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RESPONSE OF NANO UREA, ZINC AND BORON ON GROWTH, YIELD AND QUALITY OF ONION (*Allium cepa* L.)

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ABSTRACT

The study was conducted during the *Rabi* season of 2024–25 at the Research Farm, Department of Horticulture, Prof. Rajendra Singh (Rajju Bhaiya) University, Prayagraj, Uttar Pradesh, India. The experiment used a Randomized Block Design (RBD) with nine treatment combinations involving various doses and foliar applications of nano urea, boron, and zinc on the Nasik Red (N-53) onion variety. Results were found to be significant in treatments, T_3 (75% Recommended Dose of Fertilizer (RDF) + Nano Urea @ 0.4% foliar spray at 30–60 Days After Transplanting) showed the best performance in growth parameters such as plant height (81.41 cm), number of leaves (9.07), pseudo stem length (12.68 cm) and diameter (2.82 cm). In contrast, T_6 (75% RDF + Boron @ 0.4% + Zinc @ 0.4% foliar spray at 30–45 DAT) significantly improved yield and quality traits, including bulb weight (209.79 g), yield per hectare (32.19 t/ha^{-1}) and quality indicators like TSS (12.90 °Brix), ascorbic acid (11.91 mg/100g), and total sugar (5.33%). Additionally, T_4 (75% RDF + Boron @ 0.4%) recorded the highest titratable acidity (12.73%). Overall, the results indicate that integrating nano fertilizers and micronutrients can effectively enhance the growth, yield and quality of onions.

Key words : Nano urea, Boron, Zinc, RDF, Onion.

Introduction

Onion (*Allium cepa* L.) belong to family Alliaceae and chromosome no 2n= 16 is a widely cultivated vegetable bulb crop, familiar to and cultivated by various cultures around the world. (Ballesteros *et al.*, 2018). It is originated at North West India and Central Asia. It is a cross pollinated and monocot vegetable crop growing in the cool seasons. The “Queen of the Kitchen” moniker for onions is also occasionally used. Onions are a staple ingredient in virtually every kitchen, serving both as a condiment and a vegetable and thus, they hold a significant presence in the market (Aagasimani *et al.*, 2010). Both the bulbs and the leaves are utilized in a number of food preparations including salads, vegetables, seasonings and even medicine. The bulb, varies in shape from flat to globular to oblong and comes in different colors such as red, white, or yellow. Onion is an annual herb with aromatic fleshy underground bulb; leaves are linear acicular, hollow, cylindrical and fleshy, flowers white arranged in globular umbels (Pareek *et al.*, 2017).

Onion is one of the oldest vegetables known to man having been in cultivation since the recorded history of mankind, at least 5000 years ago. Global onion production area has increased considerably from less than 2 million ha^{-1} in 1990 to more than 5 million ha in 2021. Onions are the second most valuable vegetable crop in the world in terms of gross production value, after tomatoes (FAO, 2021).

The onion bulb serves as a valuable reservoir of essential minerals such as phosphorus and calcium. Additionally, it is a notable source of protein, vitamin C, quercetin and flavonoids. They can be consumed raw, cooked. The nutrients in onion bulbs include 86.84% moisture, 1.2% protein, 0.1% fat, 11.6% carbohydrates, 0.4% minerals, 0.18% calcium, 0.05% phosphorus, 0.7% iron, 0.4% nicotinic acid along with vitamin B and vitamin C (Samiksha *et al*., 2021).

Nano urea a novel technology in fertilizer designing is expected to reduce the environmental pollution caused by the granular form by reducing its excessive application that causing environmental pollution. Nano urea is gaining importance in Indian agriculture because of its ability in increasing nutrient use efficiency, increasing crop yields, and reducing excessive use of synthetic fertilizers. Being required in small quantities compared to bulky nitrogenous fertilizers like urea, it is easy to store and transport (Kumar *et al*., 2020).

