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RESPONSE OF ONION (*Allium cepa* L.) CV. BHIMA RED TO FOLIAR APPLICATION OF NAPHTHALENE ACETIC ACID, GIBBERELIC ACID AND THEIR COMBINATIONS

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ABSTRACT

A field experiment was conducted during the Rabi season (December, 2022 to May, 2023) at the Horticulture Farm, Rajasthan College of Agriculture, Udaipur, to study the effect of foliar application of naphthalene acetic acid (NAA) and gibberellic acid (GA₃), alone and in combination, on the growth, yield and quality of onion (*Allium cepa* L.) cv. Bhima Red. The experiment comprised ten treatments viz., control (water spray), NAA @ 40, 100 and 160 ppm, GA₃ @ 20, 80 and 130 ppm, and their three combinations (NAA @ 40 ppm + GA₃ @ 20 ppm, NAA @ 100 ppm + GA₃ @ 80 ppm and NAA @ 160 ppm + GA₃ @ 130 ppm), replicated thrice in a Randomized Block Design, with sprays applied at 30 and 60 days after transplanting (DAT). Combined application of NAA @ 100 ppm + GA₃ @ 80 ppm was significantly superior to all other treatments for most of the growth and yield attributes, recording the maximum number of leaves (7.60 and 15.12 plant⁻¹ at 60 and 90 DAT), leaf length (45.63 and 55.82 cm at 60 and 90 DAT), fresh weight of plant (93.66 g), dry weight of plant (79.41 g) and bulb yield (31.67 t ha⁻¹), an increase of about 86.5 per cent in yield over the control (16.98 t ha⁻¹). The lowest bolting percentage (2.26%) was recorded with NAA @ 160 ppm + GA₃ @ 130 ppm. Quality attributes viz., total soluble solids, vitamin C, total phenol content, protein content and pH of the bulb were not significantly influenced by any treatment, while the benefit-cost ratio was highest with NAA @ 40 ppm + GA₃ @ 20 ppm. It is concluded that foliar application of NAA @ 100 ppm + GA₃ @ 80 ppm at 30 and 60 DAT can be recommended for maximizing the growth and bulb yield of onion cv. Bhima Red under semi-arid conditions of Rajasthan.

Key words: Onion, Naphthalene acetic acid, Gibberellic acid, Growth regulators, Bulb yield

Introduction

Onion (*Allium cepa* L.), belonging to the family Alliaceae, is one of the most important commercial bulb vegetable crops grown across the world and is a staple flavouring and condiment crop in Indian households. India is the second largest producer of onion in the world, with an area of about 1.22 million hectares and a production

that accounts for nearly a quarter of global onion output (Anonymous, 2021), yet its productivity remains lower than that of leading producers such as China, largely on account of sub-optimal nutrient and plant growth regulator (PGR) management under field conditions.

Although weed management and nutrient management are most essential for proper production of

crops but role of plant growth regulators cannot be neglected (Meena and Jeetarwal, 2025, Jeetarwal *et al.*, 2025 and Choudhary *et al.*, 2026). Plant growth regulators are organic compounds, other than nutrients, which in small amounts promote, inhibit or otherwise modify physiological processes in plants (Choudhary *et al.*, 2026). Among these, gibberellic acid (GA_3) is known to stimulate cell division and cell elongation and thereby influences vegetative growth, while naphthalene acetic acid (NAA), a synthetic auxin, regulates cell elongation, apical dominance, vascular tissue differentiation and various other developmental processes (Davies, 1987). Foliar application of GA_3 has been reported to increase internode length, dry matter accumulation and photosynthetic efficiency in several crops (Sharma *et al.*, 1999), whereas NAA promotes cell enlargement and mobilisation of photosynthates towards developing sink organs.

