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Research Article

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Effects of Various Nutrients on Sprouting, Growth, and Development of Garlic (*Allium sativum* L.) at the Green Stage

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ABSTRACT

Garlic (*Allium sativum* L.) is a vital crop, yet its growth and sprouting at the green stage can be significantly influenced by nutrient availability, which poses a challenge for optimizing yield and quality. The present research was carried out in 2022–2023 at the Nursery Department of Horticulture, Sindh Agriculture University Tandojam, to assess the sprouting and growth of garlic (*Allium sativum* L.) at green stage under various nutrients. The experimental trial was carried out in complete randomization (CRD) with three replications. Two varieties, a Chinese and a local (Desi) (Desi) variety, were grown in the pots. Macronutrients used as treatments included N_1 (control). N_2 = NPK+TE (trace elements) 2 g, L^{-1}. N_3 = Calcium Nitrate 0.5g, L^{-1} and N_4 = NPK+TE 2g, L^{-1} + Calcium Nitrate 0.5g, L^{-1}. The results of the present studies showed a statistically significant difference for treatments and nutrient combinations. Best results for all observations were noted in plants supplied with NPK+TE 2g L^{-1} that had maximum plant height 55.83 cm, leaves plant^{-1} 6.83, leaf length 47.66 cm, leaf weight 8.96g, plant weight 13.20g, neck thickness 6.55mm, root weight 2.68g, and root depth 19.83cm. Fallow control plant height 41.00cm leaves plant^{-1} 5.00, leaf length 31.00cm, leaves weight 4.73g, plant weight 7.61g, neck thickness 3.51mm, root weight 1.46g and root depth 12.00cm. In between varieties the Chinese had maximum plant height 54.66cm, leaves plant^{-1} 7.00, leaf length 45.00cm, leaves weight 10.04g, plant weight 10.99g, neck thickness 8.26mm, root weight 2.81g and root depth 22.00cm. Based on nutrients, the Chinese variety of garlic performed better growth at the green stage than the local (Desi) variety of garlic. The findings of this study show that nutrient N_2 = NPK+TE (Trace Elements) 2g L^{-1}had better results for all parameters, and all results were statistically significant.

Keywords: Micropropagation, Embryogenic callus, Meristem, Sugarcane, In-vitro, Plant hormones Garlic sprouting, Growth enhancement, Nutrient supplementation, Macronutrients, Vegetative growth.

INTRODUCTION

Garlic commonly known by its scientific name *Allium sativum* L. has for long been valued not only for its culinary value but also medicinal and cultural value. Garlic belongs to the Allium family of crops that includes other staple vegetable crops such as onions, leeks, and shallots [1,2]. In addition to its peculiar taste, garlic is considered one of the most effective sources of vitamins and minerals popularly used for curing many diseases. It has been used traditionally to cure almost all illnesses ranging from the flu to cardiovascular diseases, and it has been used from ancient times in different traditional systems of medicine [3,4]. Garlic (*Allium sativum* L.) is one of the widely cultivated and used vegetables in the world. Because of its unique flavor and scent, it is more commonly employed as a flavoring agent in various foods and beverages. Other uses of garlic as our health benefit include its impact in preventing as well as

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curing cardiovascular diseases and its antioxidant effect [5]. Garlic (Allium Sativum L.) follows onions to be the second most cultivated Allium type around the globe. This spice is commonly incorporated in the diet and highly recommended to cure different diseases and physical ailments. Under this heading, garlic was produced in 1. 58 million hectares with yields that are, on average, 17%. 8 million tons in 2017, which overall has reached 280 million tons [6]. China is one of the major countries in the world for garlic production. According to the statistics, the annual yield of garlic in China in 2018 was about 8.89 million tons, accounting for ~70% of world output [7].. Spain is second in the world concerning exporting after China. The biggest quantity of fresh garlic is imported by Indonesia, and the other countries in the list are Brazil and Malaysia.[8]. The cultivated garlic area in Pakistan is of 8.1 thousand ha producing 70.9-ton ha^{-1} with an average yield 8.8-ton ha^{-1} [9].

In the technologically advanced area, the therapeutic potential of garlic has been invented through innovation in science which is focusing on the active compounds of garlic like dialy-sulfides and ajwain. In numerous studies, it has been evidenced that the biological components in these chemicals has shown anti-carcinogenic, anti-microbes and anti-oxidative status. The world has now accepted that garlic is a superstitious healthy food that can promote your overall health in a health-conscious era [10]. Around the globe, besides the medical benefits of the garlic, it is considered an utmost importance in traditional cooking. From Italian foods to the Asian ones, it inculcates a delicious flavor to the foods which makes it more attractive for consumption. Due to its cooking versatility and importance in health issues, garlic has been made an attractive food stuff for economic returns for farmers as well as for home gardening. Still the growth of the garlic is affected by numerous factors like soil health, climatic conditions and the availability of the nutrients from its sowing till harvesting process. For the successful growth of the garlic crop, its early growth stages, and in particular, germination makes the success of this crop [11].

The main barrier in the critical developmental phase of garlic germination is its nutrients concentration and needs. Similar to other crops, garlic also requires a variety of different nutrients for its development [12]. The nutrients can be majorly divided into macro and micronutrients. The NPK are considered as macronutrients which are required in excessive amounts, however, micronutrients such as Zn, Fe and Mn are required in a very low amount. For the formation of nucleic acid, development of roots, transfer of energy and the growth of garlic, NPK are predominantly important [13]. For water removal, osmotic regulation and activation of enzymes, K (Potassium) is important whereas micronutrient Zn is considered important for the synthesis of chlorophyll and activation of different enzymes. For the resistance against disease and promotion of garlic health, Zn and Mn are involved. From sowing till harvesting, these nutrients availability in the soil are of huge importance for garlic the growth of garlic [14].