Zinc also plays very important role for bulb formation and nutrition. Zinc deficiency is prevalent worldwide in temperate and tropical climates (Fageria *et al*., 2011). Foliar application of micronutrients during active crop growth stage was successfully used for correcting their deficits and improving the mineral status of the plants as well as increasing the crop yield and quality (Osinska and Kolota, 2001). Producing of good quality onion bulbs is an important target by onion growers whom have and for inadequate knowledge about beneficial role of micronutrients in increasing yield and quality of onion local and foreign markets.

Boron is one of the important micronutrient for onion production and is essential for cell division, nitrogen and carbohydrate metabolism, protein formation and water relation in plant growth (Manna *et al*., 2016). In the plant, it is comparatively stationary while being rapidly absorbed from the soil. The proper ratio of calcium, nitrogen, and boron in the soil must be maintained. High calcium and high nitrogen levels can reduce boron uptake. Boron deficiency has been observed in soils with high organic matter contents (Vitosh *et al*., 2001). These soils have already been reported to be deficient in boron (Mondal *et al*., 2002). Application of boron increases bulb size, weight per bulb and yield of onion (Smiriti *et al*., 2002).

Materials and Methods

A field study was conducted during Rabi season 2024-25 at the Agriculture Research Field, Prof. Rajendra Singh (Rajju Bhaiya) University, Prayagraj (U.P.) to study the effect of nano urea zinc and boron on growth, yield and quality of onion (*Allium cepa*). The experimental field's soil had a medium NPK status, was uniformly textured, medium black and had good drainage. The physico-chemical properties of the soil of the experimental field (0-15 cm) was: clay 45%, silt 15.30% and sand 25.27%, pH 7.4, electrical conductivity (EC) 0.75 dsm^{-1}, organic carbon 0.30%. Available nitrogen 67.5 kg/ha^{-1}, available P_2O_5 18.0 kg/ha^{-1}, available K_2O 268.8 kg/ha^{-1}, available $ZnSO_4$ 2.13 Kg/ ha^{-1} and available Bo 0.95 Kg/ ha^{-1}. The experiment was laid out in RBD with three replications and consisted of 9 treatments *viz*., T_1 Control (water spray); T_2 – 100% Recommended Dose of Fertilizers (RDF) (NPK 100:50:50kg/ha) as traditional fertilizer; T_3 – 75% RDF + Nano urea @ 0.4% as foliar application on 30 to 60 DAT of water as foliar application; T_4 – 75% RDF + Boron @ 0.4% as foliar application on 30 to 45 DAT of water as foliar application; T_5 – 75% RDF + Zinc @ 0.4% as foliar application on 30 to 45 DAT of water as foliar application; T_6- 75% RDF + Boron @ 0.4% + Zinc@ 0.4% as foliar application on 30 to 45 DAT of water as foliar application; T_7- 50% RDF + Nano urea @ 0.5% as foliar application on 30 to 60 DAT of water as foliar application; T_8- 50% RDF + Boron @ 0.5% as foliar application on 30 to 45 DAT of water as foliar application and T_9- 50% RDF + Zinc @ 0.5% as foliar application on 30 to 45 DAT. Vegetative growth parameters, including plant height (cm) and pseudostem length (cm)—measured from ground level to the leaf tip and top of the leaf sheath, respectively—were recorded using a meter scale at 30, 60 and 90 days after transplanting (DAT). Simultaneously, pseudostem diameter (mm) was measured using digital Vernier calipers. The total number of leaves per plant was carefully counted at 30, 60 and 90 DAT, with a final count taken at the time of harvest.

Post-harvest physical and yield attributes were assessed by selecting five random bulbs per treatment. Bulb polar length (cm) and equatorial diameter (cm) were recorded at maximum width using Vernier calipers, which were also used to measure final neck thickness (mm). Average bulb weight (g) was computed by dividing the cumulative sample weight by the number of bulbs. Net plot yield (kg) was recorded on an electronic balance after de-topping leaves 2.0–2.5 cm above the neck and was subsequently converted to total bulb yield (t/ha).