Several workers have reported the beneficial effects of NAA and GA_3 , alone or in combination, on the growth and yield of onion and allied bulb crops. Sharma *et al.* (2013) reported that combined foliar spray of GA_3 and NAA at 80 ppm significantly increased Rabi onion bulb yield in the semi-arid regions of Rajasthan, while Kumar and Shashidhar (2016) and Patel *et al.*, (2010) recorded improved growth and bulb characters of onion following growth regulator application. However, the response of onion to NAA and GA_3 , particularly in combination, varies with cultivar, dose, stage and agro-climatic conditions, and information on their combined foliar effect on the newly released cultivar Bhima Red under the semi-arid conditions of southern Rajasthan is limited.

Keeping the above facts in view, the present investigation was undertaken to study the effect of different concentrations of NAA and GA_3 , applied alone and in combination as foliar spray at 30 and 60 DAT, on the growth, yield, quality and economics of onion (*Allium cepa* L.) cv. Bhima Red.

Materials and Methods

Experimental site

The field experiment was carried out during the Rabi season of 2022-23 (December, 2022 to May, 2023) at the Horticulture Farm, Department of Horticulture, Rajasthan College of Agriculture, Maharana Pratap University of Agriculture and Technology (MPUAT), Udaipur, Rajasthan.

Planting material and transplanting

Six to seven week old healthy seedlings of onion cv. Bhima Red, procured from the ICAR-Directorate of Onion and Garlic Research, Rajgurunagar, Maharashtra, were transplanted on 13th 4 December, 2022 on flat beds

at a spacing of 15 cm × 10 cm.

Experimental design and treatments

The experiment was laid out in a Randomized Block Design (RBD) with ten treatments replicated thrice, giving thirty plots of 2 m × 1.6 m (net experimental area 96 m²). The treatments comprised: T1- control (water spray); T2- NAA @ 40 ppm; T3- NAA @ 100 ppm; T4- NAA @ 160 ppm; T5- GA_3 @ 20 ppm; T6- GA_3 @ 80 ppm; T7- GA_3 @ 130 ppm; T8- NAA @ 40 ppm + GA_3 @ 20 ppm; T9- NAA @ 100 ppm + GA_3 @ 80 ppm; and T10- NAA @ 160 ppm + GA_3 @ 130 ppm.

Preparation and foliar application of growth regulators

Stock solutions of NAA and GA_3 (1000 ppm) were prepared by dissolving 1 g of the chemical in a litre of water; GA_3 was first dissolved in a small volume of ethanol before making up the volume with distilled water. Working solutions of the required concentrations were prepared from the stock and sprayed as a fine foliar mist at 30 and 60 days after transplanting (DAT), as per the treatment schedule. Recommended agronomic practices, including application of farmyard manure and fertilizers (100:50:50 kg NPK ha⁻¹), irrigation, weeding and plant protection measures, were followed uniformly across all the plots. Bulbs were harvested manually when 50 % of the plants showed neck fall and drying of tops (1-2 May, 2023).

Growth and yield observations

Growth parameters, viz., number of leaves plant⁻¹ and length of leaves (cm), were recorded on twenty randomly tagged plants per plot at 60 and 90 DAT, while bolting percentage was worked out at harvest as the ratio of bolted plants to the total number of plants per plot, expressed in percentage.

For yield attributes, fresh weight of plant at harvest (g) and dry weight of plant (g) were recorded from twenty randomly selected plants per plot using a digital balance, and bulb yield per plot was converted to bulb yield per hectare (t ha⁻¹).

Quality analysis

Quality parameters were estimated from bulb samples of each plot. Total soluble solids (TSS, oBrix) were measured using a digital refractometer (Atago, Japan). Vitamin C content (mg 100 g⁻¹) was estimated by titration against 2,6-dichlorophenol indophenol dye. Total phenol content (mg 100 g⁻¹) was determined by the Folin-Ciocalteu method using gallic acid as standard. Protein content (%) was estimated by the micro-Kjeldahl colorimetric method of Snell and Snell (1949) and calculated as nitrogen per cent × 6.25. The pH of the

Table 1: Effect of foliar application of NAA and GA₃ on growth parameters of onion cv. Bhima Red.