For increasing the growth, yield and quality of crops, organic and synthetic amendments addition is of great importance [15–18]. Per ha^{-1} densities of plants ranging from 300000 to 350000, the appropriate fertilizer rate is 250, 100 to 200, 180 to 360, 60 & 30 N, P, K, Ca, and Mg kg ha^{-1} application is required. To attain the greatest production of commercial bulbs, P_2O_5 treatment using triple superphosphate (18% P_2O_5) is necessary. With strong relationships between N accumulation and yield, N in turn encourages increased commercial bulb production. The right source, right rate, right time, and right location (4R) decisions should all lead to the best crop and soil management to reduce environmental risks while maximizing bulb output [19]. However, during their field production, many nutrient management strategies and other variables have an impact on the development and output of garlic [20]. Garlic productivity is poor in many regions of the world despite its importance and rising output because of genetic and environmental variables that impact its yield and features that are associated with yield. Since their absorption and liberation of N, P, and S from soil organic matter relies on the availability of water, a shortage of readily available nutrients is typically the second-limiting factor in many locations that produce garlic [8].

Despite the increasing importance and widespread use of garlic in Pakistan, its productivity remains low due to poor nutrient management practices and the limited understanding of appropriate fertilizer use. A major issue faced by garlic growers is the lack of knowledge regarding the optimal type and amount of nutrients required during the critical early growth stages, such as sprouting and green-stage development. This deficiency often results in suboptimal growth, lower yields, and reduced quality, particularly in small-scale farming systems where marginal farmers dominate production. We hypothesize that the application of specific macronutrient combinations can significantly enhance the early growth and sprouting of garlic at the green stage, leading to better plant health, yield, and bulb quality. The novelty of this study lies in evaluating the combined effects of NPK and trace elements, as well as calcium nitrate, on the growth performance of two garlic varieties—Chinese and Desi (local)—under controlled conditions. This research aims to provide evidence-based recommendations for optimizing nutrient

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management strategies to improve garlic productivity in Pakistan. Thus, the primary objective of this study was to assess the effect of various macronutrient treatments on the sprouting and early-stage growth of garlic, with the goal of identifying nutrient combinations that maximize growth parameters and can be adopted by local farmers to increase garlic yields.

MATERIALS AND METHODS

The experiment was conducted during the winter of 2022–2023 at the SAU Nursery, Department of Horticulture, Sindh Agriculture University, Tandojam. The study aimed to evaluate the sprouting and early-stage growth of garlic (Allium sativum L.) under different nutrient treatments. A total of 24 pots, each with a standard size of 14 inches, were filled with a soil media mixture composed of soil, silt, and farmyard manure in a 1:1:1 ratio. The experiment followed a Completely Randomized Design (CRD) with a factorial arrangement and three replications, each containing six cloves per pot.

Experimental Factors:

The experiment consisted of two factors. Factor A was done with two garlic varieties (V1 = Sindhi, V2 = Chinese). While Factor B was done four nutrient treatments applied to evaluate their effect independently and in combination.

- N1 = Tap water (control)
- N2 = NPK+TE (Trace Elements) 2g L^{-1}
- N3 = Calcium Nitrate 0.5g L^{-1}
- N4 = NPK+TE 2g L^{-1} + Calcium Nitrate 0.5g L^{-1}

Nutrient Application

Nutrient solutions were applied after the cloves were sown. The first application was made immediately after planting, followed by subsequent applications every 15 days until the plants reached the green harvest stage (approximately 60 days). Data collection was performed at regular intervals, starting after the first application and continuing throughout the experimental period.

Planting and Maintenance

Garlic cloves were planted at a depth of 5 cm in each pot. Routine cultural practices such as weeding were performed as needed to ensure optimal growth conditions. Adequate irrigation was provided using tap water.

Observations and Measurements

The following growth parameters were measured:

- **Days to sprouting** The time taken for cloves to sprout was recorded by counting the days from sowing until sprouting was observed in each treatment.
- **Plant height (cm)** The height of three randomly selected plants per treatment was measured using a ruler from the base to the tip of the plant. The average height was recorded at the time of observation.
- **Number of leaves per plant** The average number of leaves per plant was visually counted from three randomly selected plants per treatment.
- **Leaf length (cm)** Leaf length was measured using a measuring tape from the stem to the tip of the leaf. The average leaf length was calculated for each treatment.
- **Leaf weight (g)** Fresh leaf weight was measured using an analytical balance immediately after harvesting.
- **Plant weight (g)** The total plant weight, including leaves and bulbs, was recorded using an analytical balance immediately after harvesting. The measurements were taken in grams, with water content being a contributing factor to the weight.
- **Neck thickness (mm)** Neck thickness was measured using a vernier caliper at three points (top, middle, and bottom), and the average value was calculated.
- **Root weight (g)** Root weight was determined using an analytical balance by measuring the fresh roots immediately after harvesting.
- **Root depth (cm)** Root depth was measured using a measuring tape from the base of the stem to the tip of the root.

Statistical Analysis

Data were statistically analyzed using the Statistics 8.1 software. The Least Significant Difference (LSD) test was employed to compare the significance of differences among treatments where applicable. The results were interpreted at a significance level of $p < 0.05$.

RESULTS

The pot experiment was conducted during 2022-23 to observe the Sprouting and growth of garlic (*Allium sativum* L.) at green stage under various nutrients. The trial was carried out at SAU Nursery, Department of Horticulture, Sindh Agriculture University in Tandojam during the winter season. Two varieties (Local (Desi) and Chinese) were treated with different nutrient combinations to check their response on sprouting and growth of garlic.

