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Effect of application of nitrogenous fertilizers (urea and Nano urea) on secondary nutrient content in tomato leaves and fruits

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Abstract

Efficient nutrient management is critical for enhancing both the productivity and nutritional quality of tomato (*Solanum lycopersicum* L.), a crop that requires balanced supplies of both primary and secondary nutrients. While nitrogen plays a central role in plant growth, its form and delivery method can significantly influence the uptake of secondary nutrients such as calcium (Ca), magnesium (Mg) and sulphur (S). This study evaluated the effect of nano urea and conventional urea, applied under different nitrogen regimes (100%, 75% and 50% RDN), on the accumulation of Ca, Mg and S in tomato leaves and fruits. Twelve treatment combinations involving basal and foliar applications of conventional urea and nano urea (2 ml L⁻¹) at 30 and 45 days after transplanting (DAT) were compared. Results revealed that the treatment receiving 100% RDN with nano urea applied at both 30 and 45 DAT (T₄) recorded the highest concentrations of secondary nutrients, especially sulphur (0.64% in leaves, 0.17% in fruits), followed by treatments T₂ and T₈, which also included nano urea applications. Although Ca and Mg contents did not show statistically significant differences among treatments, their levels trended higher in nano urea-inclusive treatments. The enhanced nutrient status under nano urea treatments is attributed to its high foliar absorption efficiency, controlled nitrogen release and its role in stimulating root activity and nutrient translocation. Overall, the findings suggest that nano urea, particularly when integrated with conventional nitrogen fertilizer under full RDN, can improve secondary nutrient uptake in tomato. While nano urea cannot fully compensate for reduced nitrogen levels, it functions effectively as a supplementary input that enhances nutrient efficiency and fruit nutritional quality. This highlights its potential in developing sustainable and precision-based fertilizer strategies in horticultural crop production.

Keywords: Tomato, nano urea, calcium, magnesium, sulphur, secondary nutrients, nutrient use efficiency, nitrogen management

Introduction

Tomato (*Solanum lycopersicum* L.) is a globally important horticultural crop, widely cultivated for its rich nutritional content and high market value. It is an excellent source of vitamins, antioxidants and essential minerals, including both primary (N, P, K) and secondary nutrients such as calcium (Ca), magnesium (Mg) and sulphur (S). These secondary nutrients are vital for cell wall stability, chlorophyll synthesis, enzyme activation and sulphur-containing amino acid formation, all of which are critical for optimal plant growth and fruit quality (Adhikari *et al.*, 2022; Ramesh *et al.*, 2021)^[1, 11].

Among the nutrients required for tomato production, nitrogen (N) remains the most limiting and widely applied macronutrient. However, nitrogen application must be managed judiciously, as it influences not only primary productivity but also the uptake and translocation of secondary and micronutrients. The conventional urea-based nitrogen delivery system, while popular, is plagued by inefficiencies, with only 30-50% of the applied nitrogen actually taken up by plants. The remainder is lost through volatilization, leaching and denitrification, leading to economic losses and environmental degradation (Kumar *et al.*, 2021; Bhardwaj *et al.*, 2022)^[7, 2].

To overcome these limitations, nano-fertilizers, especially nano urea, have gained considerable attention as a precision nutrient management tool. Nano urea consists of nitrogen particles at the nanometer scale (<100 nm), which enhances foliar absorption,

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facilitates controlled release and improves nitrogen use efficiency (NUE) (Raliya *et al.*, 2016; Chhipa, 2017) ^[9, 4]. Emerging studies suggest that nano urea not only improves N uptake but also positively influences the plant's capacity to absorb and translocate secondary nutrients like Ca, Mg and S by stimulating root growth and improving nutrient mobility (Singh *et al.*, 2021; Adhikari *et al.*, 2022) ^[12, 1].

