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RESEARCH ARTICLE

Enhancing growth and yield of late *kharif* season onion (*Allium cepa* L.) through natural plant growth regulators and micronutrient application

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Abstract

Abstract: Onion is the most extensively cultivated crop used for multiple purposes, including vegetable spices and medicine. In the present study, we evaluated two plant growth regulators (PGRs), Indole-3-acetic acid (IAA) and Gibberellic acid (GA_3), along with the micronutrient mixture containing 3% zinc, 2.5% iron, 1% manganese, 1% copper, 0.5% boron and 0.1% molybdenum chelated with EDTA. A total of 13 treatments were administered consisting of different concentrations of 100 to 200 ppm IAA, 50 to 100 ppm GA_3 and 0.5 to 1.0% micronutrients. These treatments were applied either through root dipping or foliar application 30 days after transplanting (DAT). All the PGR and micronutrient treatments enhanced the onion plant growth attributes. Among all the treatments, foliar application of 200 ppm IAA and 100 ppm GA_3 was found best in terms of onion bulb yield during the late *Kharif* season. The findings of the present study suggest that the application of 200 ppm IAA with a recommended dose of FYM and NPK will be helpful to improve onion yield during the late *Kharif* season and also help in maintaining onion prices from January to March in the Indian market.

Keywords: Onion, plant growth regulators, micronutrients, production improvement.

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Introduction

Among alliums, onion (*Allium cepa* L.) is the most important crop that belongs to the family Amaryllidaceae (Manape et al., 2023). Onion is globally cultivated and consumed for its nutritional, nutraceutical, and medicinal values (Teshika et al., 2019; Chadorshabi et al., 2022). Onion is consumed raw, semi-cooked, cooked, or in processed form (crushed, flakes, paste, powder, and pickles). The onion or its product consumption has been found to be beneficial in several diseases such as cardiac, cancer, diabetes and, respiratory diseases etc. (Karavelioğlu & Hoca, 2021). India is the largest onion-producing country in the world and produces onion twice (80% during the *Rabi* season and 20% during the *Kharif* season) in a year with a cultivated area (1.74 Mha) and production (30.20 MT) (FAO, 2023). Onion is a potential foreign exchange crop for India; in the financial year 2022-2023, it earned 452,2.7915 crore rupees (APEDA, 2023), which is approximately 70% of the total fresh vegetable export in India. Onion can be grown in both seasons, *viz. Kharif* and *Rabi*.

Despite India being the largest cultivator and producer of onion, its productivity is still very low (17.36 tons/ha). This low yield potential of Indian onion restricts its round-the-year availability, which generates a price crisis, especially from December to March (the late *Kharif* season harvest period). (https://www.statista.com/statistics/880862/india-retail-price-index-of-onion/). Therefore, it is very necessary to improve its yield potential. However, the varietal improvement in crops like onion is not so easy due to its high cross-pollination, high heterozygosity, self-incompatibility and severe inbreeding depression with a restricted genetic base (Manjunatha Gowda & Anjanappa, 2021). Also, it requires 10 to 15 years to develop a new variety. So, there is always an alternative need to tackle these challenges. Plant growth regulators (PGRs) and micronutrient management can play an important role in improving onion productivity in a sustainable way. PGRs are naturally occurring chemical compounds well-known for their ability to enhance various aspects of plant physiology and improve the growth and yield of onion (Dwivedi et al., 2019; Kumar et al., 2021). Among the various PGRs, Indole-3-acetic acid (IAA) and Gibberellic acid (GA_3) are very common and important growth regulators. Indole-3-acetic acid (IAA) plays an important role in controlling plant growth and development (Zhang et al., 2022). Its application at various concentrations influences the growth, development and chemical composition of onion. Their functional analysis demonstrated that they are involved in various aspects of plant development, such as root development, shoot development, sugar metabolism, and fruit ripening (Luo et al., 2018). Various studies suggest that IAA application can enhance bulb quality and yield (Solano et al., 2023). Similarly, GA_3 is also known for its ability to enhance stem elongation and plant height, increase dry matter accumulation and consequently increase yield in crops (Sisodia et al., 2012). Exogenous application of GA_3 has positively influenced various growth and yield parameters of onions, such as plant height, root fresh weight, root dry weight, bulb diameter and germination (Sisodia et al., 2012). Micronutrients are essential elements required by plants for their growth and development; they regulate various physiological and metabolic activities in plants (Ballabh et al., 2013) and their deficiencies significantly reduce onion productivity. The micronutrient spray has a significant effect on the quality and yield of onion (Rizk et al., 2014).

