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Effect of urea and citric acid on growth yield, and quality of garlic (*Allium Sativum L.*)

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Abstract

The present investigation was undertaken to evaluate the effect of foliar application of urea and citric acid, individually and in combination, on the growth, yield, and quality attributes of garlic (*Allium sativum* L.) cv. Bheema Purple. The experiment was laid out in a Randomized Block Design (RBD) with nine treatments replicated three times. Treatments included varying concentrations of urea (1% and 2%) and citric acid (50 ppm and 100 ppm) applied as aqueous foliar sprays at three intervals. A wide range of growth parameters were recorded at 30, 60, and 90 days after sowing (DAS), while yield and quality traits were assessed at harvest. The results consistently showed that Treatment T_8 (Urea @2% + Citric Acid @100 ppm) outperformed all other treatments across every measured parameter. It recorded the highest plant height (77.69 cm at 90 DAS), maximum leaves per plant (16.13), greatest leaf length (60.85 cm), thickest neck (14.07 mm), highest bulb yield (220.75 q ha^{-1}), and superior quality traits including TSS (44.29 °Brix), titratable acidity (0.69%), ascorbic acid content (27.42 mg $100g^{-1}$), and moisture content (71.49%). The Benefit-Cost ratio of T_8 was the highest at 4.10, clearly confirming its economic viability. The untreated control (T_9) consistently showed the poorest performance on all counts. These findings strongly support the combined foliar application of urea and citric acid as a cost-effective agronomic strategy to enhance garlic productivity and quality.

Keywords: *Allium sativum*, foliar nutrition, urea, citric acid, bheema purple, bulb yield, garlic quality, randomized block design

Introduction

Garlic (*Allium sativum L.*) is one of the important bulb crops and also known as Lahsoon, Poodu and Lason with chromosome number 2n =2x = 16, belongs to Alliaceae family. It originated in Central Asia and is used as a vegetable as well as for medicinal purposes (Petrovska and Cekovska 2010 [9]).

India ranks second in area and third in production of garlic in the world. In India, it is cultivated throughout the country occupying an area of 274.10thousand ha with production of 1271.30 thousand MT and productivity of 4.64 MT. In India, the major garlic producing states are Madhya Pradesh, Rajasthan, Uttar Pradesh and Gujarat. In Rajasthan, it is grown extensively in Chittorgarh, Baran, Jodhpur, Jhalawar, Kota, Bundi, Jaipur and Sikar districts. In Rajasthan, it is grown in about 60.00 thousand ha and total production of 300.00 thousand MT giving average productivity of 5.0MT perha. (Anonymous, 2015) [2].

Garlic is the second most widely produced Allium next to onion and used as a spice or condiments in many foods. It can consume as either raw vegetables (garlic seedlings, scape or cloves) or nourishments in the forms of value-added products such as garlic oils, powders, juices, dehydrated garlic and pickles. Garlic has higher nutritive value as compared to other bulb crops including protein (6.3 g), moisture (62 g), fibre (0.8 g), carbohydrate (29.8 g), energy (145 K Cal), calcium (160 mg), iron (6.5 mg), phosphorus (370 mg), zinc (1.93 mg), magnesium (71 mg) and vitamin C (13 mg) per 100 g of edible portion (Thumburaj and Singh 2019 [13]), commonly, the bulb of garlic has a spicy and fragrant aroma because it contains diallyl disulfide compounds that make dishes more delicious, it contains 0.1- 0.4% essential oil, the chief constituents of the oil are diallyl-disulphide (60%) true garlic odour, diallyl trisulfide (20%), allyl-propyl disulfide (6%) and small amount of diethyl disulphide and diallyl polysulfide (Singh and Pal 2003 [11]).

The cv. Bheema Purple is a popularly cultivated variety of garlic known for its good bulb size, attractive purple colour, pungent flavour, and relatively higher yield potential. However, to fully exploit the genetic potential of this variety, supplemental nutritional management through foliar sprays is essential.