Treatments	No. of leaves plant ⁻¹ (60 DAT) (**)	No. of leaves plant ⁻¹ (90 DAT) (**)	Leaf length (cm) (60 DAT) (**)	Leaf length (cm) (90 DAT) (**)	Bolting (%) (**)
Control (water)	5.64±0.37 ^d	10.01±0.65 ^c	34.77±0.31 ^d	41.35±1.56 ^e	3.73±0.55 ^{ab}
NAA @ 40 ppm	6.49±0.28 ^{abcd}	12.30±0.75 ^b	37.63±1.27 ^{cd}	47.44±1.60 ^{cd}	3.23±0.42 ^{abc}
NAA @ 100 ppm	6.56±0.57 ^{abcd}	12.93±0.80 ^{ab}	38.82±1.11 ^{bc}	48.52±1.03 ^c	3.27±0.35 ^{abc}
NAA @ 160 ppm	6.98±0.41 ^{abc}	13.73±0.47 ^{ab}	41.40±1.21 ^b	50.70±0.91 ^{bc}	3.46±0.37 ^{ab}
GA ₃ @ 20 ppm	5.83±0.61 ^{cd}	11.80±0.82 ^{bc}	37.70±0.89 ^{cd}	42.79±0.89 ^e	3.76±0.21 ^{ab}
GA ₃ @ 80 ppm	6.25±0.06 ^{bcd}	11.98±0.71 ^{bc}	36.28±0.56 ^{cd}	43.76±1.71 ^e	3.83±0.45 ^a
GA ₃ @ 130 ppm	6.42±0.28 ^{bcd}	12.30±0.92 ^b	37.85±1.02 ^{cd}	44.28±1.30 ^{de}	4.07±0.67 ^a
NAA @ 40 ppm + GA ₃ @ 20 ppm	7.09±0.40 ^{ab}	14.64±0.99 ^a	45.58±0.94 ^a	52.38±0.95 ^{ab}	2.92±0.18 ^{abc}
NAA @ 100 ppm + GA ₃ @ 80 ppm	7.60±0.34 ^a	15.12±0.51 ^a	45.63±0.97 ^a	55.82±1.10 ^a	2.66±0.15 ^{bc}
NAA @ 160 ppm + GA ₃ @ 130 ppm	6.95±0.37 ^{abc}	13.64±0.65 ^{ab}	38.95±2.29 ^{bc}	49.95±1.16 ^{bc}	2.26±0.05 ^c
S.E.m.±	0.23	0.452	0.681	0.705	0.232
Tukey HSD (5%)	1.169	2.29	3.453	3.576	1.174
C.V. (%)	6.066	6.09	2.989	2.561	12.084

Values are mean ± SD (n = 3). Means followed by the same superscript letter within a column do not differ significantly (at par); means with no letter in common differ significantly (Tukey's HSD, p = 0.05). ** = significant at 1%, NS = non-significant.

bulb was recorded with a digital pH meter following A.O.A.C. (2012).

Economics

Economics of the treatments was worked out in terms of net return (gross return minus cost of cultivation, Rs ha⁻¹) and benefit-cost (B:C) ratio, computed as the ratio of net return to the total cost of cultivation, based on the prevailing market rates.

Statistical analysis

The data recorded for each character were subjected to analysis of variance (ANOVA) appropriate for a Randomized Block Design using R statistical software through the RStudio interface. Treatment means were compared using Tukey's Honestly Significant Difference (HSD) test at the 5 per cent level of probability, and results are presented as mean ± standard deviation (SD) of three replications.

Results and Discussion

The present investigation was carried out to evaluate the effect of foliar application of naphthalene acetic acid (NAA) and gibberellic acid (GA₃), alone and in combination, on the growth, yield and quality of onion cv. Bhima Red. The results obtained are presented and discussed under the following heads.