Zinc and boron play an important role in plant metabolism, like the transport of water, nutrients and photosynthetic sugars to rapidly growing meristematic tissues. Their combined application could also increase its yield (Miah et al.,2020). In plants, the molybdenum plays an important role in enzyme activity pathways such as nitrogenase, catalase and peroxidase (Mendel et al., 2002). Copper helps in different phytochemicals, vitamins and amino acid formation. Its application is not only safe but also has a profound effect on the growth and yield of onion. El-Tohamy et al. (2009) studied the combined effect of iron, zinc and manganese and found that they have a significant effect on essential oil, growth and yield of onion. The mixture of micronutrients such as zinc, iron, manganese, copper, boron and molybdenum work in a coordinated way and improves different physiological, biochemical and molecular processes in the onion and ultimately improves plant overall performance (Aske et al.,2017). Therefore, the present study was conducted to improve onion productivity with the help of plant growth regulators and micronutrients in the late *Kharif* season.

Materials and Methods

Experiment site, plant growth regulators, micronutrients and treatments

The experiment was conducted at Research Farm, Department of Horticulture, RVSKVV, College of Agriculture, Indore, Madhya Pradesh, (India) during the late *Kharif* season, 2019-20, located at a latitude of 22.43° N and longitude of 75.66° E. The season's average temperature range and relative humidity during the crop growth period ranged between 16.25 to 29.25°C and 86.58 to 77.21%, respectively. Plant growth regulators IAA and GA_3 (HiMedia, Mumbai, Maharashtra, India) and micronutrients mixture, Mixol containing 3% zinc, 2.5 % iron, 1% manganese, 1% copper, 0.5% boron, and 0.1% molybdenum EDTA chelated obtained from Mahafeed Specialty Fertilizers India Pvt. Ltd. Pune, Maharashtra, India. The details of plant growth regulators and micronutrient treatment are given in (Table 1).

Seedling raising, root treatment and transplanting

Seedlings were raised on raised beds and uprooted for transplanting in the field with a spacing of 15 X 10 cm (RxP), with or without the root treatments of PGR and micronutrients (Table 1). The recommended dose of NPK in onion (100:50:50 kg ha^{-1}) was applied as per the standard schedule.

Sampling and observations

Sampling was done as per the schedule of different observations at 30, 60 and 90 DAT for growth analysis. Observations with respect to the following characters were recorded on five plants selected randomly and tagged in each plot, excluding the border plant and their means were worked out for statistical analysis.

Plant height, pseudo stem length, number of leaves, leaf area per plant and leaf area index

The plant height, pseudo stem length and number of leaves were recorded at 30, 60, and 90 DAT. The leaf area was measured in cm^2 by Li-Cor 3000 (LI-COR, Lincoln, Nebraska, US) at 30, 60, and 90 DAT and at harvest. The leaf area index per plant was recorded in cm by calculating the leaf area and ground area ratio by using the following formula.

Plant and bulb fresh and dry weight

The fresh and dry weights of the plant and bulb were recorded in grams at 30, 60, and 90 DAT, followed by dry

Table 1: Details of plant growth regulators and micronutrients treatments

T_1	Control (Normal crop)
T_2	GA_3 @50 ppm - Root dipping
T_3	GA_3 @50 ppm - Foliar spray 30 DAT (days after transplanting)
T_4	GA_3 @100 ppm - Root dipping
T_5	GA_3 @100 ppm - Foliar spray 30 DAT
T_6	IAA @100 ppm - Root dipping
T_7	IAA @100 ppm - Foliar spray 30 DAT
T_8	IAA @200 ppm - Root dipping
T_9	IAA @200 ppm - Foliar spray 30 DAT
T_{10}	Micro nutrient mixture @0.5% - Root dipping
T_{11}	Micro nutrient mixture @0.5% - Foliar spray 30 DAT
T_{12}	Micro nutrient mixture @1% - Root dipping
T_{13}	Micro nutrient mixture @1 % - Foliar spray 30 DAT

weight recording by drying plants and sliced bulbs for three days in an oven at 80°C.

Polar and equatorial diameter of bulb and yield

The polar and equatorial diameters are recorded in centimeters with the help of a Vernier Caliper. A total of five bulbs were taken from each treatment and replication. After harvesting the crop, bulbs from each plot were weighted in kilograms, and bulb yield per plot was recorded. Bulb yield per hectare was calculated with the help of the available yield of bulb per plot and by summarizing and multiplying with the factor.

Statistical analysis

The data recorded on different parameters were analyzed as per random block design (RBD) and the results have been interpreted on the basis of the 'F' test value and critical difference (CD) was calculated.

Results

Plant height

The plant height, as presented in (Fig. 1) clearly indicates that the increasing trends of average plant height were observed at 30, 60, and 90 days after transplanting (DAT). With increasing crop growth period, plants show a significant increase in height. At 30 DAT, the maximum (34.62 cm and 33.82 cm) plant height was observed in treatment T_5 (Foliar application of GA_3 @ 100 ppm) and T_9 (foliar application of IAA @ 200 ppm). Whereas in treatment T_1 (control), the minimum (23.86 cm) plant height was observed. In the case of 60 DAT, the significantly highest (49.48 cm and 48.17 cm) plant height was observed in the treatment T_5 (foliar application of GA_3 @ 100 ppm) and T_9 (foliar application of IAA @ 200 ppm). Whereas in treatment T_1 (control), the minimum (38.27 cm) plant height was observed. While after 90 DAT, maximum plant height (72.03cm) was recorded in treatment T_5 (foliar application of GA_3 @ 100 ppm) and (70.44 cm) in treatment T_9 (foliar application of IAA @ 200 ppm). Whereas in treatment T_1 (control), the minimum (54.92cm) plant height was observed (Fig. 1).