Urea — chemically represented as CO(NH2)2 — is the most nitrogen-concentrated solid fertilizer in widespread use, carrying roughly 46% nitrogen by weight. Its affordability, ease of handling, and high nutrient content Have made it a goto choice for garlic growers in many parts of the world. Nitrogen is often considered the primary driver of growth in garlic. Research has consistently demonstrated that adequate nitrogen nutrition results in more robust vegetative development, improved leaf production, and significantly larger bulb size at harvest (Stork *et al.*, 2004, as cited in Sah *et al.*., 2018) [10, 12].

Citric acid is a short-chain organic acid that occurs widely in nature. Plants produce and actively release it from their root tips, particularly when they are experiencing difficulty in absorbing phosphorus from surrounding soil. It belongs to the group of low-molecular-weight organic acids includes oxalic and malic acid which also and these compounds are known to interact with soil chemistry in ways that can benefit plant nutrition (Zhu *et al.*, 2022) [16].

Materials and Methods

The experiment was conducted during the crop year 2025-26 at the Horticulture Research Field of Prof. Rajendra Singh (Rajju Bhaiya) University, Naini, Prayagraj, Uttar Pradesh. The agro-climatic conditions of the region are characterized by a semi-arid subtropical climate, with warm summers, mild winters, and moderate annual rainfall. The experiment was laid out in a Randomized Block Design (RBD) with nine treatments, each replicated three times, giving a total of 27 experimental plots. Foliar sprays were applied three times during the crop growth period. The treatments comprised: T_1 – Urea @1% (aqueous foliar spray), T_2 – Urea @2% ,T_3 – Citric Acid @50 ppm, T_4 – Citric Acid @100 ppm, T_5 – Urea @1% + Citric Acid @50 ppm, T_6 – Urea @1% + Citric Acid @100 ppm ,T_7 – Urea @2% + Citric Acid @50 ppm, T_8 – Urea @2% + Citric Acid @100 ppm ,T_9 – Control (Plain Water Spray only) .The crop cv. Bheema Purple was planted using healthy and uniform-sized seed cloves at a rate of 500 kg/ha. All standard agronomic practices including field preparation (three ploughings), proper bed layout, timely irrigation (eight irrigations at regular intervals), weeding, and plant protection measures were carried out uniformly across all experimental plots. Basal fertilizers were applied before planting as per the recommended dose.

Statistical Analysis

All data collected were subjected to statistical analysis using the standard procedures for Randomized Block Design. The F-test was applied to determine the significance of treatment effects. Standard error of mean (SE(m)), standard error of difference (S.Ed.) and Critical Difference (CD) at P =0.05 probability level Were computed to compare treatment means. An Ftest result of 'S' indicates statistical significance and 'NS' indicates non-significance.

Results and Discussion

Growth Parameters

Plant Height (cm)

Plant height is one of the most fundamental indicators of vegetative growth and overall crop vigour. As data in Table 1 clearly show, plant height increased progressively from 30 DAS to 90 DAS in all experimental treatments, which is a natural reflection of continuous cell division and elongation during the vegetative phase.

Plant height increased steadily from 30 to 90 DAS in all treatments, indicating normal crop growth. Treatment 8 recorded the highest plant height at all stages (28.06, 57.84, and 77.69 cm at 30, 60, and 90 DAS, respectively), while Treatment 9 recorded the lowest values (24.79, 35.27, and 49.34 cm). The enhanced plant height under Treatment 8 suggests improved nutrient uptake, physiological activity, and vegetative growth, making it the most effective treatment for promoting plant vigor and development (Yadav *et al...*, 2012) [15].

Number of Leaves per Plant

The number of leaves per plant increased progressively from 30 to 90 DAS in all treatments. Treatment 8 recorded the highest number of leaves at all growth stages (8.41, 12.74, and 16.13 leaves per plant at 30, 60, and 90 DAS, respectively), while Treatment 9 recorded the lowest values (4.85, 6.98, and 8.96 leaves per plant). The superior performance of Treatment 8 indicates its effectiveness in enhancing leaf production, vegetative growth, and overall plant vigor throughout the crop growth period (Chaudhary *et al...*, 2018).