Biochemical quality analysis began with Total Soluble Solids (TSS, °Brix), assessed according to the methodology of Waskar *et al*. (1999). Titratable acidity was determined by diluting a 10 ml juice sample to 100 ml with distilled water; a 5ml aliquot of this dilution was mixed with 1–2 drops of phenolphthalein and titrated against 0.1N NaOH until a persistent pink endpoint

emerged. Ascorbic acid mg/100g was quantified by titrating freshly extracted juice against 2,6-dichlorophenol-indophenol dye. For sugar estimation, Fehling's solutions 5 ml each of A and B mixed with 25ml water were pre-standardized by boiling and rapidly titrating against a standard invert sugar solution until light blue, followed by the addition of 2–3 drops of methylene blue indicator to complete titration at a distinct brick-red precipitate endpoint. Sample juices were processed similarly to estimate reducing and total sugar percentages.

The experimental data were subjected to an Analysis of Variance (ANOVA) following the procedure for a Randomized Block Design (RBD), as described by Gomez and Gomez (1976). The significance of treatment effects was tested using the F-test and the Critical Difference (CD) at a 5% level of significance was used to compare treatment means.

Results and Discussion

Plant height (cm)

The data revealed that significant and higher plant height (cm) 81.4 cm was recorded in treatment T_3 (75% RDF + Nano urea @ 0.4% as foliar application on 30 to 60 DAT) and followed by T_6 (75% RDF + Boron @ 0.4% + Zinc @ 0.4% as foliar application on 30 to 45 DAT) at 78.18 cm and T_1 (control) had the lowest plant height (64.67 cm) (Table 1).

Treatment T_3 (75% RDF + Nano urea @ 0.4% as foliar application from 30 to 60 DAT) significantly outperformed all other treatments. This indicates that nano urea, due to its higher nutrient use efficiency and rapid foliar absorption, likely enhanced cell division and elongation processes more effectively. Similar findings were reported by Rathnayaka *et al*. (2018) and Dubey *et al*. (2023).

Number of leaves

The data revealed that significant and maximum number of leaves (9.07) was recorded in treatment T_3 (75% RDF + Nano urea @ 0.4% as foliar application on 30 to 60 DAT) and followed by T_6 (75% RDF + Boron @ 0.4% + Zinc @0.4% as foliar application on 30 to 45 DAT) at 8.73 and T_1 (control) had the minimum number of leaves (6.33) (Table 1).

Treatment T_3 (75% RDF + Nano urea @ 0.4% as foliar application from 30 to 60 DAT) significantly outperformed all other treatments a direct indicator of vegetative vigor and photosynthetic potential. Nano urea enhanced nitrogen delivery and micronutrients' regulatory roles in physiological processes likely contributed to improved leaf initiation and expansion. Similar findings were reported by Khater *et al*. (2015) and Rathnayaka *et al*. (2018).

Table 1 : Effect of Nano urea zinc and boron on growth attributes of onion (*Allium cepa*).

Treatments	Plant height (cm)	Number of leaves	Pseudo stem length (cm)	Pseudo stem Diameter (cm)
T_1 - Control	64.67± 2.11	6.33± 0.27	8.72± 0.02	1.97± 0.01
T_2- 100% RDF (NPK 100:50:50kg/ha)	65.34± 0.72	6.60± 0.40	9.88± 0.01	1.99± 0.02
T_3- 75% RDF + Nano urea @ 0.4% as foliar application on 30 to 60 DAT	81.41± 1.09	9.07± 0.07	12.68± 0.02	2.82± 0.03
T_4- 75% RDF + Boron @ 0.4% as foliar application on 30 to 45 DAT	66.29± 1.54	7.40± 0.20	9.54± 0.01	2.11± 0.01
T_5- 75% RDF + Zinc @ 0.4% as foliar application on 30 to 45 DAT	65.20± 1.22	7.27± 0.07	9.91± 0.13	2.17± 0.04
T_6- 75% RDF + Boron @ 0.4% + Zinc @ 0.4% as foliar application on 30 to 45 DAT	78.18± 3.31	8.73± 0.07	11.23± 0.27	2.61± 0.09
T_7- 50% RDF + Nano urea @ 0.5% as foliar application on 30 to 60 DAT	67.03± 1.14	7.47± 0.18	9.92± 0.03	2.12± 0.05
T_8- 50% RDF + Boron @ 0.5% as foliar application on 30 to 45 DAT	65.19± 2.27	7.93± 0.07	9.80± 0.05	2.20± 0.05
T_9- 50% RDF + Zinc @ 0.5% as foliar application on 30 to 45 DAT	67.88± 2.41	7.40± 0.20	10.26± 0.02	2.16± 0.02
S.E. m. ±	1.87	0.18	0.10	0.05
C.D. at 5%	5.67	0.53	0.29	0.14