The treatments included N_1 = Tap water (control), N_2=NPK + TE (2g L^{-1}), N_3=Calcium Nitrate (0.5g L^{-1}), N_4=NPK+ TE (2g L^{-1}) + Calcium Nitrate (0.5g L^{-1}). The observation was noted on Days to sprouting, plant height (cm), leaves plant-1, leaf length (cm), leaves weight (g), plant weight (g), neck thickness (mm), root weight (g), root depth (cm). For the above attributes, this section covers the data (Fig: 1 to 9) as well as the results assessment based on the statistical analysis (Appendix 1 to 9) for each sub-heading.

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Days to Sprouting The effect of different nutrient treatments on the day's to-sprouting of two garlic varieties, Chinese and Local (Desi). (Figure 1) presents the current data on the day-to sprouting of two varieties under the influence of nutrients, with Anova. Results pertaining to days to sprouting of two varieties show that minimum days to sprouting (3.33) were recorded in the Chinese variety supplanted with NPK+TE (2g L^{1}) + C calcium Nitrate (0.5g L^{1}), whereas maximum days to sprouting (10.33) were observed in the Chinese variety under Tap Water (control treatment where nutrient was not applied). The results pertaining to nutrients show that the minimum days to sprouting (5.00) were observed under NPK+TE (2g L^{1}) + Calcium Nitrate (0.5g L^{1}), followed by N_1-Tap Water (Control) (9.00). Response across varieties was also noticeable, where the minimum days to sprouting (5.25) were observed in local (Desi) varieties, followed by Chinese varieties (8.33). Statistically, the results are significant for nutrient varieties as well as their interactions at the 0.05% level of significance, as indicated in in Table 1.

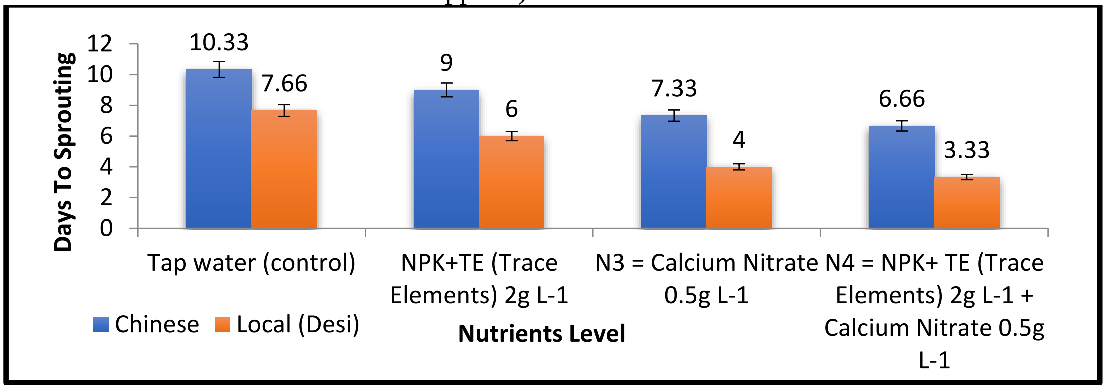

Figure 1. Effect of nutrient levels on the days to sprouting of different varieties of garlic.

Table 1. Statistical Significance of Nutrient Treatments and Varieties on Days to Sprouting

Significance level	**Nutrients (N)**	**Varieties (V)**	**N x V**
SE±	0.5289	0.3740	0.7480
LSD 0.05	1.1344	0.0802	1.6043
C.V%	13.49		

Plant height (cm) The effect of different nutrient levels on the plant height of two garlic varieties (Chinese and Local (Desi)). The present data regarding plant height (cm) of two varieties under the influence of nutrients have been presented in (Figure 2) with Anova. Results pertaining to plant height (cm) of two varieties show that maximum plant height (57.cm) was recorded in seeds of Local (Desi) Varity supplanted with NPK+TE (2g L^{-1}) where no nutrient was applied, whereas minimum plant height of (31.00cm) was observed in Local (Desi) Varity under Tap water (control). The results pertaining to nutrients show that maximum plant height was observed (55.83cm) under NPK+TE (2g L^{-1}) where it was applied, followed by N_1-tap water (control**)** (41 cm). Response across varieties was also noticeable, where a maximum plant height of 51.25 cm was observed in the Chinese variety, followed by the local (Desi) variety at 46.16 cm. Statistically, the results are significant for nutrient varieties as well as their interactions at the 0.05% level of significance as indicated in Table 2.

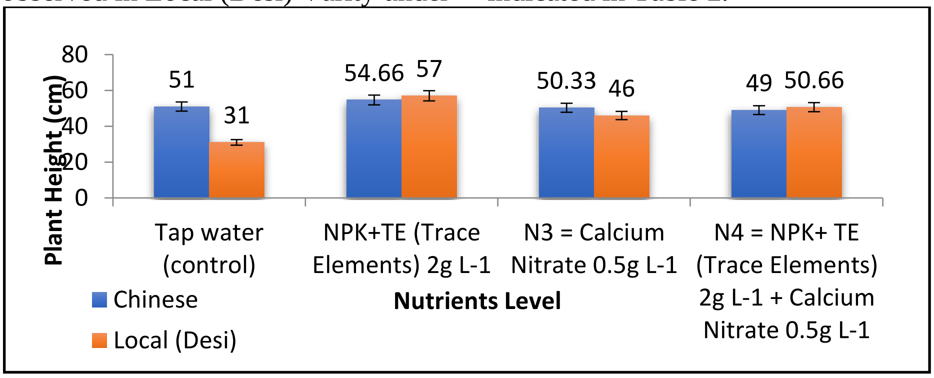

Figure 2. Effect of nutrient levels on the Plant height (cm) of different varieties of garlic

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Table 2. Statistical Significance of Nutrient Treatments and Varieties on Plant height (cm).