Table 1: Effect of Urea and Citric Acid on Plant Height and Number of leaves per plant at 30, 60, and 90 days after Sowing of Garlic

Treatments	Plant Height (cm)			No. of Leaves per Plant		
	30 DAS	60 DAS	90 DAS	30 DAS	60 DAS	90 DAS
T_1 –Urea @ 1%	26.46	38.73	53.69	5.23	7.04	9.83
T_2 – Urea @ 2%	27.62	40.57	56.15	5.22	8.14	10.48
T_3 – Citric Acid @ 50 ppm	29.24	42.90	58.98	5.92	8.73	11.27
T_4 –Citric Acid @ 100 ppm	30.55	45.19	61.36	6.29	9.27	11.99
T_5 – Urea @ 1% + Citric Acid @ 50 ppm	30.22	47.73	64.87	6.74	9.98	12.85
T_6 – Urea @ 1% + Citric Acid @ 100 ppm	33.83	50.46	68.44	7.16	10.68	13.76
T_7 – Urea @ 2% + Citric Acid @ 50 ppm	35.48	53.77	72.55	7.72	11.56	14.82
T_8- Urea @ 2% + Citric Acid @ 100 ppm	28.06	57.84	77.69	8.41	12.74	16.13
T_9- Control	24.79	35.27	49.34	4.85	6.98	8.96
CD at 5%	2.733	1.587	1.700	1.154	1.256	3.077
SE (m)±	0.966	0.561	0.601	0.408	0.444	1.088

Leaf Length (cm)

At 30 DAS, leaf length varied from 17.13 cm in T9 to 28.16 cm in T8. This early divergence between the best and worst treatments highlights how rapidly foliar nutrition begins to influence leaf expansion. At 60 DAS, T8 recorded the longest leaves at 47.59 cm, followed by T7 (43.88 cm) and T6 (40.12 cm), while T9 trailed at just 27.49 cm. At 90 DAS, the maximum leaf length of 60.85 cm was again observed in T8, while T9 produced the shortest leaves at 35.95 cm.

The superior leaf length observed under the treatment 8 indicates its effectiveness in promoting leaf expansion and vegetative growth, which may enhance photosynthetic efficiency and contribute to higher crop productivity (Wang *et al...*, 2022) [14].

Neck Thickness (mm)

Neck thickness increased progressively from 30 to 90 DAS in all treatments, indicating continuous growth and development of the root system. Treatment 8 recorded the highest neck thickness at all stages (7.53, 10.25, and 14.07 mm at 30, 60, and 90 DAS, respectively), followed by Treatments 7 and 6, while Treatment 9 recorded the lowest values (4.22, 5.73, and 7.69 mm). The superior neck thickness observed under Treatment 8 suggests enhanced root enlargement and greater accumulation of assimilates, resulting in improved plant growth and bulb development (Patel *et al*..., 2017) [8].

Table 2: Effect of Urea and Citric Acid on Leaf Length and Neck thickness at 30, 60, and 90days after Sowing of Garlic

Treatments	Leaf Length (cm)			Neck thickness (mm)		
	30 DAS	60 DAS	90 DAS	30 DAS	60 DAS	90 DAS
T_1 –Urea @ 1%	18.35	29.91	38.64	4.69	6.15	8.26
T_2 – Urea @ 2%	19.16	31.19	40.13	4.94	6.49	8.75
T_3 – Citric Acid @ 50 ppm	20.43	33.27	42.64	5.27	6.95	9.36
T_4 –Citric Acid @ 100 ppm	21.59	35.42	45.35	5.59	7.42	10.03
T_5 – Urea @ 1% + Citric Acid @ 50 ppm	22.95	37.54	48.20	5.98	7.96	10.87
T_6 – Urea @ 1% + Citric Acid @ 100 ppm	24.37	40.12	51.53	6.37	8.59	11.74
T_7 – Urea @ 2% + Citric Acid @ 50 ppm	25.94	43.88	55.98	6.89	9.33	12.75
T_8- Urea @ 2% + Citric Acid @ 100 ppm	28.16	47.59	60.85	7.53	10.25	14.07
T_9- Control	17.13	27.49	35.95	4.22	5.73	7.69
CD at 5%	1.387	0.802	0.948	1.844	0.650	1.628
SE (m)±	0.490	0.283	0.335	0.652	0.230	0.575

Yield Parameters

Fresh Weight of Bulb (g)

Fresh bulb weight varied significantly among treatments, with the highest value recorded in Treatment 8 (63.49 g), followed by Treatment 7 (57.85 g) and Treatment 6 (51.93 g), while Treatment 9 recorded the lowest fresh bulb weight (29.64 g). The superior performance of Treatment 8 indicates its effectiveness in enhancing nutrient uptake, photosynthetic activity, and assimilate translocation, leading to increased bulb growth, carbohydrate accumulation, and fresh biomass production (Bhosle, S., 2024) [4].

