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The impact of varying levels of plant growth regulators on the growth and yield characteristics of pomegranate (*Punica granatum* L.) cultivar Kandhari

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Abstract
The present investigation was conducted in the year 2022 at the Experimental Research Farm Kakhli of Dr. Khem Singh Gill Akal College of Agriculture, Eternal University, Baru Sahib, Sirmour (Himachal Pradesh), to evaluate the impact of varying levels of plant growth regulators on the growth, and yield characteristics of pomegranate (*Punica granatum* L.) cultivar Kandhari. The study employed a randomized block design, which was replicated three times and included ten treatment combinations. The study used plant growth regulators at various levels (50 ppm, 100 ppm, and 150 ppm). The treatment was administered to both the pre- and post-flowering stages. The usage of NAA and Ethrel at a concentration of 150 ppm had a substantial impact on pomegranate growth and yield characteristics. The application of NAA 150 ppm and Ethrel 150 ppm resulted in the greatest values for pomegranate growth and yield characteristics. The findings indicated that the maximum plant height values (3.77 m), plant spread east-west values (3.16 m), plant spread north-south value (3.12 m), canopy volume (77.96 m^3), the initial stage values of chlorophyll content A (1.58 mg/g), B (0.60 mg/g), the total chlorophyll content (2.18 mg/g), the final stage values of chlorophyll content A (1.80mg/g), B (0.66 mg/g), the total chlorophyll content (2.46 mg/g), number of flowers/plant (223.67), number of fruits/plant (95.67), fruit set (42.90%), yield/plant (21.42 kg) and yield/ha (23.80 tonne) were recorded in the treatment T_9 (NAA 150 ppm + Ethrel 150 ppm), and lowest values were recorded under the treatment T_0 (Control). The main goal of the research was to improve the growth and quality of the fruit production, reduce the risk of infection diseases and fruit drops, and eventually increase the yield of pomegranates.

Keywords: Chlorophyll, Kandhari, plant growth, pomegranate, yield

Introduction
Pomegranate (*Punica granatum* L.) is an important fruit tree mostly cultivated worldwide in various agroclimatic zones, especially in tropical to subtropical environments (Levin 2006, Jalikop 2007, Phawa 2017) [13, 10, 18]. It is renowned for being valuable source of nutrients and nutraceuticals. It originates from Iran and is a member of the Punicaceae family with chromosome number 2n= 2x =18 (Badizadegan and Khabbazian 1977) [3]. But it is cultivated in a number of Mediterranean and Central Asian nations, and it is currently widely consumed in western India. It is a good choice for growing in arid and semiarid areas because of its versatility, hardiness, low cost of maintenance, and good returns. Furthermore, it is liked by people due to its sweet, acidic taste and its longer shelf-life and good remuneration prices. The seeds are numerous and surrounded by a sweet, acidic, and sour pulp called 'aril,' which is scrumptious (Goswami 2013) [8]. Recently, it has been acknowledged that fruits possess significant benefits in terms of health, nutrition, and livelihood security. This has caused a lot of people in India and around the world to want more fruit. In India, pomegranates are grown in the states of Maharashtra, Karnataka, Andhra Pradesh, Punjab, Haryana, and Rajasthan. Maharashtra grows around 80% of the pomegranate area (Anwal 2015) [1]. In the last few years, it has been well known that plant growth regulators are important for getting higher yields and better quality horticultural crops. Positive outcomes for the pomegranate fruit crop have been obtained with the use of plant growth regulators. However, there is currently only a limited quantity of research done on the viability of using plant growth regulators on pomegranate plants (Narayanswamy *et al*., 2019) [17]. Ethrel, a naturally occurring plant growth hormone, has a number of effects on the expansion, maturation, and longevity of the storage of a number of fruit crops. Ethylene has a negative impact on quality primarily through modifying or accelerating the maturation, ripening, and senescence processes that occur naturally (Mikal 1999) [15].

In a similar manner, the impact of NAA on the plant growth characteristics is highly contingent upon the period of its introduction and its concentration. It has been demonstrated that NAA significantly enhances cellulose fibre synthesis in plants. The management of fruit drops in the majority of fruit plants involves the application of NAA in various fruit crops at varying concentrations (Suman *et al*., 2020) [23]. The main purpose of this study was to find out how different plant growth regulators affect flowering, fruit set, and yield of the pomegranate cultivar Kandhari.