Pseudo stem length (cm)

The data revealed that highest T_3 (75% RDF + Nano urea @ 0.4% as foliar application on 30 to 60 DAT) at maintained the lead in pseudo stem length (cm) at 12.68 cm, and followed by T_6 (75% RDF + Boron @ 0.4% + Zinc @ 0.4% as foliar application on 30 to 45 DAT) at 11.23 cm and Control plants (T_1) were still the shortest pseudo stem length (cm) at 8.72 cm (Table 1).

Treatment T_3 (75% RDF + Nano urea @ 0.4% as foliar application from 30 to 60 DAT) significantly outperformed all other treatments. A longer pseudo stem may indicate better inter nodal elongation and overall shoot growth. This again can be attributed to the availability of sufficient nitrogen from nano urea, which is critical for vegetative growth and the presence of boron and zinc, which are known to improve hormone regulation and metabolic functions in the plant (Moghadam *et al*., 2012).

Pseudo stem Diameter (cm)

The data revealed that significant and higher pseudo stem diameter 2.82 cm was recorded in treatment T_3 (75% RDF + Nano urea @ 0.4% as foliar application on 30 to 60 DAT) and followed by T_6 (75% RDF + Boron @ 0.4% + Zinc @0.4% as foliar application on 30 to 45 DAT) at 2.61 cm and T_1 (control) had the lowest pseudo stem diameter (1.97 cm) (Table 1).

The treatment combination involving T_3 75% RDF + Nano urea @ 0.4% as foliar spray on 30 to 45 DAT resulted in an enhanced Pseudo stem diameter (cm) in onions compared to other treatments. The synergy of nano urea foliar application could be attributed due to the effect of nitrogen on cell division, elongation, protein synthesis etc., which enhanced the Pseudo stem diameter and growth. Similar findings were reported by Khater *et al*. (2015), Rathnayaka *et al*. (2018), Dubey *et al*. (2023).

Equatorial diameter (cm)

The results on equatorial diameter (cm) at harvest, treatment T_6 (75% RDF + Boron @ 0.4% + Zinc @ 0.4% as foliar application on 30 to 45 DAT) recorded the greatest equatorial diameter (cm) (7.62 cm), which was significantly similar to results obtained from treatment T_3 (75% RDF + Nano urea @ 0.4% as foliar application on 30 to 60 DAT) at 7.23, however, treatment T_1 with control resulted with lowest equatorial diameter (cm) of 5.29 cm (Table 2).

These results suggest that a combined application of Boron and Zinc may enhance cell division and expansion

Table 2 : Effect of Nano urea zinc and boron on growth and yield of onion (*Allium cepa*).