Significance level	Nutrients (N)	Varieties (V)	N x V
SE±	0.7306	0.5166	1.0332
LSD 0.05	1.5669	1.1080	2.2160
CV%	2.60		

Leaves plant^{-1}: The effect of different nutrient treatments on the number of leaves per plant for two garlic varieties. The present data regarding leaves plant^{-1} of two varieties under the influence of nutrients have been presented in (Figure 3) with Anova. Results pertaining to leaves plant^{-1} of two varieties show that leaves plant^{-1} (7) were recorded in the Chinese variety supplanted with Tap water (control), whereas minimum leaves plant^{-1} (4.33) of were observed in the local (Desi) variety under control treatment, where no nutrient was applied. The results pertaining to nutrients show that maximum leaves plant^{-1} (6.83) were noticed under nutrient NPK+TE (2g L^{-1}**),** followed by N_4-NPK+TE (2g L-1) and calcium nitrate (0.5g L^{-1}) nutrients applied (4.83). Response on varieties was also noticeable, where maximum leaf plant-1 (5.75) was observed in the Chinese variety, followed by the local (Desi) variety (5.1). Statistically, the results are significant for nutrient varieties as well as their interactions at the 0.05% level of significance, as indicated in Table 3.

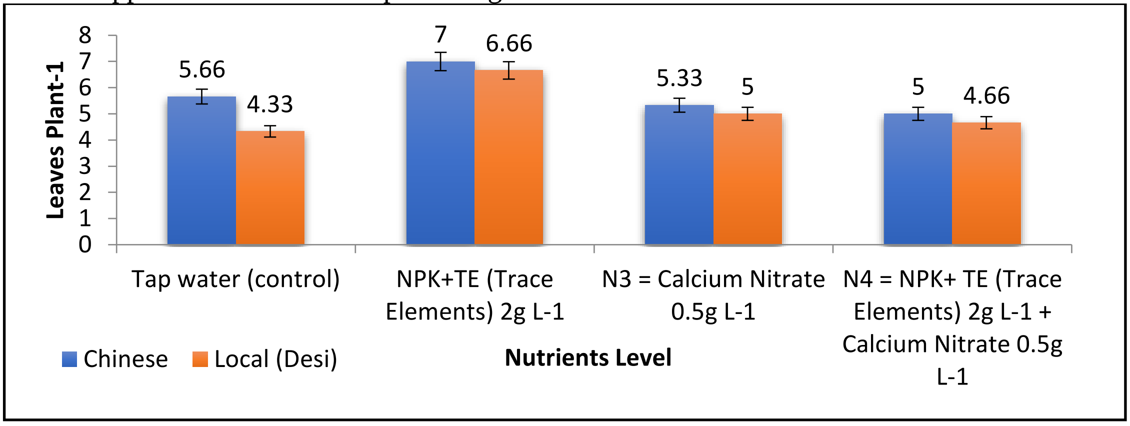

Figure 3. Effect of nutrient levels on the Leaves plant-^{1} of different varieties of garlic

Table 3. Statistical Significance of Nutrient Treatments and Varieties on Leaves plant^{-1}

Significance level	Nutrients (N)	Varieties (V)	N x V
SE±	0.4432	0.3134	0.6268
LSD 0.05	0.9506	0.6722	1.3443
C.V%	14.06		

Leaf length (cm): The effect of different nutrient levels on the leaf length of two varieties of garlic. The present data regarding Leaves length (cm) of two varieties under nutrients influence have been presented in (Figure 4) with Anova. Results pertaining to Leaves length of two varieties shows that Leaves length (50.33cm) were recorded in Local (Desi) Varity supplanted with NPK+TE (2g L^{-1}), whereas minimum Leaves length of (22.00cm) were observed in Local (Desi) variety under control treatment where no nutrient was applied. The results pertaining to nutrients show that maximum leaf length (47.66cm) was noticed under the nutrients NNPK+TE (2g L^{-1}) followed by N_4-NPK+TE (2 g L^{-1}) and calcium nitrate (0.5 g L-1) (4.83cm). Response on varieties was also noticeable, where maximum leaf length (5.75cm) was observed in Chinese Varity, followed by local (Desi) Varity (5.1cm). Statistically, the results are significant for nutrient varieties as well as their interaction at the 0.05% level of significance, as indicated in Table 4.

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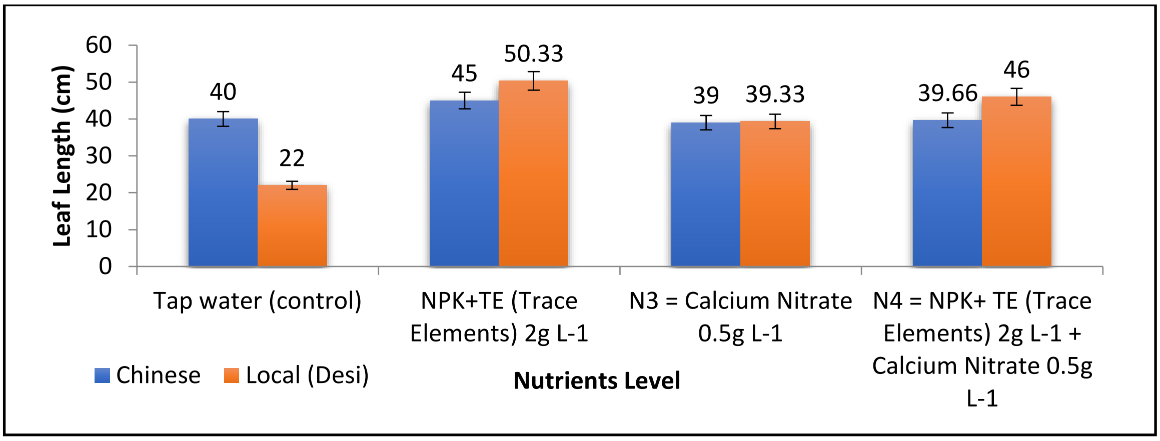