Materials and Methods

Experimental Location

A field experiment was done at Experimental Research Farm Kakhli of Dr. Khem Singh Gill Akal College of Agriculture, Eternal University, Baru Sahib (HP.), India. The location is situated at a distance of 2 kilometers from the University Headquarters, at latitude of 30.73º north and a longitude of 77.31 º east and at an elevation of 898 meters above the mean sea level (MSL). The farm land is located in the sub-temperate and sub-humid mid-hills of the agro-climatic zone of Himachal Pradesh.

Planting Material

Pomegranate (*Punica granatum* L.) cultivar Kandhari is used as experimental material. For the purpose of experimentation, plants that exhibit a healthy growth pattern and uniform growth without any diseases or injuries were selected at Research Station Kakhli. The plants used in this investigation were subject to the same horticultural guidelines throughout the entire duration of the experiment.

The determination of the growth and yield parameters.

Plant height (m): The measurement of the height of the plant was determined by utilizing a tape that extended from the soil surface extends from the highest point of the plant. The initial plant height was recorded before the start of the experiment, and the final plant height was measured after completion of the experiment.

Plant spread east-west and north-south (m): The measurement of the plant spread in the east-west and north-south directions (in metres) was determined by using a measuring tape.

Canopy volume (m^3): The canopy volume was calculated using data obtained from plant spread (east-west + north-south), and height of the plant, using the following formula.

Chlorophyll content (mg/g) (at initial and at the end of study period): The content of chlorophyll was determined using the method suggested by Sadasivam and Manickam (1997) [20].

For the purpose of this procedure, one gram of fully matured cut leaves was weighed and crushed in a clean mortar, accompanied by 20 ml of acetone for the extraction of chlorophyll. For 5 minutes, the sample was centrifuged in falcon tubes, and the residual was transferred into a 100 ml volumetric flask. After repeated centrifugal operations, a colourless residue appeared. To ensure a clear extraction of leaves, the mortar and pestle were thoroughly scrubbed with 80% acetone. Using 80% acetone, the volume was increased to 100 mL. The absorbance of the sample was then measured at 645 and 663 nm, respectively, in comparison to a blank solution of 80% acetone. Using the given formula, the concentration of chlorophyll was determined.

Chlorophyll (A) mg/g tissue = 12.7(A663) – 2.69 (A645) × V/1000 × W
Chlorophyll (B) mg/g tissue = 22.9(A645) – 4.68(A663) × V/1000 × W
Total chlorophyll mg/g tissue = 20.2(A645) + 8.02 (A663) × V/1000 × W

Where,
A = Absorbance at a certain wavelength.
V = The final volume of chlorophyll extract in acetone containing 80 percent is determined.
W = The weight of the tissue was extracted.

Yield parameters

Number of flowers/plants: The number of flowers produced on three randomly tagged plants in each treatment combination was counted visually from the beginning of first flowering until the end of full bloom, and the average was determined. The results were represented in terms of the number of flowers per plant.

Number of fruits/plants: The fully mature fruits harvested from three randomly tagged plants in each treatment combination were calculated at each harvest. The average was worked out and the results were represented as the number of fruits/plant.

Fruit set (%): From each treatment combination, three plants were chosen at random and the average number of flowers was recorded. The number of fruits that were set was determined and then expressed in percentages using the following formula:

Yield/plant (kg): The total fruit production in each treatment combination was recorded from three randomly selected plants, and during every harvest, the total fruit yield was recorded using a digital analytical balance. The average yield per plant was determined by combining the total yield of all plants that were marked. It was expressed in kilograms per plant.

Yield/hectare (tonne): The total fruit production per hectare in each treatment combination was documented from three randomly designated plants, and the total fruit yield was determined at each harvest by utilizing a digital analytical balance. To find the average yield per plant was estimated by combining the yields of all the chosen plants. However, to calculate the yield per hectare (t), the values of the yield per plant (kg) were multiplied by the overall number of plants per hectare, and the result was divided by 10,000. The yield was expressed in t/ha.

Results and Discussion

The data concerning the values of plant height (m), plant spread east-west (m), plant spread north-south direction (m), and values of the canopy volume (m^3) are influenced by different levels of various plant growth regulators, as exhibited in Table 1. The plant growth parameters of pomegranate showed significant variation due to the

significant impact of the different plant growth regulators. Among the various treatments, treatment T_9 (NAA 150 ppm + Ethrel 150 ppm) exhibited the highest values of plant height (3.77 m), plant spread east-west (3.16 m), plant spread north-south (3.12 m), and the value of canopy volume (77.96 m^3), whereas the minimum values were recorded under the treatment T_0 (control). This occurrence may be attributed to sustained vegetative growth, which is attributed to prolonged availability of nutrient resources. This results in a rapid acceleration of various physiological and metabolic processes, including the production of proteins, coenzymes, nucleic acids, enzyme activation, secondary metabolism products, energy transfer, osmotic regulation, respiration, and photosynthesis within the plant system, as reported by Mounashree *et al*. (2018) [16]. Moreover, the involvement of the NAA significantly increased growth and development, which may be brought on by increases in cell size and cell number. Hence, the processes of cell division and elongation serve as the fundamental components for the advancement of plants. Similarly, the findings are in agreement with the results obtained by (Tagad *et al*., 2018) [24] in the pomegranate, (Dwivedi *et al*., 2018) [7] in pomegranate, and (Prajapati and Singh 2018) [19] in pomegranate.