Number of leaves, leaf area per plant and leaf area index (LAI)

The increasing trend of the average number of leaves per plant was recorded at 30 DAT to 90 DAT. It is clear from the data that the average number of leaves per plant at these growth stages was found to be significant. After 30 DAT maximum number of leaves per plant (6.30 and 6.11) were observed in treatment T_9 (IAA @200 ppm foliar spray 30 DAT) and treatment T_5 (GA_3 @100 ppm foliar spray 30 DAT). Whereas in treatment T_1 (control), the minimum (3.98) number of leaves was observed. In the case of 60 DAT, the significantly highest (8.45) number of leaves per plant was observed in treatment T_9 (IAA @200 ppm foliar spray 30 DAT) and (8.28) in treatment T_5 (GA_3 @100 ppm foliar spray 30 DAT). Whereas in treatment T_1 (control), the minimum (6.01) number of leaves was observed. While after 90 DAT, the significantly highest (12.42) number of leaves was observed in treatment T_9 (foliar application of IAA @200 ppm) and (12.20) in treatment T_5 (foliar application of GA_3 @100 ppm). Whereas in treatment T_1 (control), the minimum (9.18) number of leaves was observed (Fig. 2). Leaf area was noted at 30, 60, and 90 DAT and it is clear from the data that the leaf area at these growth stages was found significant. At 30 DAT, the highest (107.47 cm^2) leaf area was observed under treatment T_9 (IAA @200 ppm foliar spray 30 DAT) and (102.57 cm^2) in treatment T_5 (GA_3 @100 ppm foliar spray 30 DAT). Whereas in treatment T_1 (control), the minimum (28.23 cm^2) leaf area was observed. In the case of 60 DAT, the highest (518.69 cm^2) leaf area was observed under the treatment T_9 (IAA @200 ppm foliar spray 30 DAT) and (512.33 cm^2) in treatment T_5 (GA_3 @100 ppm foliar spray 30 DAT). Whereas in treatment T_1 (control), the minimum (176.81 cm^2) leaf area was observed. While at 90 DAT, significantly highest leaf area (826.37 and 814.45 cm^2) was observed under the treatment T_9 (IAA @ 200 ppm foliar spray 30 DAT) and treatment T_5 (GA_3 @100 ppm foliar spray 30 DAT). Whereas in treatment T_1 (control), the minimum (287.71 cm^2) leaf area was observed (Fig. 3). Leaf area index (LAI) was recorded at 30, 60, and 90 DAT and it is clear from the data that the LAI at these growth stages was found significant. At 30 DAT, the highest (0.71) LAI was recorded in treatment T_9 (IAA @200 ppm foliar spray 30 DAT) and (0.68) in treatment T_5 (GA_3@100 ppm foliar spray 30 DAT). Whereas in treatment T_1 (control), the minimum (0.18) LAI was observed. In case of 60 DAT, the highest (3.46) LAI was observed under the treatment T_9 (IAA @200 ppm foliar spray 30 DAT) and (3.41) in treatment T_5

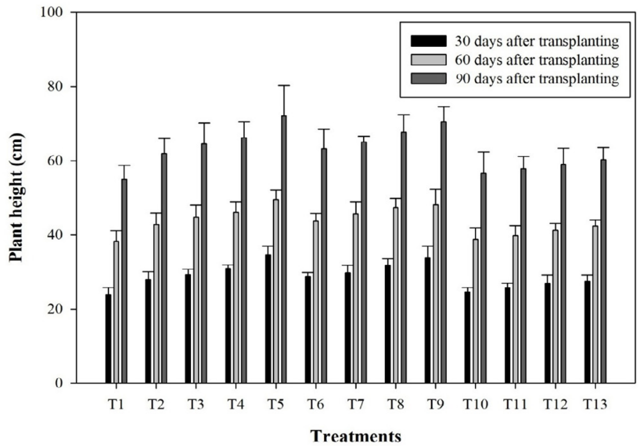

Fig. 1: Plant height under different treatment after 30, 60 and 90 days of transplanting

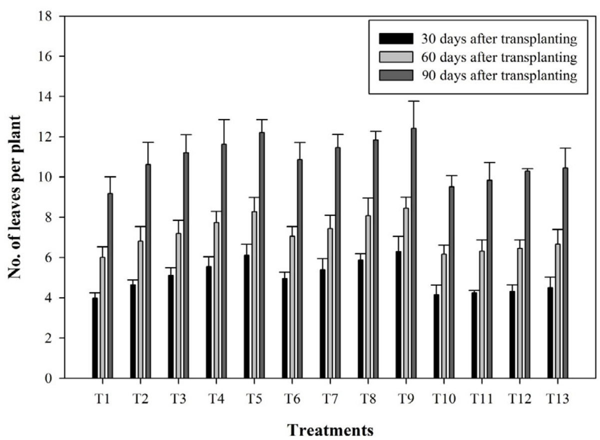

Fig. 2: Number of leaves per plants under different treatment after 30, 60 and 90 days of transplanting