Dry Weight of Bulb (g)

Dry bulb weight was significantly influenced by the treatments, with the highest value recorded in Treatment 8 (19.68 g), followed by Treatment 7 (17.83 g) and Treatment 6 (16.05 g), while Treatment 9 recorded the lowest dry weight (7.47 g). The superior dry matter accumulation under Treatment 8 suggests enhanced photosynthetic activity, efficient nutrient uptake, and better translocation of assimilates to the bulbs, resulting in increased synthesis and storage of carbohydrates and other structural compounds (Kenea, A. and Gedamu, S., 2020) [6].

Diameter of Bulb (mm)

Bulb diameter varied significantly among the treatments, with the highest diameter recorded in Treatment 8 (66.73 mm), followed by Treatment 7 (61.85 mm) and Treatment 6 (57.59 mm), while Treatment 9 recorded the lowest diameter (34.85 mm). The superior bulb diameter observed under Treatment 8 indicates enhanced cell division, cell enlargement, and greater accumulation of photosynthates in the bulb, resulting in improved bulb enlargement and overall plant growth (Kenea, A. and Gedamu, S., 2020) [6].

Number of Cloves per bulb

The number of cloves per bulb was significantly influenced by the treatments, with the highest value recorded in Treatment 8 (31.18 cloves bulb^{-1}), followed by Treatment 7 (28.31) and Treatment 6 (26.20), while Treatment 9 recorded the lowest number of cloves (16.42). The superior performance of Treatment 8 indicates enhanced bulb differentiation, improved nutrient uptake, greater photosynthetic activity, and efficient assimilate partitioning, leading to increased clove formation and higher yield potential (Patel *et al*..., 2019) [7].

Bulb yield (q ha⁻¹)

Bulb yield was significantly affected by the treatments, with the highest yield recorded in Treatment 8 (220.75 q ha^{-1}), followed by Treatment 7 (201.37 q ha^{-1}) and Treatment 6 (184.93 q ha^{-1}), while Treatment 9 produced the lowest yield (115.66 q ha^{-1}). The superior yield under Treatment 8 can be attributed to its positive effects on vegetative growth and yield-contributing traits, including plant height, leaf production, neck thickness, bulb size, bulb weight, and number of cloves per bulb, which enhanced photosynthetic efficiency and assimilate translocation, resulting in increased bulb development and productivity (Aryal, A., 2020) [3].

Table 3: Effect of Urea and Citric Acid on Yield Parameters of Garlic

Treatments	Fresh Weight of Bulb (g)	Dry Weight of Bulb (g)	Diameter of Bulb (mm)	Number of Cloves per bulb	Yield (q/ha)
T_1 –Urea @ 1%	32.85	10.35	42.19	18.43	128.43
T_2 – Urea @ 2%	35.68	11.19	44.64	19.88	136.59
T_3 – Citric Acid @ 50 ppm	38.96	12.17	47.26	21.35	145.38
T_4 –Citric Acid @ 100 ppm	42.74	13.29	50.47	22.97	156.85
T_5 – Urea @ 1% + Citric Acid @ 50 ppm	47.57	14.74	53.95	24.56	170.66
T_6 – Urea @ 1% + Citric Acid @ 100 ppm	51.93	16.05	57.59	26.20	184.93
T_7 – Urea @ 2% + Citric Acid @ 50 ppm	57.85	17.83	61.85	28.31	201.37
T_8- Urea @ 2% + Citric Acid @ 100 ppm	63.49	19.68	66.73	31.18	220.75
T_9- Control	29.64	7.47	34.85	16.42	115.66
CD at 5%	1.464	1.099	2.513	1.289	5.625
SE (m)±	0.518	0.388	0.888	0.456	1.988