While research has increasingly focused on the benefits of nano urea in cereal crops like wheat, rice and maize, data on its effects in horticultural crops particularly on secondary nutrient dynamics in tomato is still limited. Moreover, the potential of combining nano urea with conventional urea under varying nitrogen regimes has not been sufficiently explored in terms of its impact on the accumulation of Ca, Mg and S in different plant tissues. Since these nutrients play crucial roles in fruit firmness, flavour and post-harvest life, understanding how nitrogen formulations affect their availability is essential for improving both productivity and quality in tomato cultivation.

Therefore, the present study was undertaken to evaluate the influence of nano urea and conventional urea applied under different nitrogen levels on the secondary nutrient content (Ca, Mg and S) in tomato leaves and fruits. The study aims to determine whether nano urea in combination with conventional urea, can enhance the assimilation of these essential nutrients, offering a more sustainable and nutrient-efficient approach to tomato nutrition management.

Material and Methods

The study was conducted at the College of Horticulture Bagalkot (2022-2023), situated in Karnataka's northern dry zone (Zone-3) at 16°10' N latitude, 74°42' E longitude, and 542 meters elevation. The region receives an average annual rainfall of 548 mm and has a mean temperature of 23.01 °C. The soil at the experimental site was classified as red sandy loam. During the study period, the region experienced a total rainfall of 49.9 mm, relative humidity ranging from 77.64% (morning) to 28.75% (afternoon), and temperatures between 18.57 °C and 35.71 °C. The experiment used a Randomized Complete Block Design (RCBD) with 12 treatments and three replications. Tomato plants (Abhilash hybrid) were spaced 90 x 45 cm apart and grown under irrigated conditions during spring-summer.

Experimental details

T₁ (100% RDN): 50% as basal dose + 25% urea at 30 DAT + 25% urea at 45 DAT

T₂ (100% RDN): 50% as basal dose + nano urea (2 ml L⁻¹) at 30 DAT + 25% urea at 45 DAT

T₃ (100% RDN): 50% as basal dose + 25% urea at 30 DAT + nano urea (2 ml L⁻¹) at 45 DAT

T₄ (100% RDN): 50% as basal dose + nano urea (2 ml L⁻¹) at 30 and 45 DAT

T₅ (75% RDN): 50% as basal dose + 25% urea at 30 DAT + 25% urea at 45 DAT

T₆ (75% RDN): 50% as basal dose + nano urea (2 ml L⁻¹) at 30 DAT + 25% urea at 45 DAT

T₇ (75% RDN): 50% as basal dose + 25% urea at 30 DAT + nano urea (2 ml L⁻¹) at 45 DAT

T₈ (75% RDN): 50% as basal dose + nano urea (2 ml L⁻¹) at 30 and 45 DAT

T₉ (50% RDN): 50% as basal dose + 25% urea at 30 DAT + 25% urea at 45 DAT

T₁₀ (50% RDN): 50% as basal dose + nano urea (2 ml L⁻¹)

at 30 DAT + 25% urea at 45 DAT

T₁₁ (50% RDN): 50% as basal dose + 25% urea at 30 DAT + nano urea (2 ml L⁻¹) at 45 DAT

T₁₂ (50% RDN): 50% as basal dose + nano urea (2 ml L⁻¹) at 30 and 45 DAT

RDN: recommended dose of nitrogen, **DAT:** Days after transplantation

Fertilizer application

Fertilizer application for tomato cultivation adhered to the University of Horticultural Sciences Bagalkot's recommendations, which prescribe 38 tons of FYM and 250:250:250 kg N: P₂O₅: K₂O per hectare. The application schedule included soil application of urea, single super phosphate (SSP), and muriate of potash (MOP), as well as foliar application of IFFCO nano urea. The fertilizers were applied in two stages: a basal dose consisting of half dose of nitrogen and full dose of phosphorus and potassium, followed by top dressing with urea and nano urea (2ml L⁻¹) at 30 and 45 days after transplanting.

Plant sample collection and analysis

Leaf and fruit samples from each treatment were collected from field and were brought to laboratory, washed with 0.2% detergent and 0.1% hydrochloric acid, and rinsed with distilled water. After air-drying, they were oven-dried at 65-70 °C for 48 hours. The dried samples were then powdered in a stainless-steel mixer and preserved in airtight containers for analysis.