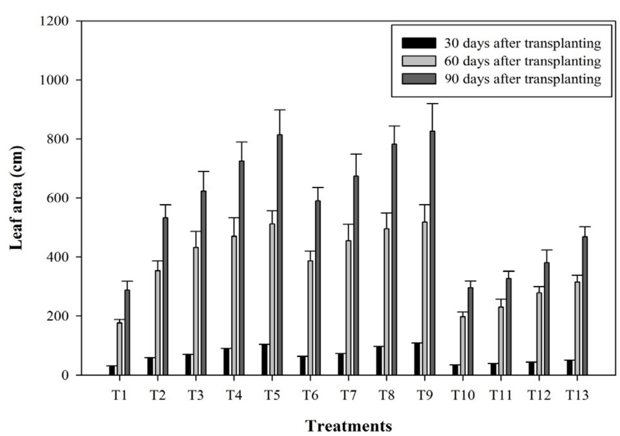

Fig. 3: Leaf area under different treatment after 30, 60 and 90 days of transplanting

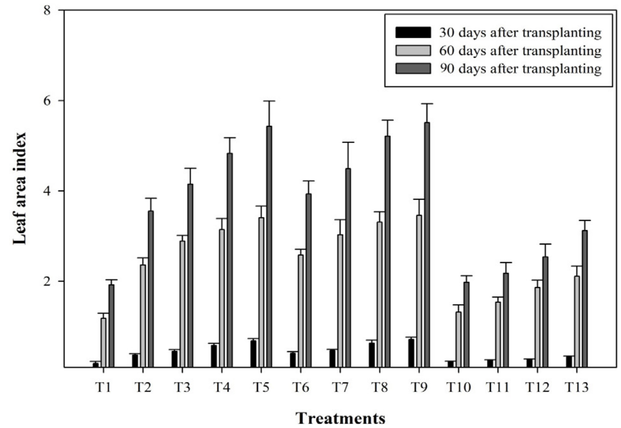

Fig. 4: Leaf area index under different treatment after 30, 60 and 90 days of transplanting

(GA_3 @100 ppm foliar spray 30 DAT). Whereas in treatment T_1 (control), the minimum (1.18) LAI was observed. In contrast, at 90 DAT, significantly highest, i.e., 5.51 and 5.43 LAI was observed under the treatment T_9 (IAA @ 200 ppm foliar spray 30 DAT) and treatment T_5 (GA_3 @100 ppm foliar spray 30 DAT), respectively. Whereas in treatment T_1 (control), the minimum (1.92) LAI was observed (Fig. 4).

Pseudo-stem length

With increasing crop growth period, plants showed a significant increase in pseudo stem length. At 30 DAT, the maximum (5.44 cm) pseudo stem length was observed in treatment T_9 (foliar application of IAA @200 ppm) and (5.38 cm) in treatment T_5 (foliar application of GA_3 @ 100 ppm). In contrast, the minimum (2.96 cm) pseudo stem length was observed in treatment T_1 (control). At 60 DAT, the significant maximum (8.56 and 8.48 cm) pseudo stem length was observed in the treatment T_9 (IAA @ 200 ppm foliar spray 30 DAT) and treatment T_5 (GA_3 @100 ppm foliar spray 30 DAT). Whereas in treatment T_1 (control), the minimum (6.31 cm) pseudo stem length was observed. In the case of 90 DAT maximum significant pseudo stem length (9.96 cm) was noted in treatment T_9 (foliar application of IAA @ 200 ppm) and (9.89 cm) in treatment T_5 (foliar application of GA_3 @ 100 ppm). Whereas in treatment T_1 (control), the minimum (8.44 cm) pseudo stem length was observed (Fig. 5).

Fresh and dry weight of a plant

At 30 DAT, the plant's fresh weight varied significantly due to various treatments. The highest (29.27 g) fresh weight of the plant was observed with treatment T_9 (IAA @ 200 ppm foliar spray 30 DAT) and (27.71 g) in treatment T_5 (GA_3 @100 ppm foliar spray 30 DAT). Whereas in treatment T_1 (control), the minimum (16.52 g) fresh weight of the plant was observed. At 60 DAT, the highest (57.29 and 55.87 g) plant fresh weight was observed in the treatment T_9 (IAA @ 200 ppm foliar spray 30 DAT) and T_5 (GA_3 @100 ppm foliar spray 30 DAT). Whereas in treatment T_1 (control), the minimum (36.49 g)