Figure 4. Effect of nutrient levels on the leaf length (cm) of different varieties of garlic

Table 4. Statistical Significance of Nutrient Treatments and Varieties on Leaf length (cm).

Significance level	Nutrients (N)	Varieties (V)	N x V
SE±	0.8079	0.5713	1.1426
LSD 0.05	1.7329	1.2253	2.4507
C.V%	3.48		

Leaves weight (g): The effect of different nutrient levels on the leaf weight of two varieties of garlic. The present data regarding leaves weight of two varieties under nutrients influence have been presented in (Figure 5) with Anova. Results pertaining to leaves weight of two varieties show that maximum leaves weight (10.04g) were recorded in Chinese Variety supplanted with under NPK+TE (2g L^{-1}) treatment where nutrient was applied, whereas minimum leaves weight of (1.83g) were observed in Local (Desi) variety under Tap water (control). The results pertaining to nutrients show that the maximum leaves weight (8.96g) were noticed when the nutrient NPK+TE (2g L^{-1}) was applied, followed by N_1-Tap water (control) (4.73g). Response on varieties was also noticeable, where the maximum leaf weight (8.28g) was observed in the Chinese variety, followed by the local (Desi) variety (5.18g). Statistically, the results are significant for nutrient varieties as well as their interaction at the 0.05% level of significance, as presented in Table 5.

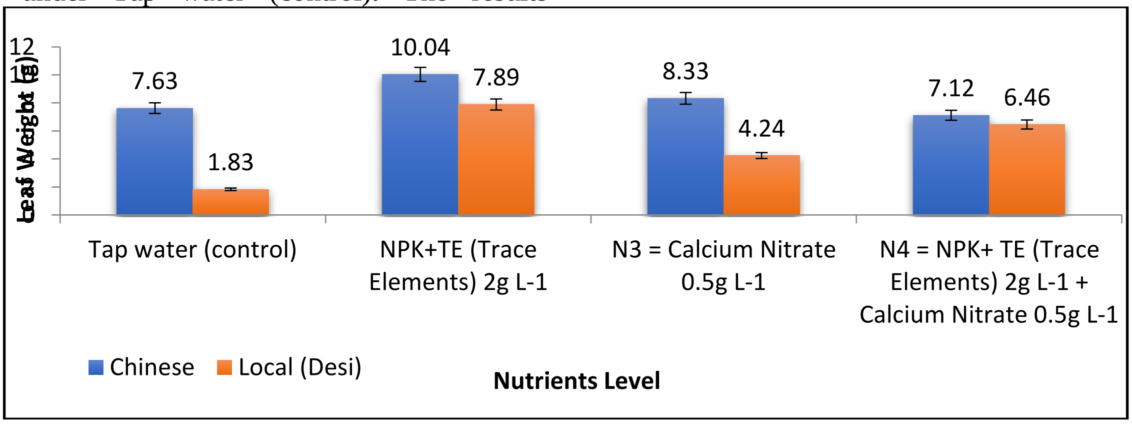

Figure 5: Effect of nutrient levels on the Leaves weight (g) of different varieties of garlic

Table 5. Statistical Significance of Nutrient Treatments and Varieties on Leaves weight (g).

Significance level	Nutrients (N)	Varieties (V)	N x V
SE±	0.1520	0.1075	0.2149
LSD 0.05	0.3260	0.2305	0.4610
C.V%	3.93		

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Plant weight (g): The effect of different nutrient treatments on the plant weight of two garlic varieties. The present data regarding plant weight of two varieties under nutrients influence have been presented in (Figure 6) with Anova. Results pertaining to plant weight of two varieties show that maximum plant weight (15.42g) were recorded in Local (Desi) Variety supplanted with under NPK+TE (2g L^{-1}) treatment where nutrient was applied, whereas minimum plant weight of (4.06g) observed in Local (Desi) variety under Tap water (control). The results pertaining to nutrients show that the maximum plant weight (13.20g) was noticed when the nutrient NPK+TE (2g L^{-1}) was applied, followed by N_1-Tap water (control) (7.61g). Response on varieties was also noticeable, where maximum plant weight (12.38g) was observed in the Chinese variety, followed by the local (Desi) variety (9.56g). Statistically, the results are significant for nutrient varieties as well as their interaction at the 0.05% level of significance, as presented in Table 6.