Growth parameters

Data presented in Table 1 revealed that foliar application of growth regulators significantly ($p \leq 0.01$) influenced the number of leaves plant⁻¹, leaf length and bolting percentage of onion at both 60 and 90 DAT. Combined application of NAA @ 100 ppm + GA₃ @ 80 ppm (T9) recorded the maximum number of leaves (7.60 and 15.12 plant⁻¹ at 60 and 90 DAT, respectively) and the

longest leaves (45.63 and 55.82 cm at 60 and 90 DAT, respectively), which was statistically at par with NAA @ 40 ppm + GA₃ @ 20 ppm (T8) for most of these attributes, and significantly superior to the control (T1), which recorded the lowest values throughout the crop growth period. The magnitude of improvement over the control was considerable: T9 recorded about 34.8 and 51.0 per cent more leaves, and 31.2 and 35.0 per cent longer leaves, than the control at 60 and 90 DAT, respectively, indicating a strong cumulative growth response to the combined hormonal treatment as the crop advanced from the vegetative to the bulb-development stage. Bolting percentage was highest with GA₃ @ 130 ppm (T7, 4.07%) and lowest with NAA @ 160 ppm + GA₃ @ 130 ppm (T10, 2.26%), the latter being significantly superior (i.e., least bolting) to the control and to GA₃ applied alone, suggesting that the presence of NAA in the tank-mix moderated the bolting-promoting tendency of GA₃ when applied at the higher dose.

The stimulatory effect of combined NAA and GA₃ application on vegetative growth is in conformity with the findings of Bista *et al.*, (2022), who reported that foliar application of growth regulators enhanced vegetative growth of onion through increased cell division, cell elongation and vascular tissue differentiation. GA₃ is known to stimulate cell elongation and division in the sub-apical meristem by promoting hydrolysis of stored starch to soluble sugars and increasing cell wall plasticity, while NAA activates the plasma membrane proton pump, acidifying the cell wall and thereby promoting cell wall loosening and elongation (Davies, 1987); the synergism of the two hormones when applied together, as observed for T8 and T9 in the present study, is consistent with the

reports of Patel *et al.*, (2010), Chattopadhyay *et al.*, (2015) and Singh *et al.*, (2014), who recorded increased leaf number and leaf length in onion and garlic following combined application of NAA and GA₃. A broadly similar growth-promoting response to exogenous growth regulators has also been documented in other bulb and ornamental crops, for instance by Kanwar and Khandelwal (2013) in African marigold, lending additional support to the general physiological basis of auxin-gibberellin synergism observed in the present investigation.

The comparatively higher bolting recorded with GA₃ applied alone agrees with the general observation that GA₃ can substitute for the low-temperature vernalisation requirement and thereby hasten the reproductive (bolting) phase in bulb crops, whereas its combination with NAA at higher doses appeared to restrict premature bolting, possibly because NAA-mediated auxin dominance delayed floral transition and maintained the plants in a vegetative phase for a longer duration under the present study. Since leaf number and leaf length together determine the total photosynthetic leaf area of the plant, the consistently superior canopy development recorded under NAA @ 100 ppm + GA₃ @ 80 ppm (T9) throughout the crop cycle would be expected to translate into greater carbohydrate synthesis and, consequently, higher biomass accumulation and bulb yield, a relationship examined further under yield attributes below.

Yield attributes

Yield attributes are presented in Table 2. Fresh weight of plant, dry weight of plant and bulb yield per hectare were all significantly ($p \leq 0.01$) influenced by the treatments. The combination NAA @ 100 ppm + GA₃ @ 80 ppm (T9) recorded the highest fresh weight of plant (93.66 g), dry weight of plant (79.41 g) and bulb yield (31.67 t ha⁻¹) - increases of about 29.4, 33.3 and 86.5 per cent, respectively, over the control (72.36 g, 59.56 g and 16.98 t ha⁻¹). T9 was statistically at par with NAA @ 160 ppm + GA₃ @ 130 ppm (T10) for fresh weight of plant, but significantly superior to all other treatments, including T10, for bulb yield - indicating that the moderate 100 + 80 ppm combination converted vegetative growth into economic bulb yield more efficiently than the higher 160 + 130 ppm dose. The lowest values for all three attributes were recorded in the control, and a broadly increasing trend in fresh weight, dry weight and yield was evident with increasing NAA and GA₃ concentration up to the 100 + 80 ppm combination, beyond which the response tended to plateau or decline slightly.