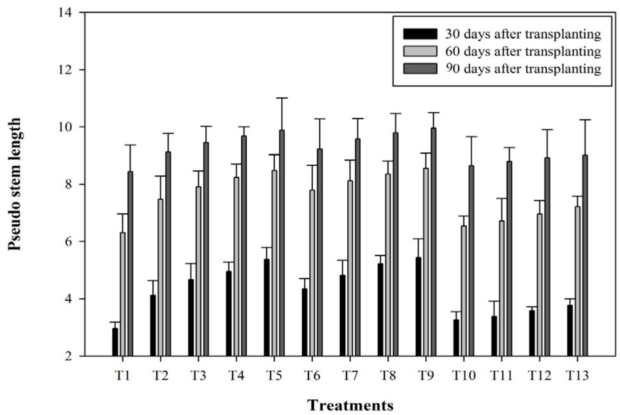

Fig. 5: Pseudo stem length under different treatment after 30, 60 and 90 days of transplanting

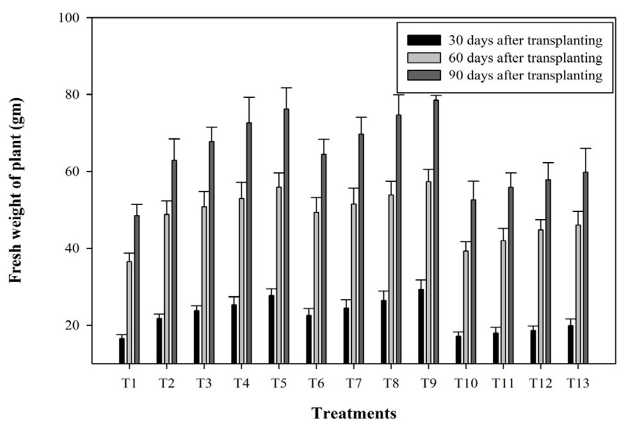

Fig. 6: Fresh weight of plant under different treatment after 30, 60 and 90 days of transplanting

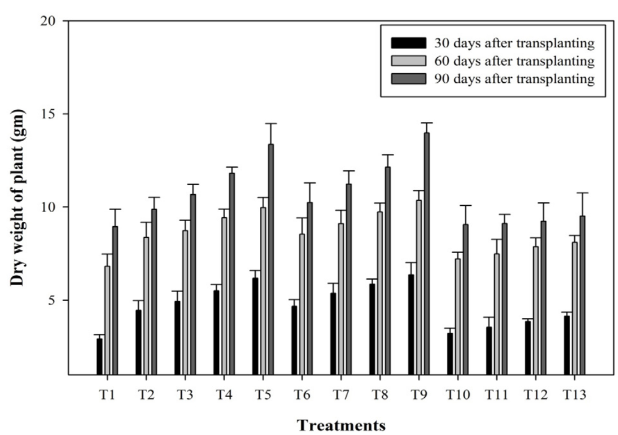

Fig. 7: Dry weight of plant under different treatment after 30, 60 and 90 days of transplanting.

fresh weight of the plant was observed. While at 90 DAT, the highest significant fresh weight of the plant (78.52 and 76.20 g) was observed under the treatment T_9 (IAA @ 200 ppm foliar spray 30 DAT) and T_5 (GA_3 @100 ppm foliar spray 30 DAT). Whereas in treatment T_1 (control), the minimum (48.53 g) fresh weight of the plant was observed (Fig. 6).

The increasing trends of the average dry weight of the plant were observed at 30, 60, and 90 DAT (Fig. 7). At 30 DAT, the dry weight of plant was influenced significantly by various treatments. The highest (6.37 g) dry weight was observed under treatment T_9 (IAA @ 200 ppm foliar spray 30 DAT) and (6.18 g) in treatment T_5 (GA_3 @100 ppm foliar spray 30 DAT). Whereas in treatment T_1 (control), the minimum (2.93 g) plant dry weight was recorded. In the case of 60 DAT, the highest (10.36 g) dry weight was observed under the treatment T_9 (IAA @ 200 ppm foliar spray 30 DAT) and T_5 (GA_3 @100 ppm foliar spray 30 DAT). Whereas in treatment T_1 (control), the minimum (6.82 g) dry weight of the plant was observed. While at 90 DAT, the highest dry weight of the plant (13.98 g and 12.14 g) was observed under the treatment T_9 (IAA @ 200 ppm foliar spray 30 DAT) and T_5 (GA_3 @100 ppm foliar spray 30 DAT). Whereas in treatment T_1 (control), the minimum (8.95 g) dry weight of the plant was observed (Fig. 7).

The fresh and dry weight of the bulb

Various treatments influenced both the fresh as well as dry weight of the bulb. The highest (84.70 g) bulb fresh weight was observed under treatment T_9 (IAA @ 200 ppm foliar spray 30 DAT) and (81.97 g) in treatment T_5 (GA_3 @100 ppm foliar spray 30 DAT). Whereas in treatment T_1 (control), the minimum (38.17 g) fresh weight of the bulb was observed.