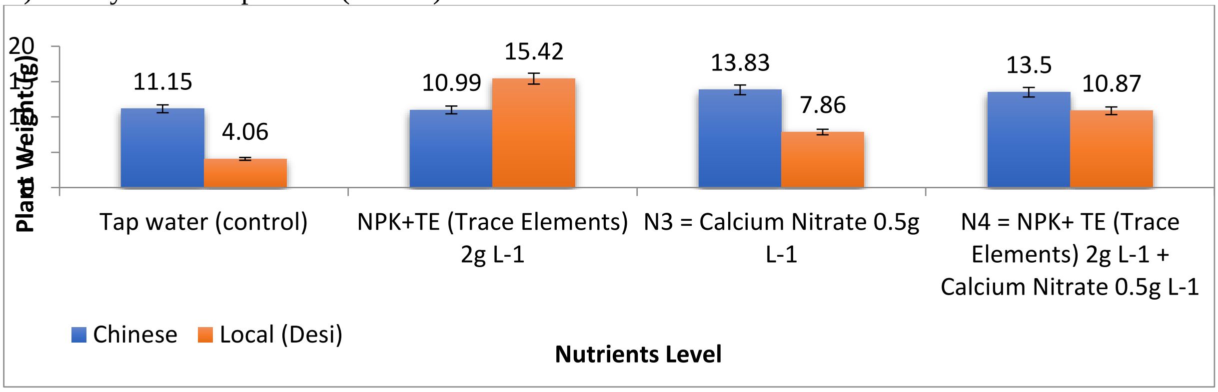

Figure 6: Effect of nutrient levels on the Plant weight (g) of different varieties of garlic

Table 6. Statistical Significance of Nutrient Treatments and Varieties on Plant weight (g).

Significance level	**Nutrients (N)**	**Varieties (V)**	**N x V**
SE±	0.8695	0.6148	1.2297
LSD 0.05	1.8649	1.3187	2.6374
C.V%	13.73		

Neck Thickness (mm): The effect of different nutrient treatments on the neck thickness of two garlic varieties. The present data regarding neck Thickness of two varieties under nutrients influence have been presented in (Figure 7 with Anova. Results pertaining to neck Thickness of two varieties show that maximum neck Thickness (8.26) were recorded in Chinese Variety supplanted with under NPK+TE (2g L^{-1}) treatment where nutrient was applied, whereas minimum neck Thickness of (1.07mm) were observed in Local (Desi) variety under Tap water (control). Results pertaining to nutrients show that maximum neck thickness (6.55mm) was noticed when nutrient NPK+TE (2g L^{-1}) was applied, followed by N_1-Tap water (control) (3.51mm). Response on varieties was also noticeable, where maximum neck thickness (7.22mm) was observed in the Chinese variety, followed by the local (Desi) variety (3.05mm). Statistically, the results are significant for nutrient varieties as well as their interaction at the 0.05% level of significance, as shown in Table 7.

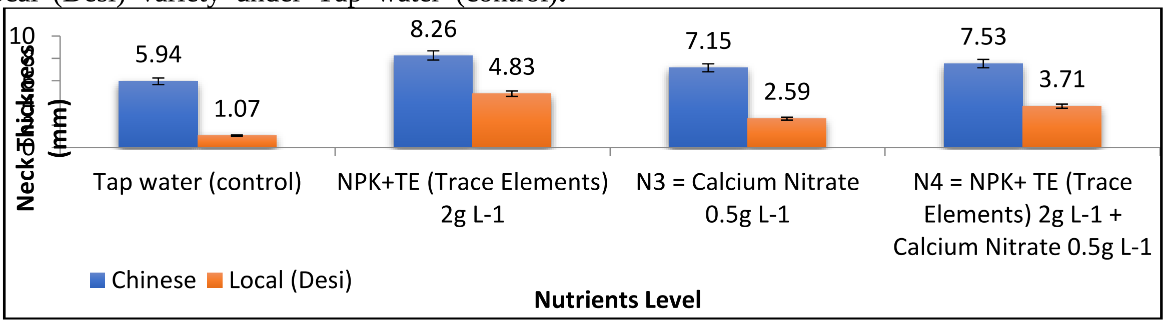

Figure 7: Effect of nutrient levels on the neck Thickness (mm) of different varieties of garlic

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Table 7. Statistical Significance of Nutrient Treatments and Varieties on Neck thickness (mm).

Significance level	**Nutrients (N)**	**Varieties (V)**	**N x V**
SE±	0.0952	0.0673	0.1347
LSD 0.05	0.2042	0.1444	0.2888
C.V%	3.21		

Root weight (g): The effect of different nutrient treatments on the root weight of two garlic varieties. The present data regarding root weight of two varieties under nutrients influence have been presented in (Figure 8) with Anova. Results pertaining to root weight of two varieties show that maximum root weight (2.90g) were recorded in Chinese Variety supplanted with under NPK+TE (2g L^{-1}) + Calcium Nitrate (0.5g L^{-1}) treatment where nutrient was applied, whereas minimum root weight of (1.05g) were observed in Local (Desi) variety under Tap water (control)**.** Results pertaining to nutrients show that maximum root weight (2.68g) was noticed when nutrient NPK+TE (2g L^{-1}) was applied, followed by N_1-Tap water (control) (1.46g). Response on varieties was also noticeable, where maximum root weight (2.47g) was observed in the Chinese variety, followed by the local (Desi) variety (1.86g). Statistically, the results are significant for nutrient varieties as well as their interaction at the 0.05% level of significance, as presented in Table 8.