These findings corroborate the reports of Shukla *et al.*, (2010), who observed that GA₃ and NAA, applied alone or in combination, significantly improved the growth

Table 2: Effect of foliar application of NAA and GA₃ on yield attributes of onion cv. Bhima Red.

Treatments	Fresh weight of plant (g) (**)	Dry weight of plant (g) (**)	Bulb yield (t ha ⁻¹) (**)
Control (water)	72.36±2.01 ^f	59.56±1.51 ^h	16.98±0.95 ^b
NAA @ 40 ppm	80.17±1.14 ^{de}	68.76±0.72 ^{def}	22.71±0.48 ^{ef}
NAA @ 100 ppm	82.63±1.98 ^{cd}	69.88±1.57 ^{de}	24.27±0.48 ^{de}
NAA @ 160 ppm	85.42±1.08 ^{bc}	71.32±0.95 ^{cd}	25.31±0.62 ^{cd}
GA ₃ @ 20 ppm	75.71±1.71 ^{ef}	64.81±1.21 ^g	19.17±0.65 ^{gh}
GA ₃ @ 80 ppm	76.33±2.94 ^{ef}	65.26±0.51 ^{fg}	21.56±0.62 ^{fg}
GA ₃ @ 130 ppm	78.41±1.96 ^{de}	66.59±1.91 ^{efg}	21.88±0.31 ^{ef}
NAA @ 40 ppm + GA ₃ @ 20 ppm	89.16±1.53 ^{ab}	74.85±1.31 ^{bc}	29.48±0.95 ^{ab}
NAA @ 100 ppm + GA ₃ @ 80 ppm	93.66±0.60 ^a	79.41±0.88 ^a	31.67±1.57 ^a
NAA @ 160 ppm + GA ₃ @ 130 ppm	90.86±0.58 ^a	75.50±1.21 ^b	27.71±1.18 ^{bc}
S.E.m±	0.98	0.713	0.476
Tukey HSD (5%)	4.971	3.616	2.413
C.V. (%)	2.059	1.775	3.424

Values are mean ± SD (n = 3). Means followed by the same superscript letter within a column do not differ significantly (at par); means with no letter in common differ significantly (Tukey's HSD, p = 0.05).
** = significant at 1%, NS = non-significant.

and yield of onion. The higher bulb yield with the combined treatment may be attributed to an improved source-sink relationship, wherein GA₃-induced enhancement of photosynthetic efficiency and chlorophyll synthesis coupled with NAA-mediated cell division and elongation at the growing point resulted in greater accumulation of photosynthates, more bulb scales and, consequently, higher dry matter and bulb yield, as also suggested by Sharma *et al.*, (2013) and Kumar and Shashidhar (2016) for onion. Similar synergistic effects of combined auxin-gibberellin application on yield have also been reported by Devi *et al.*, (2018) in onion. The comparatively lower efficiency of the higher-dose combination (T10) relative to T9, despite receiving higher concentrations of both hormones, points to a supra-optimal effect at very high PGR doses, wherein excess exogenous auxin can trigger ethylene biosynthesis and partially offset the intended growth-promoting response - a possibility that merits further physiological investigation under the semi-arid conditions of the present study.

Quality attributes and economics

Data on quality attributes of onion bulb are presented in Table 3. Total soluble solids, vitamin C, total phenol content, protein content and pH of the bulb were not significantly influenced by the foliar application of NAA and GA₃, either alone or in combination, indicating that exogenous hormone application in the present study did

Table 3: Effect of foliar application of NAA and GA₃ on bulb quality attributes and benefit-cost ratio of onion cv. Bhima Red.