The highest (10.61 and 10.13 g) dry weight of the bulb was recorded under the treatment T_9 (IAA @ 200 ppm foliar spray 30 DAT) and T_5 (GA_3 @100 ppm foliar spray 30 DAT). Whereas in treatment T_1 (control), the minimum (4.47 g) dry weight was observed (Fig. 8).

The polar and equatorial diameter of the bulb

Various levels of the treatments significantly influenced the mean polar diameter of the bulb. The treatment T_9 (IAA @200 ppm foliar spray 30 DAT) and T_5 (GA_3 @100 ppm foliar spray 30 DAT) were found to be superior (5.51 and 5.43 cm). The minimum (4.03 cm) polar diameter of the bulb was observed in treatment T_1 (control) (Fig. 9). Various levels of the treatment influenced the mean equatorial diameter of the bulb. The treatment T_9 (IAA @200 ppm foliar spray 30 DAT) and T_5 (GA_3 @100 ppm foliar spray 30 DAT) were found to be superior (5.84 and 5.71 cm). Whereas in treatment T_1 (control), the minimum (5.03 cm) equatorial diameter of the bulb was observed (Fig. 10).

Bulb yield (kg/plot and q/ha)

Significant maximum (6.21 and 6.13 kg) bulb yield per plot was observed in treatment T_9 (IAA @ 200 ppm foliar spray 30 DAT) and treatment T_5 (GA_3 @100 ppm foliar spray 30 DAT). Whereas in treatment T_1 (control), the minimum (4.91 kg) bulb yield per plot was observed. Significantly highest (207.21 and 204.30 q) bulb yield q/ha was observed in treatment T_9 (IAA @ 200 ppm foliar spray 30 DAT) and T_5 (GA_3@100 ppm foliar spray 30 DAT). Whereas in treatment

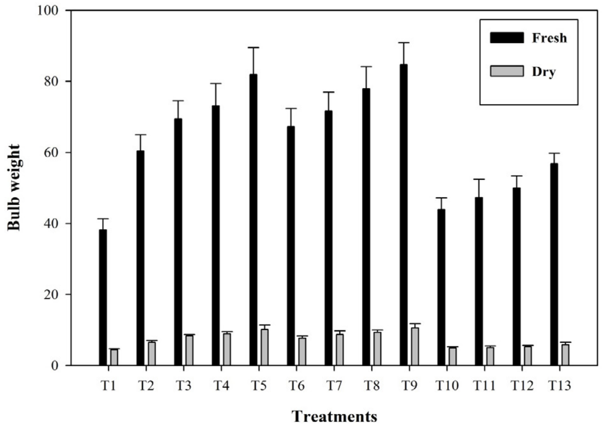

Fig. 8: Bulb weight of plant under different treatment after 30, 60 and 90 days of transplanting

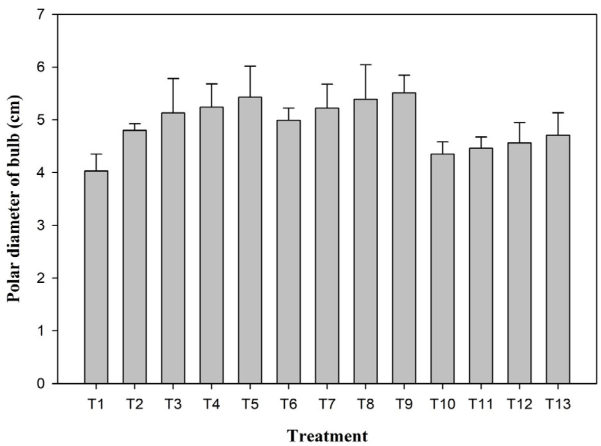

Fig. 9: Polar diameter of bulb under different treatment

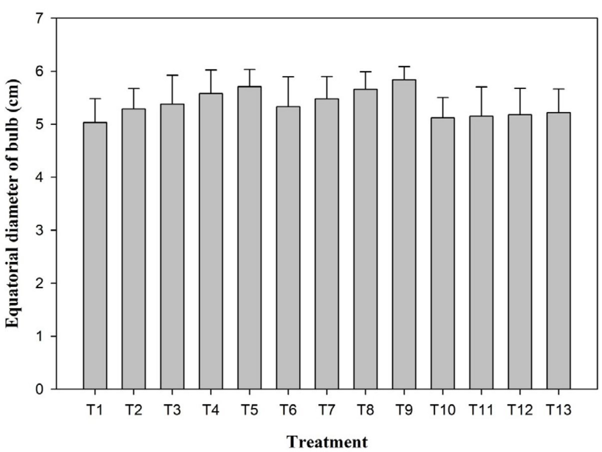

Fig. 10: Equatorial diameter of bulb under different treatment

T_1 (control), the minimum (163.83 kg) bulb yield per ha was observed (Table 2).