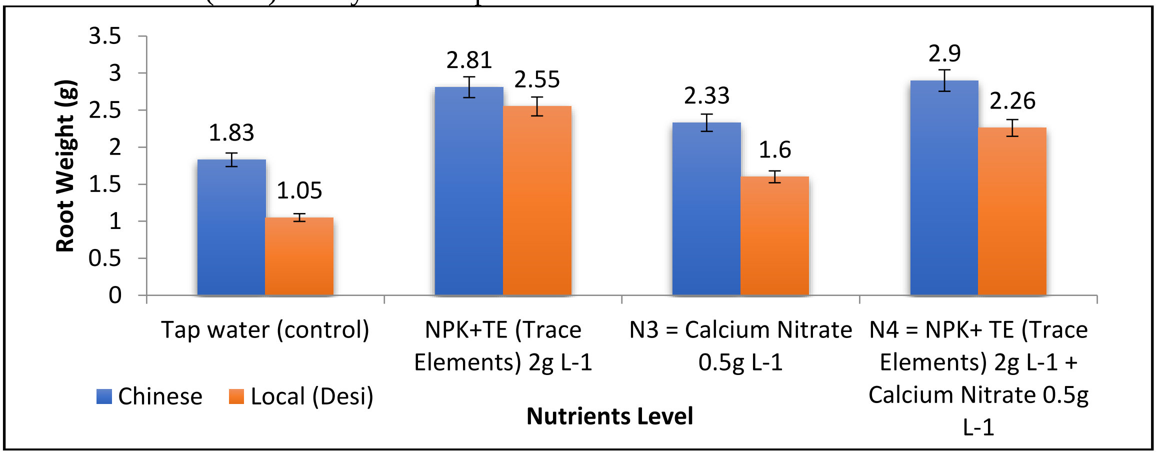

Figure 8: Effect of nutrient levels on the root weight (g) of different varieties of garlic

Table 8. Statistical Significance of Nutrient Treatments and Varieties on Days to Sprouting

Significance level	**Nutrients (N)**	**Varieties (V)**	**N x V**
SE±	0.0564	0.0399	0.0798
LSD 0.05	0.1211	0.0856	0.1712
C.V%	4.50		

Root depth (cm): The effect of different nutrient treatments on the root depth of two garlic varieties. The present data regarding root depth of two varieties under nutrients influence have been presented in (Figure 9) with Anova. Results pertaining to root depth of two varieties show that maximum root depth (22.00cm) were recorded in Chinese Variety supplanted with under NPK+TE (2g L^{-1}) treatment where nutrient was applied, whereas minimum root depth of (10.00cm) were observed in Local (Desi) variety under Tap water (control)**.** The results pertaining to nutrients show that maximum root depth at the days (19.83cm) was noticed under nutrient NPK+TE (2g L^{-1}) was applied, followed by N_1-Tap water (control) (12.00cm). Response on varieties was also noticeable, where maximum root depth (18.66cm) was observed in the Chinese variety, followed by the local (Desi) variety (13.66cm). Statistically, the results are significant for nutrient varieties as well as their interaction at the 0.05% level of significance, as presented in Table 9.

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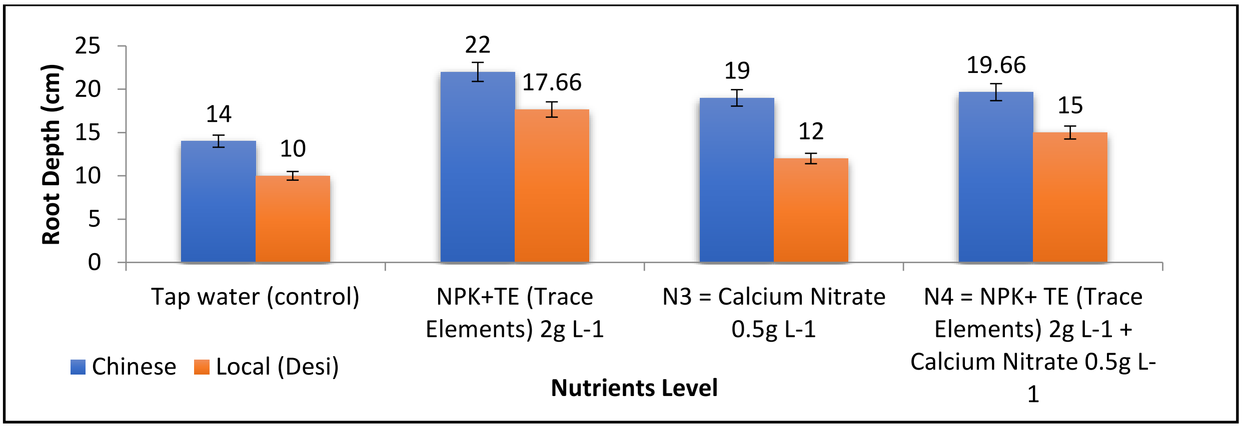

Figure 9. Effect of nutrient levels on the root depth of different varieties of garlic

Table 9. Statistical Significance of Nutrient Treatments and Varieties on Root depth.

Significance level	Nutrients (N)	Varieties (V)	N x V
SE±	0.5617	0.3972	0.7943
LSD 0.05	1.2047	0.8518	1.7037
C.V	6.02		

DISCUSSION

The sprouting period of garlic can vary from 7 to 15 days depending on the type of garlic used in field experiments. Research indicates that planting garlic cloves at a depth of 3–4 cm leads to the quickest sprouting period, with shallow planting resulting in earlier sprouting and faster growth [22]. Nitrogen is a crucial nutrient for garlic, significantly impacting plant height and bulb yield. Studies have shown that higher nitrogen levels can lead to increased plant height and improved yield attributes. For instance, a study found that applying nitrogen at 235 kg/ha resulted in the highest plant height and yield in certain garlic varieties [23]. Another study demonstrated that nitrogen application at 150 kg/ha resulted in the tallest plants and the highest bulb yield, indicating the importance of adequate nitrogen supply for optimal garlic growth [24]. Abadi (2015) found that using nitrogen fertilizer, especially a mix of urea and ammonium sulphate significantly reduced the sprouting time of garlic cloves [25]. However, sprouting times can differ based on various factors like garlic type, planting conditions, and climate. The effect of different nutrient concentrations on the height of two garlic varieties (Local/Desi and Chinese) showed plant heights ranging from 31 to 57 cm under different treatments. This aligns with Diriba-Shiferaw et al. (2016), who found that nitrogen, phosphorus, and potassium (NPK) significantly increased garlic plant height [26]. Youssef et al. (2017) also noted that biofertilizers with nitrogen-fixing and potassium-solubilizing bacteria boosted plant height [27]. The variety of garlic used and environmental conditions such as temperature and humidity may also influence these results.