The secondary nutrient concentration in the plant samples was thoroughly determined through a range of established analytical methodologies, wherein Total Calcium (Ca) and Magnesium (Mg) content (%) were quantified using the complexometric titration method as per the protocol suggested by Hesse in 1971, and Total Sulphur (S) content (%) was estimated employing the turbidimetric method in accordance with the detailed guidelines outlined by Black in 1965.

Statistical analysis

The data in respect of all the parameters were tabulated and subjected to the statistical analysis (ANOVA) by adopting Randomized Complete Block Design and results were tested at 5 percent level of significance using Fischer's method of analysis of variance as suggested by Panse and Sukhatme (1967). Critical difference at 5 percent was worked out whenever 'F' test was significant (Karmnath Kumar *et al.*, 2024) ^[10].

Results and Discussion

The secondary nutrient content calcium (Ca), magnesium (Mg) and sulfur (S) in tomato leaves (Table 1) and fruits (Table 2) was influenced by the type and timing of nitrogen application. While no significant differences (NS) were observed among treatments for Ca and Mg at the 5% level, the sulphur content exhibited statistically significant variation across treatments.

Calcium Content in Leaves and Fruits

Although calcium content differences were statistically non-significant, treatment T₄ (100% RDN: urea as basal dose and foliar application of nano urea at both 30 and 45 DAT) recorded the highest Ca concentration in both leaves

(2.46%) and fruits (0.59%), followed by T₂ (2.24% and 0.57%). These values were superior to those observed in conventional urea-only treatments such as T₁ and T₅. The enhanced calcium content under nano urea treatments may be attributed to improved root activity and cellular uptake induced by better nitrogen availability, which positively affects the movement of calcium, a relatively immobile nutrient in plants (Adhikari *et al.*, 2022; Ramesh *et al.*, 2021) [1, 11]. Nano urea likely promotes better root-to-shoot signaling and apoplastic transport pathways that facilitate higher Ca assimilation, especially during fruit development. Treatments involving 75% and 50% RDN (T₅-T₁₂) recorded generally lower Ca levels. Among these, T₈ (75% RDN: 50% as basal dose + nano urea at 30 and 45 DAT) showed comparatively better Ca accumulation (2.17% in leaves; 0.59% in fruits), indicating that nano urea may mitigate calcium limitation to some extent even under reduced nitrogen inputs. However, the overall non-significance implies that calcium content may be less sensitive to nitrogen form and more dependent on other factors like cultivar physiology or water availability.

Magnesium Content in Leaves and Fruits

The magnesium content across treatments also showed no significant statistical differences but followed a notable trend. The highest Mg content was observed in T₄ (1.65% in leaves, 0.33% in fruits), followed by T₂ and T₈, both of which involved nano urea application. This suggests that treatments enhancing nitrogen availability likely supported higher chlorophyll synthesis and enzymatic activity, both of which are Mg-dependent processes (Chhipa, 2017; Singh *et al.*, 2021) [4, 12].

Lower magnesium levels were generally observed in reduced RDN treatments such as T₉ (1.04% in leaves, 0.17% in fruits), indicating that insufficient nitrogen impairs nutrient absorption and physiological processes. However, the inclusion of nano urea in low-N regimes (e.g., T₁₀-T₁₂) showed modest improvements in Mg content, suggesting a partial compensatory effect of nano-fertilizer.

Sulphur Content in Leaves and Fruits

Sulphur content varied significantly across treatments in both leaves and fruits. The highest sulphur concentrations were recorded in T₄ (0.64% in leaves, 0.17% in fruits),

which was significantly superior to most treatments. This may be attributed to the enhanced uptake of sulphur under balanced nitrogen supply, as S and N exhibit synergistic assimilation in plant metabolism (Kumar *et al.*, 2021) [7]. Foliar-applied nano urea may also enhance stomatal conductance and metabolic activity, indirectly supporting sulfur uptake and incorporation into amino acids and other sulphur-containing compounds (Raliya *et al.*, 2016) [9].