Treatments	TSS (°Brix) (NS)	Vitamin C (mg 100g ⁻¹) (NS)	Total phenol (mg 100g ⁻¹) (NS)	Protein (%) (NS)	pH (NS)	B:C ratio (**)
Control (water)	11.76±0.41 ^a	11.93±0.02 ^a	112.98±2.33 ^a	5.13±0.26 ^a	4.19±0.10 ^a	1.12±0.09 ^d
NAA @ 40 ppm	11.63±0.51 ^a	12.50±0.03 ^a	121.09±0.86 ^a	4.72±0.48 ^a	4.88±0.42 ^a	1.53±0.32 ^{bcd}
NAA @ 100 ppm	11.37±0.14 ^a	12.20±0.58 ^a	119.84±7.13 ^a	4.52±0.45 ^a	5.56±0.30 ^a	1.85±0.06 ^{abcd}
NAA @ 160 ppm	12.62±0.21 ^a	12.46±0.01 ^a	119.72±7.24 ^a	4.71±0.52 ^a	5.35±0.44 ^a	2.24±0.07 ^{ab}
GA ₃ @ 20 ppm	12.03±0.50 ^a	12.17±0.59 ^a	112.13±9.16 ^a	5.06±0.02 ^a	5.46±0.48 ^a	1.43±0.47 ^{cd}
GA ₃ @ 80 ppm	12.27±0.31 ^a	12.54±0.01 ^a	114.76±11.64 ^a	5.06±0.08 ^a	5.30±0.53 ^a	1.77±0.10 ^{abcd}
GA ₃ @ 130 ppm	11.84±0.74 ^a	12.47±0.02 ^a	119.86±2.03 ^a	5.15±0.03 ^a	5.41±0.27 ^a	1.24±0.29 ^{cd}
NAA @ 40 ppm + GA ₃ @ 20 ppm	11.95±0.88 ^a	12.47±0.02 ^a	116.46±6.35 ^a	5.44±0.02 ^a	5.48±0.40 ^a	2.03±0.25 ^{abc}
NAA @ 100 ppm + GA ₃ @ 80 ppm	11.76±0.24 ^a	12.42±0.01 ^a	110.50±1.73 ^a	5.14±0.04 ^a	4.92±0.79 ^a	2.45±0.53 ^a
NAA @ 160 ppm + GA ₃ @ 130 ppm	11.90±0.60 ^a	12.32±0.01 ^a	115.19±4.94 ^a	4.53±0.62 ^a	5.51±0.80 ^a	1.63±0.28 ^{bcd}
S.Em.±	0.287	0.143	3.848	0.201	0.276	0.158
Tukey HSD (5%)	NS	NS	NS	NS	NS	0.8
C.V. (%)	4.177	2.011	5.733	7.035	9.19	15.81

Values are mean ± SD (n = 3). Means followed by the same superscript letter within a column do not differ significantly (at par); means with no letter in common differ significantly (Tukey's HSD, p = 0.05).
** = significant at 1%, NS = non-significant.

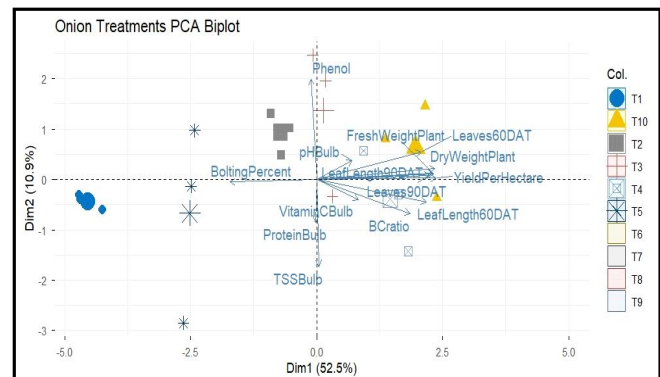
not compromise the biochemical quality of the produce even at the highest bulb yield. The highest benefit-cost ratio (2.90) was recorded with NAA @ 40 ppm + GA₃ @ 20 ppm (T8), and the lowest (1.12) with the control (T1), while the highest-yielding treatment (T9) recorded a comparatively lower B:C ratio (2.45) on account of the additional cost of the higher-dose combination relative to its yield advantage.