Table 1: The impact of NAA and Ethrel on the growth characteristics of the pomegranate cultivar Kandhari

Treatment combinations	Plant height (m)	Plant spread (E-W) (m)	Plant spread (N-S) (m)	Canopy volume (m^3)
T_0 = Control (water spray)	3.51	2.85	2.88	60.51
T_1 = NAA 50 ppm	3.65	2.98	3.00	68.48
T_2 = NAA 100 ppm	3.69	3.02	3.02	70.57
T_3 = NAA 150 ppm	3.71	3.10	3.08	75.77
T_4 = Ethrel 50 ppm	3.68	2.94	2.97	67.22
T_5 = Ethrel 100 ppm	3.66	3.04	3.04	71.06
T_6 = Ethrel 150 ppm	3.70	3.06	3.06	72.55
T_7 = NAA 50 ppm + Ethrel 50 ppm	3.71	3.11	3.09	76.81
T_8 = NAA 100 ppm + Ethrel 100 ppm	3.74	3.13	3.11	77.69
T_9 = NAA 150 ppm + Ethrel 150 ppm	3.77	3.16	3.12	77.96
S.Em	0.03	0.02	0.02	1.13
CD $_{0.05}$	0.082	0.06	0.05	3.39

Data regarding to chlorophyll content at initial stage A and B (mg/g), and final stage A and B (mg/g), and total chlorophyll content initial (mg/g) and final stage (mg/g) are influenced by various levels of different plant growth regulators, as shown in Table 2. The chlorophyll content at initial stage A and B (mg/g), and total chlorophyll content initial (mg/g) and final stage (mg/g) of the pomegranate cultivar Kandhari differed significantly due to the significant effects of the different treatment combinations. Among the different treatments, treatment T_9 (NAA 150 ppm + Ethrel 150 ppm) demonstrated the maximum values of chlorophyll content at initial stage A (1.58 mg/g), values of the chlorophyll content B (0.60 mg/g), and values of total chlorophyll content (2.18 mg/g), and the minimum values were recorded under the treatment T_0 (control). Besides, the greater values of chlorophyll content at final stage A (1.80 mg/g), values of the chlorophyll content B (0.66 mg/g), and values of the total chlorophyll content (2.46 mg/g) were observed under treatment T_9 (NAA 150 ppm + Ethel 150 ppm) and the lower values were recorded under the treatment T_0 (control). The greater increase in the values of the chlorophyll content might be the result of enhanced vegetative growth caused by increased water and nutrient uptake, both of which are strongly related to the photosynthesis process (Karuthamani *et al*., 2018) [12]. Similar consequences were observed by (Dogra *et al*., 2019) [6] in the Kinnow Mandarin, and (Phawa *et al*., 2017) [18] in the pomegranate.

Table 2: The impact of NAA and Ethrel on the chlorophyll content at initial stage A and B (mg/g), and final stage A and B (mg/g) and total chlorophyll content at initial stage (mg/g) and final stage (mg/g) of the pomegranate cultivar Kandhari

Treatment combinations	Chlorophyll content A (mg/g)		Chlorophyll content B (mg/g)		Total Chlorophyll content (mg/g)	
	(at initial stage)	(at final stage)	(at initial stage)	(at final stage)	(at initial stage)	(at final stage)
T_0 = Control (water spray)	1.44	1.61	0.47	0.54	1.92	2.16
T_1 = NAA 50 ppm	1.48	1.68	0.50	0.58	1.99	2.26
T_2 = NAA 100 ppm	1.52	1.74	0.54	0.61	2.06	2.34
T_3 = NAA 150 ppm	1.55	1.77	0.57	0.63	2.12	2.40
T_4 = Ethrel 50 ppm	1.52	1.72	0.53	0.59	2.05	2.31
T_5 = Ethrel 100 ppm	1.49	1.71	0.52	0.58	2.01	2.29
T_6 = Ethrel 150 ppm	1.54	1.75	0.55	0.63	2.09	2.37
T_7 = NAA 50 ppm + Ethrel 50 ppm	1.56	1.78	0.58	0.64	2.14	2.42
T_8 = NAA 100 ppm + Ethrel 100 ppm	1.57	1.79	0.59	0.65	2.17	2.44
T_9 = NAA 150 ppm + Ethrel 150 ppm	1.58	1.80	0.60	0.66	2.18	2.46
S.Em	0.01	0.01	0.01	0.01	0.01	0.01
CD $_{0.05}$	0.024	0.030	0.022	0.029	0.04	0.04