Discussion

In India, the main season of onion cultivation is *Rabi* and *Kharif*; approximately 80% of Indian onion production is produced in the *Rabi* season, December-January to April-May, but it cannot be stored for a long period for creating stock buffer due to storage losses (40–50%, weight loss, rotting and sprouting) and lack of advance storage facilities. In most of the observations, about 20% of onion production had been recorded in the *Kharif* season (*Kharif*; July-August to October-December and late *Kharif* season; August-September to January-February) (Soumia et al., 2020). This huge production gap between two seasons causes a yearly crisis in demand and supply. Consequently, the onion prices go very high during *Kharif* and Late *Kharif* season (especially September to March). In the present study, we tried to improve the onion yield during the *Kharif* season by plant growth regulators (PGR) and micronutrient management. Among various treatments, maximum significant plant height was recorded in treatments T_5 and $T_{9,}$ found at par with each other. Whereas in treatment T_1, the minimum plant height was observed. Plant height depends upon various aspects of different growth regulators and micronutrients, as it elevates cell division, elongation and differentiation, which results in enhanced plant growth. Gibberellin is an example of a chemical with a gibbane skeleton that promotes cell elongation, cell division, or both. These results are confirmatory with the finding of Devi et al., (2018). The foliar application of micronutrients also affected plant height; maximum plant height was recorded in treatment $T_{13.}$ Our results are in support of Maurya et al., (2018), who reported similar findings in *Kharif* season onion. The per plant leaves counting was noted maximum in treatments T_9 and $T_{5,}$ which were not significantly differ from each other, whereas in treatment T_1, the minimum number of leaves was observed. Leaves play an important role in the entire life cycle of the plants and contribute to yield. Plant growth regulators can enhance cell division, elongation and differentiation activity, which further may result in a higher number of leaves. Similar findings were also obtained by Sisodia et al. (2012) in different crops. The use of micronutrients also has a positive effect on the number of leaves. Their foliar application has significantly increased the number of leaves per plant in treatment $T_{13,}$ whereas their root dipping has not been much affected. Similar results were also reported by Maurya et al. (2018). Positive impact on leaf area and area index was observed in various treatments, greater effect was noticed with treatment T_9 and treatment T_5. Whereas in treatment T_1, the minimum leaf area and leaf area index (LAI) were observed (Sainath et al., 2012). Foliar application of micronutrients has significantly increased leaf area and leaf area index (LAI). A significant effect was noticed in treatment $T_{13.}$ With an increasing crop growth period, plants show a significant increase in pseudo stem length. Maximum pseudo stem length was observed in treatment T_9 and treatment T_5. Whereas in treatment T_1, the minimum pseudo stem length was observed. This may be due to cell division and cell elongation by the plant growth regulators, resulting in a higher pseudo stem length. Micronutrients have also

Table 2: Effect of different treatments on bulb yield (kg/plot and q/ha)

Treatments	*Bulb yield per plot (kg)*	*Bulb yield per ha (q)*	*Increase over control (%)*
T_1	4.91 ± 0.325	163.83 ± 8.75	0.00 ± 0.00
T_2	5.14 ± 0.421	171.49 ± 11.6	4.67 ± 0.115
T_3	5.39 ± 0.652	179.75 ± 12.5	9.72 ± 0.625
T_4	5.63 ± 0.486	187.83 ± 11.9	14.65 ± 1.62
T_5	6.13 ± 0.732	204.30 ± 17.6	24.70 ± 1.19
T_6	5.22 ± 0.621	174.13 ± 15.6	6.29 ± 0.452
T_7	5.56 ± 0.465	185.36 ± 13.9	13.14 ± 1.22
T_8	5.74 ± 0.387	191.61 ± 11.5	16.96 ± 1.45
T_9	6.21 ± 0.523	207.21 ± 18.2	26.47 ± 2.44
T_{10}	5.00 ± 0.448	166.72 ± 14.1	1.76 ± 0.142
T_{11}	5.02 ± 0.224	167.36 ± 13.7	2.15 ± 0.183
T_{12}	5.06 ± 0.219	168.70 ± 8.45	2.97 ± 0.228
T_{13}	5.11 ± 0.321	170.55 ± 16.5	4.10 ± 0.324

positively influenced the pseudo stem length. Their foliar application has good results, as observed in treatment $T_{13;}$ however, the root dipping method of application does not have a much-pronounced effect.