Treatments	Equatorial diameter (cm)	Polar diameter (cm)	Neck thickness (cm)	Weight of bulb (gm)	Plot yield (kg/plot)	Yield per hectare (t/ha^{-1})
T_1 - Control	5.29± 0.09	4.29± 0.26	2.09± 0.04	100.02± 6.48	5.08± 0.25	12.70± 0.67
T_2- 100% RDF (NPK 100:50:50kg/ha)	5.47± 0.27	4.24± 0.36	2.03± 0.11	105.66± 1.42	8.17± 0.60	20.42± 1.50
T_3- 75% RDF + Nano urea @ 0.4% as foliar application on 30 to 60 DAT	7.23± 0.28	5.45± 0.24	2.73± 0.17	199.63± 8.59	9.82± 0.11	24.56± 0.27
T_4- 75% RDF + Boron @ 0.4% as foliar application on 30 to 45 DAT	6.49± 0.19	4.83± 0.12	2.26± 0.04	156.20± 9.63	10.12± 0.29	24.86± 0.44
T_5- 75% RDF + Zinc @ 0.4% as foliar application on 30 to 45 DAT	6.50± 0.28	4.93± 0.09	2.23± 0.10	171.10± 7.97	9.51± 0.29	23.77± 0.72
T_6- 75% RDF+ Boron @ 0.4% + Zinc @ 0.4% as foliar application on 30 to 45 DAT	7.62± 0.07	5.68± 0.21	2.89± 0.09	209.79± 7.40	12.88± 0.36	32.19± 0.89
T_7- 50% RDF + Nano urea @ 0.5% as foliar application on 30 to 60 DAT	6.55± 0.12	4.86± 0.06	2.29± 0.09	161.49±12.61	9.68± 0.20	24.21± 0.49
T_8- 50% RDF + Boron @ 0.5% as foliar application on 30 to 45 DAT	6.63± 0.14	5.09± 0.21	2.38± 0.17	168.02± 3.45	9.42± 0.30	23.55± 0.75
T_9- 50% RDF + Zinc @ 0.5% as foliar application on 30 to 45 DAT	6.43± 0.17	4.97± 0.22	2.27± 0.14	135.69±10.17	9.51± 0.37	23.79± 0.93
S.E. m. ±	0.14	0.13	0.08	8.47	0.35	0.83
C.D. at 5%	0.41	0.39	0.23	25.61	1.05	2.52

in bulb tissues, thereby increasing bulb dimensions. Boron is known to play a critical role in cell wall synthesis and integrity, while Zinc influences enzymatic activities and auxin metabolism, both contributing to improved morphological development (Acharya *et al*., 2015; Dake *et al*., 2011).

Polar diameter (cm)

Different treatments had significant maximum polar diameter (5.68 cm) was recorded when T_6 (75% RDF + Boron @ 0.4% + Zinc @ 0.4% as foliar application on 30 to 45 DAT) and followed by T_3 with polar diameter (cm) of 5.45 cm, which was applied with 75% RDF + Nano urea @ 0.4% as foliar application on 30 to 60 DAT, whereas minimum polar diameter (cm) (4.29 cm) was recorded in treatment with T_1 Control (Table 2).

The treatment combination involving T_6 75% RDF + Boron @ 0.4% + Zinc @ 0.4% as foliar application on 30 to 45 DAT resulted in an enhanced polar diameter. Role of micronutrients (Zn and B) in cell division, meristematic activity of plant tissue and expansion of cells (Patil *et al*., 2009).

Neck thickness (cm)

Different treatments had significant maximum neck thickness (2.89 cm) was recorded when T_6 (75% RDF + Boron @ 0.4% + Zinc @ 0.4% as foliar application on 30 to 45 DAT) and followed by T_3 with neck thickness (cm) of 2.73 cm, which was applied with 75% RDF + Nano urea @ 0.4% as foliar application on 30 and 60 DAT, whereas minimum neck thickness (cm) 2.09 cm was recorded in treatment with T_1 Control (Table 2).

T_6 (75% RDF + Boron @ 0.4% + Zinc @ 0.4% as foliar application on 30 to 45 DAT) also demonstrated a significantly higher neck thickness (cm). Increased neck thickness may be attributed to improved nutrient translocation and hormonal regulation supported by the micronutrient synergy in T_6. A sturdier neck could also reduce post-harvest losses and improve storage longevity (El Shaikh *et al*., 2019).

Average bulb weight (gm)

The highest average bulb weight (gm) 209.79 g was recorded under the T_6 (75% RDF + Boron @ 0.4% + Zinc @ 0.4% as foliar application on 30 and 45 DAT), which was succeeded by T_3 (75% RDF + Nano urea @ 0.4% as foliar application on 30 and 60 DAT) at 199.63 gm. However, the lowest (100.02 gm) average bulb weight (gm) was recorded in the treatment T_1 control (Table 2).

Bulb weight is a direct indicator of yield potential, and T_6 (75% RDF + Boron @ 0.4% + Zinc @ 0.4% as foliar application on 30 and 45 DAT) outperforming all other treatments. Zinc and boron play an essential role in improving plant growth, through the biosynthesis of endogenous hormones which is responsible for promotion of plant growth (El-Samad *et al*., 2011).