The non-significant response of biochemical quality parameters to NAA and GA₃ application observed in the present study is in agreement with Abu-grab and Ebrahim (2000) and Safdari *et al.*, (2014), who similarly reported limited influence of growth regulator treatments on the biochemical composition of onion bulbs, suggesting that these attributes are governed more strongly by genotype and bulb maturity than by exogenous hormone application at the doses tested - a view also consistent with the observation of Misra (1963) that the nutritional composition of vegetable crops is primarily a varietal characteristic rather than one readily altered by short-term agronomic interventions. Comparable non-significant trends for total soluble solids and protein content following GA₃ application were also noted by Mushtaq *et al.*, (2018) and Shaikh *et al.*, (2002) in onion. The higher B:C ratio recorded with the lower-cost combination (T8) despite T9 giving the highest absolute yield indicates that, from an economic standpoint, a lower-dose combination of NAA and GA₃ may be more remunerative for growers under prevailing input costs, a trend also reported by Dwivedi and Asati (2019) in Kharif onion; nevertheless, where maximisation of total bulb yield is the primary objective, as in seed-production or export-oriented

cultivation, the NAA @ 100 ppm + GA₃ @ 80 ppm combination (T9) remains the treatment of choice.

PCA analysis

The PCA biplot showed clear differences among the onion treatments based on the studied growth, physiological, yield, and quality parameters (Fig. 1). The first two principal components explained 63.4% of the total variation, with Dim1 and Dim2 accounting for 52.5% and 10.9%, respectively. Most growth and yield-related traits were positively associated and clustered on the positive side of Dim1, indicating a close relationship among these parameters. The treatments were distinctly separated, demonstrating differential responses to the application of NAA, GA₃, and their combinations. Overall, the combined plant growth regulator treatments, particularly those positioned closer to the positive association of growth and yield attributes, showed a comparatively favourable response, whereas the control treatment was clearly separated from most treated combinations.

**Fig. 1:** Principle component analysis of different traits effected due to different treatments.

Conclusion

On the basis of the present investigation, it can be concluded that foliar application of NAA @ 100 ppm + GA₃ @ 80 ppm at 30 and 60 DAT was the most effective treatment for improving the growth (number and length of leaves) and yield attributes (fresh and dry weight of plant, bulb yield) of onion cv. Bhima Red, recording an increase of about 86.5 per cent in bulb yield over the control. Quality attributes of the bulb were not significantly affected by any of the treatments, while the lower-dose combination of NAA @ 40 ppm + GA₃ @ 20 ppm gave the highest benefit-cost ratio. Hence, foliar spray of NAA @ 100 ppm + GA₃ @ 80 ppm at 30 and 60 DAT may be recommended for realising higher growth and bulb yield of onion cv. Bhima Red under semi-arid conditions of Rajasthan, though further multi-location trials are suggested to validate the economic optimum dose.