Treatments T₂ and T₈, also involving nano urea with partial or full conventional N supplementation, recorded similarly high sulphur content in fruits (0.17% and 0.15%, respectively), reinforcing the role of nano urea in improving S assimilation during fruit development. On the contrary, the lowest sulphur content was observed under T₉ (0.27% in leaves, 0.07% in fruits), which received only 50% RDN with conventional urea, highlighting the deficiency effects of low nitrogen on sulphur availability and mobility.

Notably, sulphur uptake was consistently enhanced in nano-inclusive treatments across nitrogen regimes, even when total nitrogen was reduced. Treatments such as T₁₀, T₁₁ and T₁₂ all recorded higher sulphur levels in fruits compared to their urea-only counterparts at the same RDN levels (e.g., T₉), suggesting that nano urea helps maintain metabolic sulphur balance even under nutrient-limited conditions, an effect supported by Bhardwaj *et al.* (2022) [12] and Khan *et al.* (2020) [6].

The results suggest that while calcium and magnesium uptake were not significantly altered by different nitrogen treatments, they still trended higher under nano urea applications, especially at full nitrogen rates. In contrast, sulphur content responded significantly to nitrogen form and application strategy, with nano urea treatments substantially improving S content in both leaves and fruits.

The superior performance of T₄ (nano urea at both 30 and 45 DAT under 100% RDN) across all secondary nutrients indicates that balanced nitrogen nutrition via nano-fertilizer enhances the systemic availability of secondary nutrients by improving nutrient uptake efficiency, metabolic activity and nutrient transport mechanisms. This aligns with the growing literature on the synergistic effects of nano urea in improving both macro-and micro-nutrient dynamics in crops (Adhikari *et al.*, 2022; Chhipa, 2017; Singh *et al.*, 2021) [1, 4, 12].

Table 1: Influence of nitrogenous fertilizers (urea and nano urea) on secondary nutrient content in tomato leaves

Treatments	Secondary nutrient concentration in tomato leaves		
	Ca (%)	Mg (%)	S (%)
T ₁ (100% RDN): 50% as basal dose + 25% urea at 30 DAT + 25% urea at 45 DAT	1.81	1.43	0.47 ^{bc}
T ₂ (100% RDN): 50% as basal dose + nano urea (2 ml L ⁻¹) at 30 DAT +25% urea at 45 DAT	2.24	1.49	0.57 ^{ab}
T ₃ (100% RDN): 50% as basal dose + 25% urea at 30 DAT + nano urea (2 ml L ⁻¹) at 45 DAT	1.94	1.16	0.46 ^{bc}
T ₄ (100% RDN): 50% as basal dose + nano urea (2 ml L ⁻¹) at 30 and 45 DAT	2.46	1.65	0.64 ^a
T ₅ (75% RDN): 50% as basal dose + 25% urea at 30 DAT + 25% urea at 45 DAT	1.75	1.24	0.36 ^{cd}
T ₆ (75% RDN): 50% as basal dose + nano urea (2 ml L ⁻¹) at 30 DAT + 25% urea at 45 DAT	1.84	1.34	0.46 ^{bc}
T ₇ (75% RDN): 50% as basal dose + 25% urea at 30 DAT + nano urea (2 ml L ⁻¹) at 45 DAT	1.75	1.28	0.41 ^{bc}
T ₈ (75% RDN): 50% as basal dose + nano urea (2 ml L ⁻¹) at 30 and 45 DAT	2.17	1.4	0.58 ^{ab}
T ₉ (50% RDN): 50% as basal dose + 25% urea at 30 DAT + 25% urea at 45 DAT	1.73	1.04	0.27 ^d
T ₁₀ (50% RDN): 50% as basal dose + nano urea (2 ml L ⁻¹) at 30 DAT + 25% urea at 45 DAT	1.87	1.32	0.33 ^{cd}
T ₁₁ (50% RDN): 50% as basal dose + 25% urea at 30 DAT + nano urea (2 ml L ⁻¹) at 45 DAT	1.98	1.10	0.40 ^{cd}
T ₁₂ (50% RDN): 50% as basal dose + nano urea (2 ml L ⁻¹) at 30 and 45 DAT	1.94	1.36	0.38 ^{cd}
S.Em±	0.45	0.14	0.05
CD (5%)	NS	NS	0.16