Plot yield (kg/plot)

The maximum plot yield (kg/plot) of 12.88 kg was obtained with T_6 (75% RDF + Boron @ 0.4% + Zinc @ 0.4% as foliar application on 30 and 45 DAT), which was followed by 10.12 kg yield from T_4 (75% RDF + Boron @ 0.4% as foliar application on 30 and 45 DAT), whereas the minimum yield (5.08 kg) was recorded in the treatment T_1 (control) (Table 2).

The treatment combination involving T_6 75% RDF + Boron @ 0.4% + Zinc @0.4% as foliar application on 30 to 45 DAT resulted in an enhanced plot yield (kg/plot). Zinc and boron also promote skin thickness and size of bulb. Indicating that even single micronutrient applications can contribute to improved productivity (Alam *et al*., 2010 and El-Samad *et al*., 2011).

Yield t/ha^{-1}

The maximum mean data of the Yield t/ha^{-1} was recorded as 12.88 t/ha^{-1} at harvest in T_6 (75% RDF + Boron @ 0.4% + Zinc @ 0.4% as foliar application on 30 to 45 DAT), followed by 10.12 t /ha^{-1} in T_4 (75% RDF + Boron @ 0.4% as foliar application on 30 and 45 DAT), and a minimum of 5.08 kg in T_1 Absolute Control (Table 2).

The treatment combination involving T_6 75% RDF + Boron @ 0.4% + Zinc @ 0.4% as foliar application on 30 to 45 DAT resulted in an enhanced Yield t/ha^{-1}. Role of micronutrients (Zn and B) in cell division, meristematic activity of plant tissue and expansion of cells. Application of zinc and boron through soil or foliar or in combination had a beneficial effect on the growth of onion regardless of stages (Patil *et al*., 2009).

TSS (^{o}Brix)

The maximum of the TSS (^{o}Brix) was recorded as 12.90 ^{o}Brix at harvest in T_6 (75% RDF + Boron @ 0.4% + Zinc @ 0.4% as foliar application on 30 to 45 DAT), followed by 12.22 ^{o}Brix at T_4 (75% RDF + Boron @ 0.4% as foliar application on 30 and 45 DAT) and a minimum of 9.53 ^{o} Brix in T_1 Absolute Control (Table 3).

This improvement is attributed to the role of Boron and Zinc in enhancing photosynthetic efficiency and assimilate translocation. Boron facilitates sugar transport across membranes and cell walls, while Zinc activates enzymes involved in carbohydrate metabolism. Their combined foliar application likely accelerated sugar synthesis and accumulation in the bulbs (Smriti *et al*.,

Table 3 : Effect of nano urea zinc and boron on quality attributes of onion (*Allium cepa*).

Treatments (%)	TSS content (°Brix)	Titrable Acidity (%)	Ascorbic acid (mg/100gm)	Total Sugar
T_1 - Control	9.52± 0.19	10.38± 0.08	7.00± 0.44	2.32± 0.18
T_2- 100% RDF (NPK 100:50:50kg/ha)	9.83± 0.18	10.55± 0.14	8.17± 0.60	3.07± 0.25
T_3- 75% RDF + Nano urea @ 0.4% as foliar application on 30 to 60 DAT	10.14± 0.39	11.09± 0.27	9.82± 0.09	4.31± 0.24
T_4- 75% RDF + Boron @ 0.4% as foliar application on 30 to 45 DAT	12.22± 0.13	12.73± 0.43	10.43± 0.29	4.43± 0.19
T_5- 75% RDF + Zinc @ 0.4% as foliar application on 30 to 45 DAT	10.84± 0.27	10.87± 0.17	10.16± 0.38	3.39± 0.15
T_6- 75% RDF + Boron @ 0.4% + Zinc @ 0.4% as foliar application on 30 to 45 DAT	12.90± 0.12	11.46± 0.13	11.91± 0.88	5.33± 0.08
T_7- 50% RDF + Nano urea @ 0.5% as foliar application on 30 to 60 DAT	10.03± 0.30	11.14± 0.31	8.93± 0.88	3.62± 0.18
T_8- 50% RDF + Boron @ 0.5% as foliar application on 30 to 45 DAT	10.37± 0.20	12.40± 0.23	10.09± 0.45	3.64± 0.28
T_9- 50% RDF + Zinc @ 0.5% as foliar application on 30 to 45 DAT	10.43± 0.38	11.80± 0.06	9.42± 0.30	3.64± 0.06
S.E. m. ±	0.23	0.23	0.50	0.19
C.D. at 5%	0.70	0.70	1.52	0.57

2002; Alam *et al.*, 2010).