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References

- A.O.A.C. (2012). Official methods of analysis of the association of official analytical chemists (AOAC) international. Method 932.06, Method 933.09, 19th ed. AOAC International, Washington.
- Abu-grab, O. and Ebrahim M. (2000). Physiological response of field grown onion to some growth regulators. *Egyptian Journal of Horticulture*, **27**(1), 117-130.
- Anonymous (2021). Area and production of vegetable crops in India, Indian Horticulture Database, National Horticulture Board.
- Bista, D., Sapkota D., Paudel H. and Adhikari G. (2022). Effect of foliar application of growth regulators on growth and yield of onion (*Allium cepa* L.). *International Journal of Horticultural Science and Technology*, **9**(2), 247-254.
- Chattopadhyay, N., Lalrinpuii F. and Thapa U. (2015). Influence of plant growth regulators on growth and yield of garlic (*Allium sativum* L.). *J. of Crop and Weed*, **11**(2), 67-71.
- Choudhary, M., Prasad M. and Mahawer S.K. (2025). Nutrient Management Strategies for Sustainable Forage Production. *Indian J. of Fertilisers*, **21**(11), 1160-1169.
- Choudhary, R.N., Gupta S., Jeetarwal V., Saini S., Parshar V., Bohi S.P., Prajapat V. and Parewa H.P. (2026). Herbicide resistance in weeds: Evolution, mechanisms and agronomic mitigation strategies. *Journal of Advances in Biology & Biotechnology*, **29**(4), 86-96.
- Davies, P.J. (1987). Plant hormone and their role in plant growth and development. *Martinus Nijhoff Publication, Dordrecht, Netherlands*, **8**(3), 142-144.
- Devi, J., Singh R. and Walia I. (2018). Effect of foliar application of GA₃. *Plant Archives*, **18**(2), 1209-1214.
- Dwivedi, B. and Asati K.P. (2019). Effect of PGRs and their methods of application on yield, quality and economics of Kharif onion (*Allium cepa* L.) cv. Agrifound Dark Red. *The Pharma Innovation Journal*, **8**(10), 70-73.
- Jeetarwal, V., Singh S.P. and Saini S. (2025). Effect of different herbicides on weed dynamics in green gram under western arid region of Rajasthan. *Annals of Agricultural Research* **46**(3), 280-285.
- Kanwar, J. and Khandelwal S.K. (2013). Effect of plant growth regulators on growth and yield of African marigold (*Tagetes erecta* L.). *Madras Agricultural J.*, **100**(3), 45-47.
- Kumar, H.M.S. and Shashidhar T.R. (2016). Effect of foliar application of growth regulators and bio stimulants on growth and yield of onion var. Bhima Shakti. *Journal of Farm Sciences*, **29**(1), 50-52.
- Meena, B.R. and Jeetarwal V. (2025). Weed control methods affect weed dynamics, productivity and economics of clusterbean [*Cyamopsis tetragonoloba* (L.) Taub.]. *Annals of Agricultural Research*, **46**(1), 65-70.
- Misra, S. (1963). Nutritional qualities of vegetables. *Indian Food Packer*, **3**(1), 14-18.
- Mushtaq, S., Amjad M., Ziaf K. and Afzal I. (2018). Gibberellins application timing modulates growth, physiology, and quality characteristics of two onion (*Allium cepa* L.) cultivars. *Environmental Science and Pollution Research*, **25**(25), 25155-25161.
- Patel, M.J., Patel H.C. and Chavda J.C. (2010). Effect of plant growth regulators and their application methods on growth and yield of onion (*Allium cepa* L.). *Advance Research Journal of Crop Improvement*, **1**(2), 85-87.
- Safdari, M., Dardar A. and Khaniki G.B. (2014). The independent effect of time and hormonal concentration treatments on reproductive traits in onion. *Indian Journal of Fundamental and Applied Life Sciences*, **4**(4), 3009-3015.
- Shaikh, A.M., Vyakaranahal B.S., Shekhargouda, M. and Dharmatti P.R. (2002). Influence of bulb size and growth regulators on growth, seed yield and quality of onion cv. Nasik Red. *Seed Research*, **30**(2), 223-229.
- Sharma, A.K., Kumar S. and Yadav G.L. (2013). Effect of bioregulators on productivity and quality of Rabi onion (*Allium cepa*) in semi-arid regions of Rajasthan. *Annals of Biology*, **29**(1), 1-2.
- Sharma, N., Kaur N. and Gupta A.K. (1999). Effects of gibberellic acid and chlorocholine chloride on tuberization and growth of potato (*Solanum tuberosum* L.). *J. Science of Food Agriculture*, **78**(4), 466-470.
- Shukla, N., Mondal S., Dikshit S.N., Trivedi J., Tamrakar S. and Sharma P. (2010). Effect of different concentrations of GA₃ and NAA and their methods of application on growth and yield of onion (*Allium cepa* L.). *Progressive Horticulture*, **42**(1), 111-113.
- Singh, A., Pankaj S. and Singh G. (2014). Effect of growth regulators on growth, yield and quality of onion. *Punjab Horticulture Journal*, **23**(1), 102-104.
- Snell and Snell (1949). On the probable identity of several unidentified growth factors. *Archives of Biochemistry and Biophysics*, **23**, 326-328.