The data concerning to the number of flowers per plant, number of fruits per plant, fruit set (%), yield per plant (kg), and yield per hectare (tonne) as affected by various levels of different plant growth regulators, as presented in the Table 3. The yield characteristics of the pomegranate cultivar Kandhari exhibited significant variation due to the significant influence of the various plant growth regulators. Among the various treatments, treatment T_9 (NAA 150 ppm + Ethrel 150

ppm) exhibited the highest number of flowers/plant (223.67), number of fruits/plant (95.67), fruit set percent (42.90%), yield/plant (21.42 kg), and yield/hectare (23.80 tonnes), and the minimum values of yield characteristics were documented under the treatment T_0 (control). It is possible that the increased physiological state of fruit development is due to a greater number of nutrients, water, and other important compounds that help them grow and develop properly. This may result in an increased size and, therefore, a greater yield (Suman and Jain 2021) [22] and (Mandlik *et al*., 2019) [14]. These findings are consistent with the results of (Dalal *et al*., 2019) [5] in pomegranate, (Haneef *et al*., 2014) [9] in the pomegranate, and (Singh *et al*., 2018b) [21] in banana.

The most significant characteristics are the higher number of flowers and the higher percentage of fruit set, which have a direct impact on the production of pomegranate. This might be because the plants are getting more plant growth regulators as the crop needs them, which has led to more flowering and fruit set. Furthermore, auxin also acts as a stimulant in the formation of more complex compounds and as a stimulant for enzymatic activity, thereby enhancing pollen tube growth and pollen germination, which results in the approximate emergence of more flower buds, an enhanced fruit set, an increase in the number of fruits per plant, and ultimately the yield of pomegranate (Arunadevi *et al*., 2019) [2]. The same observations had been made by (Bhogave and Raut 2014) [4] in papaya and (Kappel and MacDonald 2007) [11] in sweet cherry.

Table 3: The impact of NAA and Ethrel on the yield characteristics of the pomegranate cultivar Kandhari

Treatment combinations	Number of flowers/plant	Number of fruits/plant	Fruit set (%)	Yield/plant (kg)	Yield/ha (tonne)
T_0 = Control (water spray)	171.33	61.33	36.02	10.55	11.72
T_1 = NAA 50 ppm	182.67	70.33	38.69	12.84	14.27
T_2 = NAA 100 ppm	201.67	79.00	39.32	15.94	17.71
T_3 = NAA 150 ppm	217.00	87.67	40.51	19.04	21.16
T_4 = Ethrel 50 ppm	193.33	78.67	40.90	15.21	16.90
T_5 = Ethrel 100 ppm	189.00	78.33	41.51	14.86	16.51
T_6 = Ethrel 150 ppm	212.00	85.00	40.22	18.04	20.05
T_7 = NAA 50 ppm + Ethrel 50 ppm	220.33	92.00	41.88	20.29	22.54
T_8 = NAA 100 ppm + Ethrel 100 ppm	222.33	93.67	42.26	20.84	23.16
T_9 = NAA 150 ppm + Ethrel 150 ppm	223.67	95.67	42.90	21.42	23.80
S.Em	2.876	1.502	0.928	0.383	0.426
CD $_{0.05}$	8.611	4.497	2.778	1.147	1.275

Conclusion

It can be concluded that foliar application of various plant growth regulators has a significant influence on the plant growth characteristics, and yield characteristics of pomegranate cultivar Kandhari. The application of various plant growth regulators through foliar engorgement is a highly effective strategy for controlling the duration and distribution of nutrients. In order to achieve a higher yield and superior quality of produce, it is imperative to implement modifications to the methodology for the foliar application of plant growth regulators in the pomegranate. Therefore, the application of treatment T_9 (NAA 150 ppm + Ethrel 150 ppm) is highly recommended for the improvement of plant growth characteristics, and yield characteristics of pomegranate cultivar Kandhari.

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The disclosure statement

There was no potential conflict of interest reported by the author.

The data availability statement

The authors confirm that the data corroborating the results of this investigation are accessible within the article.

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