Titrable acidity (%)

The highest of the Titrable Acidity (%) was recorded as 12.73% at harvest in T_4 (75% RDF + Boron @ 0.4% as foliar application on 30 and 45 DAT), followed by 12.40 (%) at T_8 (50% RDF + Boron @ 0.4% as foliar application on 30 and 45 DAT) and a minimum of 10.38% in T_1 Absolute Control (Table 3).

Boron is known to influence the biosynthesis and regulation of organic acids by maintaining cell membrane integrity and enzyme activities. Enhanced acidity may improve the flavor profile and storage quality of the bulbs (Alam *et al.*, 2010; Kumar *et al.*, 2020).

Ascorbic acid (mg/100g)

The maximum of the Ascorbic acid (mg/100g) was recorded as 11.91 mg at harvest in T_6 (75% RDF + Boron @ 0.4% + Zinc @ 0.4% as foliar application on 30 to 45 DAT), followed by 10.43 mg in T_4 (75% RDF + Boron @ 0.4% as foliar application on 30 and 45 DAT) and a minimum of 7.00 mg in T_1 Absolute Control (Table 3).

Zinc plays a direct role in antioxidant enzyme systems, while Boron influences hormonal balance and metabolic activities that enhance Vitamin C biosynthesis. The improved nutrient status and reduced oxidative stress under these treatments likely contributed to higher ascorbic acid concentration (El-Samad *et al.*, 2011; Dake *et al.*, 2011).

Total sugar (%)

The maximum of the Total sugar (%) was recorded as 5.33% at harvest in T_6 (75% RDF + Boron @ 0.4% + Zinc @ 0.4% as foliar application on 30 to 45 DAT), followed by 4.43 % in T_4 (75% RDF + Boron @ 0.4% as foliar application on 30 and 45 DAT) and a minimum of 2.32% in T_1 Absolute Control (Table 3).

The increase can be linked to the role of Boron in phloem loading and sugar transport and Zinc's involvement in regulating carbohydrate metabolic enzymes like carbonic anhydrase and dehydrogenases. Their foliar application during active growth stages likely promoted more efficient sugar synthesis and accumulation in bulbs (Kumar *et al.*, 2020).

Conclusion

Based on the results of the present investigation, it can be concluded that the foliar application of T_3 (75% RDF + Nano urea @ 0.4% as foliar spray 30 to 60 DAT) significantly enhanced the vegetative growth. The treatment T_6 (75% RDF + Boron @ 0.4% + Zinc @ 0.4% as foliar spray (30 to 45 DAT) was found to be most effective in improving yield and quality parameters.

Considering the superior performance in terms of growth, yield and quality, the foliar application of T_3 (75% RDF + Nano urea @ 0.4% as foliar spray 30 to 60 DAT)

and T_6 (75% RDF + Boron @ 0.4% + Zinc @ 0.4% as foliar spray 30 to 45 DAT), along with the recommended dose of fertilizers (RDF), can be recommended for adoption by farmers cultivating onion cv. Nasik Red (N-53).

Authors' contributions

Conceptualization, L.P.; Data curation, L.P., and R.M.; Formal analysis, L.P. and R.M.; Investigation, L.P. and R.M.; Methodology, L.P., Supervision, L.P.; Validation, L.P., and R.M.; Visualization, L.P., and A.Y..; Writing - original draft, L.P.; Writing - review and editing, L.P, R.M. and A.Y., All authors read and approved the final manuscript.

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Conflict of interests

The authors declare that there are no conflicts of interest related to this article.

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