Table 2: Influence of nitrogenous fertilizers (urea and nano urea) on secondary nutrient content in tomato fruits

Treatments	Secondary nutrient concentration in tomato fruits		
	Ca (%)	Mg (%)	S (%)
T ₁ (100% RDN): 50% as basal dose + 25% urea at 30 DAT + 25% urea at 45 DAT	0.53	0.22	0.12 ^{cde}
T ₂ (100% RDN): 50% as basal dose + nano urea (2 ml L ⁻¹) at 30 DAT + 25% urea at 45 DAT	0.57	0.31	0.17 ^a
T ₃ (100% RDN): 50% as basal dose + 25% urea at 30 DAT + nano urea (2 ml L ⁻¹) at 45 DAT	0.54	0.20	0.13 ^{cde}
T ₄ (100% RDN): 50% as basal dose + nano urea (2 ml L ⁻¹) at 30 and 45 DAT	0.59	0.33	0.17 ^a
T ₅ (75% RDN): 50% as basal dose + 25% urea at 30 DAT + 25% urea at 45 DAT	0.49	0.18	0.08 ^{ef}
T ₆ (75% RDN): 50% as basal dose + nano urea (2 ml L ⁻¹) at 30 DAT + 25% urea at 45 DAT	0.51	0.22	0.13 ^{cde}
T ₇ (75% RDN): 50% as basal dose + 25% urea at 30 DAT + nano urea (2 ml L ⁻¹) at 45 DAT	0.56	0.23	0.11 ^{ef}
T ₈ (75% RDN): 50% as basal dose + nano urea (2 ml L ⁻¹) at 30 and 45 DAT	0.59	0.25	0.15 ^{abc}
T ₉ (50% RDN): 50% as basal dose + 25% urea at 30 DAT + 25% urea at 45 DAT	0.49	0.17	0.07 ^f
T ₁₀ (50% RDN): 50% as basal dose + nano urea (2 ml L ⁻¹) at 30 DAT + 25% urea at 45 DAT	0.50	0.21	0.12 ^{cde}
T ₁₁ (50% RDN): 50% as basal dose + 25% urea at 30 DAT + nano urea (2 ml L ⁻¹) at 45 DAT	0.51	0.22	0.11 ^{cdef}
T ₁₂ (50% RDN): 50% as basal dose + nano urea (2 ml L ⁻¹) at 30 and 45 DAT	0.53	0.24	0.09 ^{def}
S.Em±	0.08	0.06	0.01
CD (5%)	NS	NS	0.04

Conclusion

The present study highlights the pivotal role of nano urea in enhancing the secondary nutrient profile calcium, magnesium and sulphur in tomato plants. While calcium and magnesium content remained statistically unaffected by fertilizer treatments, their levels consistently trended higher under nano urea-inclusive strategies, especially when applied at both 30 and 45 days after transplanting under 100% RDN (T₄). More notably, sulphur content in both leaves and fruits responded significantly to treatment variations, with nano urea treatments particularly T₄, T₂ and T₈ showing marked improvements over conventional urea-only applications.

These results underscore the ability of nano urea to synergize with conventional nitrogen sources, not only improving nitrogen efficiency but also supporting the uptake and assimilation of less mobile secondary nutrients. The enhanced performance is likely driven by nano urea's precise nutrient delivery, higher foliar absorption and stimulation of root and metabolic activity, which collectively boost nutrient translocation and utilization.

In conclusion, the strategic integration of nano urea especially under full nitrogen regimes can be a powerful approach to improve the nutritional quality of tomato crops. While nano urea may not fully replace conventional nitrogen under low input systems, it serves as an efficient and sustainable enhancer of nutrient availability, with clear benefits for sulphur enrichment. These findings add to the growing evidence that nano-fertilizer technologies offer a transformative path toward more resilient, productive and nutrient-rich horticultural systems.

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