The application of NPK fertilizers, particularly with trace elements, has been shown to significantly enhance garlic leaf growth. This is consistent with findings that NPK fertilizers improve plant growth by providing essential nutrients that are often deficient in soils [28]. Nutrient treatments also impacted the number of leaves produced by two types of garlic. Results showed that the number of leaves ranged from 4.33 to 7.00 under different treatments. The application of NPK with trace elements was particularly effective in enhancing leaf growth, consistent with other studies highlighting the benefits of nitrogen, phosphorus, and potassium on plant growth [28]. However, soil characteristics and environmental conditions, not evaluated in this study, and could also affect leaf development. Different nutrient concentrations influenced the leaf length of two garlic types, with results showing leaf lengths between 22 to 50 cm under various treatments. Heni Krestini et al. (2020) found that NPK significantly increased garlic leaf length [29].

Organic fertilizers, such as cattle manure, have been observed to increase garlic leaf length more effectively than chemical fertilizers [30]. Akhil et al. (2022) noted that organic treatments resulted in longer leaves compared to chemical fertilizers [31], which may be attributed to the gradual release of nutrients

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and improvement in soil structure. The use of compost and potassium silicate was also found to enhance leaf number and growth parameters in garlic, suggesting that organic amendments can complement chemical fertilizers to improve plant performance [32]. Exogenous germanium and beneficial bacteria also increased garlic plant height, leaf length, and breadth, according to Li et al. (2021)[33]. The specific treatments and varieties used, as well as environmental conditions, could have influenced these outcomes.

The impact of nutrient treatments on the leaf weight of two garlic varieties showed weights ranging from 1.83 to 10.04 g under different treatments. Yang et al. (2021) found that both organic and inorganic fertilizers increased garlic leaf weight, with the combined treatment yielding the highest leaf weight [34]. Conversely, Li et al. (2021) found that exogenous germanium and beneficial microbes did not significantly impact leaf weight but did increase germanium accumulation in the leaves [33]. This suggests that fertilizer effects on leaf weight vary depending on the type and combination of fertilizers, growing conditions, and garlic variety. Plant weight varied with different nutrient levels and garlic varieties, with results showing plant weights between 4.06 to 15.42 g under different treatments.

Studies have shown that organic fertilizers, such as cow and chicken manure, significantly enhance garlic yield and bulb weight. For instance, cow manure combined with urea-formaldehyde (UF) nitrogen fertilizer resulted in higher yields compared to chicken manure in certain conditions [35]. Compost application also improved growth parameters like bulb diameter and neck thickness, with the best results observed at higher compost levels [32]. The use of mineral fertilizers, particularly those rich in nitrogen, phosphorus, and potassium (NPK), has been shown to increase garlic plant height, leaf area, and yield. Specific NPK combinations, such as N10P10K40, resulted in significant yield improvements [36]. Additionally, garlic-specific fertilizers tailored to the plant's nutrient absorption patterns have been developed, leading to increased yield and improved nutritional quality [37]. Yang et al. (2021) reported that organic and inorganic fertilizers significantly increased garlic plant weight compared to controls [34]. Li et al. (2021) also noted increased plant biomass with exogenous germanium and effective microorganisms [33]. These findings indicate that nutrient application enhances plant weight, but the specific effects depend on nutrient treatments and garlic varieties. Nutrient levels also significantly influenced the neck thickness of different garlic types, ranging from 1.06 to 8.26 mm under various treatments. These findings are consistent with previous studies showing that organic and inorganic fertilizers enhance garlic neck thickness. Li et al. (2021) also reported improved neck thickness with exogenous germanium and beneficial microbes [33]. Increased neck thickness is desirable as it indicates good quality bulbs that store well. This study highlights the importance of proper nutrient management in garlic production for high-quality bulbs.

Root weight varied between 1.05 to 2.81 g under different nutrient treatments, with the highest weight observed under NPK and trace elements treatment. This suggests that fertilizers, particularly those containing nitrogen, phosphorus, and potassium, can increase garlic root weight. Root depth, recorded between 10 to 22 cm under different treatments, was also enhanced by appropriate fertilizers. Ali et al. (2023) found that nitrogen and potassium fertilizers increased root depth [28], while Hasanuzzaman et al. (2018) reported similar effects with calcium and boron fertilizers [38].

CONCLUSION

In conclusion, this study demonstrates that nutrient levels play a crucial role in the sprouting, growth, and development of garlic varieties. Among the treatments, the application of NPK with trace elements (N2) consistently showed the best results across most growth parameters, including the shortest sprouting times, tallest plant height, longest leaves, highest leaf weights, and maximum plant weights. Specifically, the Chinese garlic variety performed better than the local (Desi) variety under this treatment, achieving sprouting in just 3.33 days compared to 6.66 days for Desi garlic. This suggests that the combined application of NPK and trace elements is the most effective for enhancing early-stage garlic growth and biomass production. For future research, it would be beneficial to explore the long-term effects of these nutrient treatments on bulb yield and quality at later growth stages. Additionally, studies could investigate the potential benefits of integrating organic fertilizers or biofertilizers with these nutrient treatments to further enhance growth and sustainability in garlic production.

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