In general, the bulb yield depends on the aggregation of photoassimilate and partitioning into the plant's various portions. It is strongly affected due to the implementation of different plant growth regulators and micronutrients, which further results in an improvement in yield. Significant variations are observed among various treatments in yield and its attributing traits such as fresh and dry weight of the plant, and fresh and dry weight of the bulb, polar diameter of the bulb, equatorial diameter of the bulb, bulb yield per plot and bulb yield per hectare. Plant fresh and dry weight was significantly affected due to various treatments, the highest plant fresh and dry weight was noted under the treatment T_9 and treatment T_5. Whereas in treatment T_1, the lowest plant fresh and dry weight was recorded. It might be caused by a higher concentration of growth promoters causing the rapid increase and proliferation of plant cells necessary for healthy plant growth. The results of this investigation concerning the maximum fresh weight and dry weight of the plant are consistent with the findings previously reported by Suheela et al. (2005). The application of micronutrients has also contributed to plant fresh and dry weight. However, a greater contribution was found in treatment $T_{13.}$ Significantly highest bulb fresh and dry weight was recorded under the treatment T_9 and T_5, whereas in treatment T_1, the lowest bulb fresh and dry weight was recorded. The probable reason behind the improvement in the fresh and dry weight of the bulb may be due to rapid cell division and elongation activity, leading to a larger size of the bulb. Bulb fresh and dry weight was also found to be increased due to the foliar application of micronutrients. However, maximum effects were found in treatment T_{13}. Kumar et al., 2021 also reported similar findings. Various levels of the treatments significantly influenced the polar and equatorial diameter of the bulb. The treatment T_9 (IAA @200 ppm foliar spray 30 DAT) and treatment T_5 (GA_3 @100 ppm foliar spray 30 DAT) were found to be significantly superior to others. Whereas in treatment T_1 (control), the minimum polar and equatorial diameter of the bulb was recorded. It may be due to rapid cell division and elongation, which leads to larger size of bulbs caused by IAA and GA_3. Similar results were reported by (Dwivedi et al., 2019). Significantly higher bulb yield per plot and per hectare q/ha was recorded in treatment T_9 (IAA @200 ppm foliar spray 30 DAT) and treatment T_5 (GA_3 @100 ppm foliar spray 30 DAT), which were at par with each other. Whereas in treatment T_1 (control), the minimum bulb yield per plot and per hectare was observed. Higher yield may be due to fresh biomass assimilation in shoot and bulb resulting from the effect of cell expansion growth, sugar metabolism, increased proline accumulation, reduced ABA content and balancing hormonal activity. It resulted in vigorous plant growth and enhanced the synthesis and translocation of photosynthates to the bulb, ultimately enhancing bulb yield. The results of this investigation concerning maximum bulb yield are similar to findings previously reported by Devi et al. (2018). The application of micronutrients also has significant effects on bulb yield, but a foliar method of application has a pronounced effect. Among the various treatments of micronutrients highest bulb yield was recorded in treatment T_{13}. Similar results were also reported by Maurya et al. (2018) and Kumar et al. (2021). Judicious application of plant growth regulators, micronutrients and their method of application results in the higher yield of onion bulbs.

Conclusion

The present study reveals that PGR and micronutrient treatments significantly enhanced the onion yield. The application of IAA @ 200 ppm 30 DAT and GA_3 @ 100 ppm foliar spray 30 DAT, along with a recommended dose of FYM and NPK to the onion crop, was found to be the best treatment for obtaining higher vegetative growth and yield of onion bulbs during the *Kharif* season. The micronutrient mixture treatment @1 % - foliar spray also showed good results and enhanced yield. Therefore, the present study will also open a new avenue of onion yield improvement through the integrated management of PGR and micronutrients during *Kharif*.

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सारांश

प्याज़ एक सबसे व्यापक रूप से उगाई जाने वाली फ़सल है जिसका उपयोग सब्जी, मसाले और औषधि के रूप में किया जाता है। वर्तमान अध्ययन में दो पादप वृद्धि नियामकों (PGRs) — इंडोल-3-एसिटिक एसिड (IAA) और जिबरेलिक एसिड (GA3) — के साथ एक सूक्ष्म पोषक तत्व मिश्रण का मूल्यांकन किया गया, जिसमें 3% जिंक, 2.5% आयरन, 1% मैंगनीज, 1% कॉपर, 0.5% बोरॉन और 0.1% मोलिब्डेनम EDTA के साथ चीलेटेड रूप में शामिल थे। कुल 13 उपचार दिए गए जिनमें 100-200 पीपीएम IAA, 50-100 पीपीएम GA3 और 0.5-1.0% सूक्ष्म पोषक तत्वों की विभिन्न सांद्रताएँ शामिल थीं। इन उपचारों को या तो जड़ों को डुबोकर या रोपाई के 30 दिन बाद पत्तियों पर छिड़काव के रूप में दिया गया। सभी PGR और सूक्ष्म पोषक उपचार ने प्याज़ के पौधे की वृद्धि विशेषताओं को बढ़ाया। सभी उपचारों में से, 200 पीपीएम आईएए और 100 पीपीएम जीए3 का पत्तियों पर छिड़काव लेट खरीफ मौसम में प्याज की उपज के मामले में सबसे अच्छा पाया गया। वर्तमान अध्ययन के निष्कर्षों से पता चलता है कि एफ. वाई. एम और एन. पी. के. की अनुशंसित खुराक के साथ 200 पीपीएम आईएए का छिड़काव लेट खरीफ सीजन में प्याज की उपज में सुधार करने में सहायक होगा और भारतीय बाजार में जनवरी से मार्च के दौरान प्याज की कीमतों को बनाए रखने में भी मदद करेगा।