ripening (77.38). S₃ (4 true leaf stage + 15 days after first application + 15 days after second application) found the minimum number of days to fruit ripening (63.02) and S₁ (4 true leaf stage) recorded the maximum days to fruit ripening (68.03). E₆S₃ showed the minimum days to fruit ripening (58.35) and the maximum days for fruit ripening (77.38) were reported with E₁S₁ (Table 12). This is because ethephon decomposes to form ethylene and ethylene plays an important role in the regulation of fruit maturity and ripening. As concentration increases, more ethylene gas is emitted, resulting in earlier fruit ripening (21). The result of interactions is in accordance with another study, which recorded minimum days to fruit ripening with foliar application of ethephon at 300 ppm at three different stages (11).

On number of seeds per fruit

The factorial mean showed a maximum number of seeds (31.20) than the non-factorial mean (23.55) (Table 13). The maximum number of seeds per fruit (33.48) was recorded in E₆, which was significantly higher than other factorial treatments and the minimum (28.86) was reported in E₁. Among the stages of application, a larger number of seeds per fruit (35.53) was

reported in S₃, whereas a lower number (26.68) was found in S₁. In case of treatment combinations, E₆S₃ (300ppm at 4 true leaf stage + 15 days after first application + 15 days after second application) resulted in the maximum number of seeds per fruit (37.90), which was significantly higher than the E₁S₁ (24.15) combination, i.e., 50 ppm at 4 true leaf stage. The results are supported by the fact that using ethephon causes greater accumulation of sufficient food reserves in developing fruits and seeds that were set early, promoting the supply of photosynthates and mobilisation efficiency in vines by an increased maturity period of fruits on plants, giving rise to more and better-developed seeds (22).

On seed yield per plot (g) and per hectare (kg)

The mean of all the factorial treatment results in maximum seed yield per plot (134.26 g) as well as seed yield per ha (1073.32 kg) and the non-factorial mean results in minimum seed yield per plot (93.88 g) and seed yield per hectare (751.13 kg) (Table 14, 15). Maximum seed yield per plot (143.73 g) as well as seed yield per hectare (1149.91 kg) was reported in E₆ and lower concentration E₁ (50 ppm) recorded minimum seed yield per plot (119.73 g) and seed yield per hectare (953.42 kg). Seed yield per plot was significantly influenced by the stages of application as maximum seed yield per plot (155.75 g) and per hectare (1245.8 kg) being recorded in S₃, whereas a lower seed yield per plot (112.93 g) per hectare (903.51 kg) was found in S₁. Maximum seed yield per plot (167.20 g) and seed yield per hectare (1149.91 kg) was recorded in treatment combination E₆S₃ and minimum seed yield per plot (94.53 g) and per hectare (756.26 kg) in treatment E₁S₁ ethephon increases the number of female flowers, the percentage of fruit set, number of fruits, number of seeds, weight of 100 seeds all of which lead to an

Table 12. Effect of foliar application of ethephon, stages of application and their interaction on the number of days to maturity

Ethephon concentration	Stages of application			Mean	Control
	S ₁	S ₂	S ₃		
					78.53
E ₁	77.38	73.95	71.83	74.38	CD (0.05) F VS NF 0.88 E 0.85 S 0.47 E*S 1.23
E ₂	72.41	71.10	65.71	69.74	
E ₃	69.41	67.41	61.66	66.16	
E ₄	65.00	62.36	60.50	62.62	
E ₅	63.06	62.23	60.06	61.78	
E ₆	60.95	61.11	58.35	60.13	
Mean	68.03	66.36	63.02	65.80	

Table 13. Effect of foliar application of ethephon, stages of application and their interaction on the number of seeds per fruit

Ethephon concentration	Stages of application			Mean	Control
	S ₁	S ₂	S ₃		
					23.55
E ₁	24.15	28.38	33.70	28.86	CD (0.05) F VS NF 0.59 E 0.47 S 0.33 E*S 0.84
E ₂	25.75	30.36	34.16	30.09	
E ₃	26.65	30.83	35.06	30.85	
E ₄	26.86	32.01	35.80	31.56	
E ₅	27.73	32.80	36.55	32.36	
E ₆	28.58	33.96	37.90	33.48	
Mean	26.68	31.39	35.53	31.20	

Table 14. Effect of foliar application of ethephon, stages of application and their interaction on seed yield per plot (g)

Ethephon concentration	Stages of application			Mean	Control
	S ₁	S ₂	S ₃		
E ₁	94.53	124.65	140.01	119.73	CD (0.05) FVS NF 0.73 E 0.59 S 0.41 E*S 1.01
E ₂	110.25	129.38	151.18	130.27	
E ₃	114.35	132.46	154.38	133.73	
E ₄	117.16	136.93	159.60	137.90	
E ₅	119.23	139.31	162.13	140.22	
E ₆	122.10	141.91	167.20	143.73	
Mean	112.93	134.11	155.75	134.26	

Table 15. Effect of foliar application of ethephon, stages of application and their interaction on seed yield per hectare (kg)

Ethephon concentration	Stages of application			Mean	Control
	S ₁	S ₂	S ₃		
E ₁	756.26	983.86	1120.13	953.42	CD (0.05) FVS NF 9.8 E 7.8 S 5.53 E*S 13.5
E ₂	882	1035.06	1209.46	1042.17	
E ₃	914.8	1059.73	1235.06	1069.86	
E ₄	937.33	1095.46	1275.46	1102.75	
E ₅	953.86	1114.53	1297.06	1121.82	
E ₆	976.8	1135.33	1337.6	1149.911	
Mean	903.51	1070.66	1245.8	1073.32	

increase in seed yield (23–26). The results are in accordance with the previous study, where 300 ppm ethephon was applied at three different stages in bitter melon (12).

Conclusion

The findings of this study indicate that ethephon application can be effectively utilised to regulate sex expression and improve growth and seed yield in bitter melon. Among the evaluated treatments, a concentration of 300 ppm applied at the 4-true-leaf-stage followed by two subsequent sprays at 15-day intervals emerged as the most suitable agronomic practice, owing to its consistent positive influence on female flower production and yield-related traits. This spray schedule may therefore be recommended for bitter melon seed production under similar agro-climatic conditions. Nevertheless, considering the dose and stage-specific nature of ethephon responses, further multi-location and season-based studies are required to confirm its stability, economic feasibility and safety before large-scale adoption.

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Authors' contributions

SS contributed to writing the original draft, visualisation and conceptualisation. DS contributed to writing the original draft, supervision and conceptualisation. MK contributed to writing, review, editing and conceptualisation. AT, JT, ST, VK and NK reviewed the final version of the manuscript. All authors read and approved the final manuscript.

Compliance with ethical standards

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