Quality Parameters

Total soluble solids (TSS)

Total soluble solids (TSS) were significantly influenced by the treatments, with the highest TSS recorded in Treatment 8 (44.29 °Brix), followed by Treatment 7 (42.17 °Brix) and Treatment 6 (40.86 °Brix), while Treatment 9 recorded the lowest value (33.09 °Brix). The superior TSS under Treatment 8 indicates enhanced photosynthetic activity and greater accumulation of soluble sugars and carbohydrates in the bulbs, resulting in improved bulb quality, flavor, processing suitability, and storage potential (Kenea, A. and Gedamu, S., 2020) [6].

Titratable acidity (%)

Titratable acidity was significantly affected by the treatments, with the highest acidity recorded in Treatment 8 (0.69%), followed by Treatment 4 (0.56%), Treatment 2 (0.50%), and Treatment 1 (0.44%), while Treatment 9 recorded the lowest value (0.13%). The higher titratable acidity under Treatment 8 indicates enhanced metabolic activity and greater accumulation of organic acids in the bulbs, contributing to improved flavor, quality, and storage characteristics (Ali *et al.*.., 2017).

Ascorbic acid (mg/ 100 g)

Ascorbic acid content was significantly influenced by the treatments, with the highest value recorded in Treatment 8 (27.42 mg 100 g^{-1}), followed by Treatment 7 (24.66 mg 100 g^{-1}) and Treatment 6 (22.79 mg 100 g^{-1}), while Treatment 9 recorded the lowest content (14.57 mg 100 g^{-1}). The superior ascorbic acid content under Treatment 8 indicates enhanced physiological activity, efficient nutrient utilization, and increased biosynthesis of antioxidant compounds, thereby improving the nutritional quality of the bulbs (Kenea, A. and Gedamu, S., 2020) [6].

Moisture content (%)

Moisture content was significantly affected by the treatments, with the highest value recorded in Treatment 8 (71.49%), followed by Treatment 7 (69.13%) and Treatment 6 (67.36%), while Treatment 9 recorded the lowest moisture content (55.97%). The higher moisture content under Treatment 8 indicates improved water uptake, nutrient absorption, and cellular development, leading to enhanced bulb hydration, greater fresh bulb weight, and improved bulb growth (Ali *et al.*.., 2017).

Table 4: Effect of Urea and Citric Acid on Quality Parameters of Garlic

Treatments	TSS (Brix)	Titrable Acidity (%)	Ascorbic Acid (mg/100g)	Moisture Content (%)
T_1 –Urea @ 1%	34.27	0.44	15.51	60.43
T_2 – Urea @ 2%	35.19	0.50	16.74	61.59
T_3 – Citric Acid @ 50 ppm	36.55	0.19	17.93	62.85
T_4 –Citric Acid @ 100 ppm	37.94	0.56	19.37	64.24
T_5 – Urea @ 1% + Citric Acid @ 50 ppm	39.43	0.25	21.05	65.97
T_6 – Urea @ 1% + Citric Acid @ 100 ppm	40.86	0.28	22.79	67.36
T_7 – Urea @ 2% + Citric Acid @ 50 ppm	42.17	0.31	24.66	69.13
T_8- Urea @ 2% + Citric Acid @ 100 ppm	44.29	0.69	27.42	71.49
T_9- Control	33.09	0.13	14.57	55.97
CD at 5%	1.648	0.630	6.288	2.021
SE (m)±	0.583	0.223	2.223	0.714

Conclusion

The use of Treatment 8 was the most successful treatment for enhancing garlic growth, yield, quality, and financial returns, according to the findings of the current study. Compared to other treatments, the treatment greatly increased plant height, leaf count, leaf length, neck thickness, bulb weight, bulb diameter, number of cloves per bulb, and overall bulb yield. Important quality characteristics such total soluble solids, titratable acidity, ascorbic acid concentration, and moisture content were also enhanced. Additionally, Treatment 8 demonstrated higher economic viability and profitability with the highest Benefit-Cost ratio (4.10). Therefore, Treatment 8 can be recommended for achieving higher productivity and better bulb quality in garlic cultivation under the agro-climatic conditions of the experiment.

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